RADIO EVIDENCE FOR INTERPLANETARY STREAMERS IN THE RANGE 10-170 SOLAR RADII

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ABSTRACT

Type III radio storms are observed by the radio experiment on board ISEE-3 out to 0.5-0.8 AU from the Sun, at a rate of 2 to 3 storms per solar rotation near solar maximum. They correlate with the type I and type III radio storms observed at higher frequencies, originating closer to the Sun. They are associated with an almost continuous injection of suprathermal electrons into the interplanetary medium. Some of the properties of the regions where the particles propagate are discussed, using the radio emission as a tracer.

Storms of type III solar radio bursts are frequently observed by the radio instrument on board ISEE-3. This experiment (Knoll et al., 1978) monitors the solar radio phenomena in the interplanetary medium over the height range from about 0.05 AU (10 solar radii) to 1 AU. The interplanetary type III radio storms (hereafter IP storms) consist of many thousands of type III radio bursts emitted per day. They last from 1 to 12 days. About 100 IP storms have been observed during the first four years of observation of ISEE-3, and up to 3 storms were observed per solar rotation near solar maximum. The IP storms are related to other solar radio emissions at all levels of the corona.

Figure 1 shows the intensity profiles at several frequencies during a typical interval. Each point is a 30 minute average. An IP storm is clearly seen from May 31 to June 6, as well as the formation of another storm near June 10. In this case we see a progressive delay in the peak of the storm, probably due to directivity effects.

Figure 2 shows 16.5 months of data from ISEE-3 along with ground based solar data which describe solar activity originating at much lower coronal levels. It is clear that radio emissions from individual storms can be followed through all ranges of elevations, from tens of solar radii, at ISEE-3 frequencies, down to well below 2 solar radii (heliocentric). The IP storms represent the interplanetary extension of solar active regions.

The ISEE-3 radio instrument has the capability of accurately determining the arrival direction (solar elongation) of the storm radio sources in the ecliptic plane. Figure 3 shows the solar elongation measured at a variety of frequencies during a typical IP storm. For each frequency we can see the East to West motion of the storm region as it crosses the line-of-sight to the Sun. The different

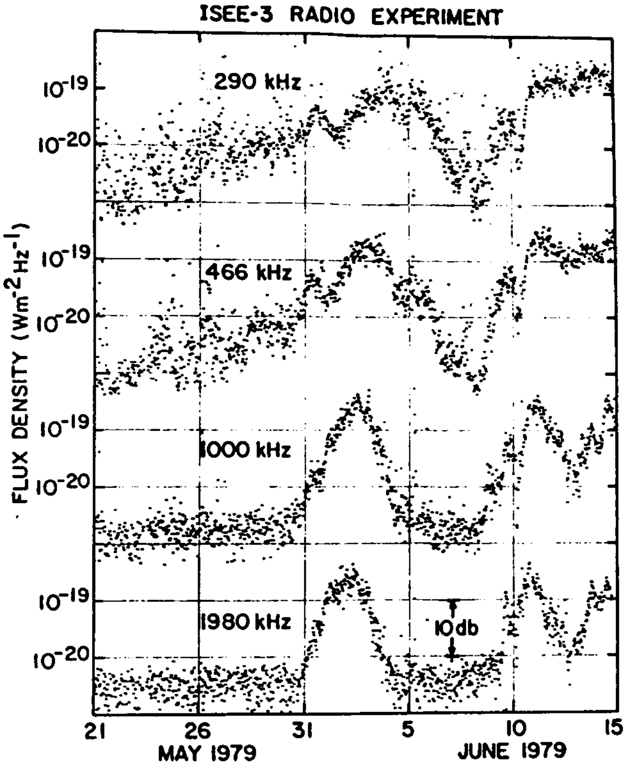


Figure 1 - Typical IP storm. Each point is a 30 minute average and may hence represent many individual storm bursts. The flux increase that precedes the storm at the lower frequencies is attributed to earth's radiation (TKR).

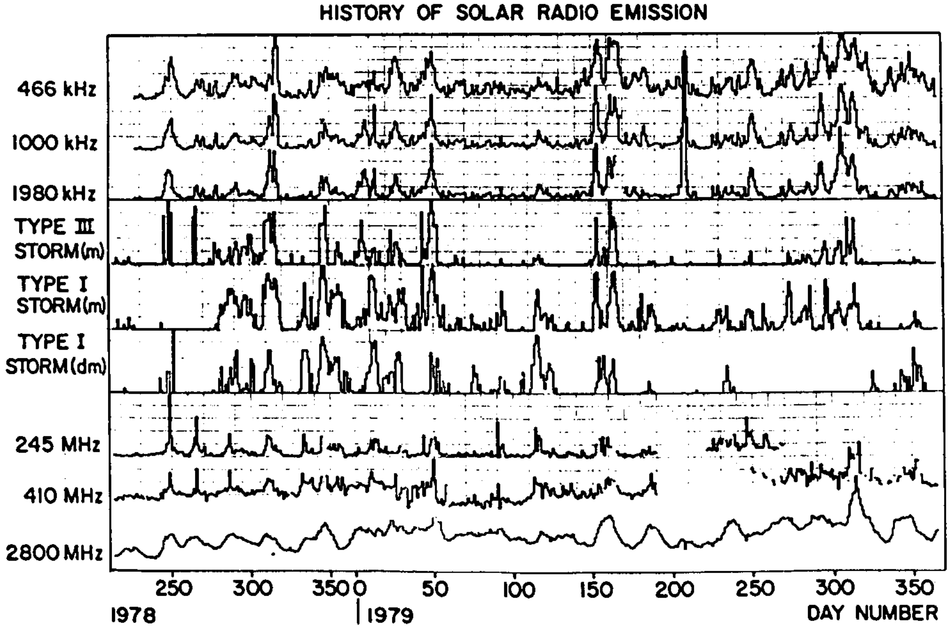


Figure 2 - Time history of a few ground-observed radio fluxes, of a few indices describing the radio storm activity in the lower corona and of a few ISEE-3 radio fluxes. Each point is a daily average (after Bougeret et al., 1982a).

slopes are due to a foreshortening effect. The sources which are closer to the observer (at lower frequencies) cross the line-of-sight with a higher angular velocity than the distant ones (at higher frequencies). This geometrical effect allows us to locate the distance from the spacecraft to the emission region with very few assumptions. In other words, we are able to determine the emission levels directly from the measurement of the slopes of the solar elongation profiles. In addition, we observe that the time of central meridian crossing is later at lower frequencies. This progressive delay is a direct measurement of the time it takes the solar wind to progress between levels we determined from the slope analysis. These results are summarized for one IP storm in Figure 4. Each point results from one frequency of observation. We can see that the data are consistent with an average solar wind speed of about 250 km s^{-1} from 25 to 125 solar radii. Since we are using all data within one or two days around central meridian passage, the earth moves only by a few degrees and we are viewing the same solar wind portion as it moves outward.

In situ observations show that within a few days of the arrival of this storm at 1 AU the velocity ranges from 300 to 400 km s^{-1}. This apparent discrepancy may be due to several reasons. (i) The storm analysis yields a solar wind speed of 250 km s^{-1} in the range 25 to 125 solar radii only; the solar wind may have accelerated between 125 and 215 solar radii. For instance fitting to the 4 last points in Figure 4 implies a higher velocity than is measured otherwise. (ii) This technique averages the solar wind speed over the radio source region and tracks structures that may extend out of the ecliptic plane, thus contributing to speeds different from those observed at 1 AU.

The fluctuations of the observations around the model shown in Figure 4 may suggest a kink or irregularity in the overall magnetic field. This particular storm is one for which these undulations are the most conspicuous. However, we cannot exclude that this is due to large scale refraction and scattering of radio waves (Steinberg, 1972) and at this point we prefer to consider only the average behavior shown by the curve in Figure 4 as significant.

Figure 5 shows the emission frequency versus the heliocentric distance. A slope of -1 on this frequency scale corresponds to -2 in electron density. The heavy black line are levels deduced from the first radio storm observed by RAE-1 (Fainberg and Stone, 1970a,b; 1971). These results were derived by a completely separate technique -from an analysis of the centre-to-limb variation of drift rates. The levels studied by RAE-1 were from 12 to 40 solar radii. The ISEE-3 data from 4 storms are superimposed and show excellent agreement. We also show a four year average of in-situ plasma density measurement from HELIOS (Bougeret, King, and Schwenn, 1983). We see that the radiation in the storm regions is very likely the harmonic of the plasma frequency -a result discussed often in the past. In addition the fall-off is generally faster than R^{-2}. Each storm on this log-log plot is roughly a straight line and can be described by two parameters: a coefficient and an exponent (slope of the emission level scale). Figure 6 shows the results of 16 storms, with each storm described by a value of k (the log of the coefficient) and a value of the exponent alpha. There seems to be a relation between the value of k and alpha. The higher the enhancement the more rapid the fall-off. The implication of these results is that by about 60-100 solar radii the enhanced density regions merge with the average solar wind densities. It is likely that these structures will not be visible at 1 AU.

We have seen that the IP storms are associated with density enhancements in

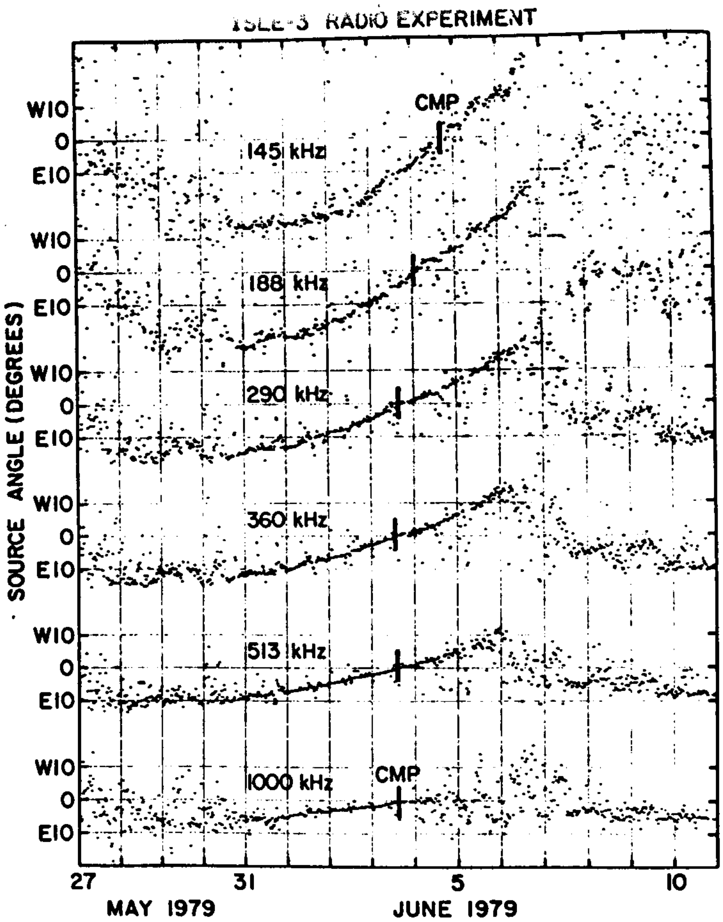


Figure 3 - Time variation of the solar elongation at six frequencies for the storm shown in Figure 1. The source angle is corrected for the Galactic background contribution (after Bougeret et al., 1982b).

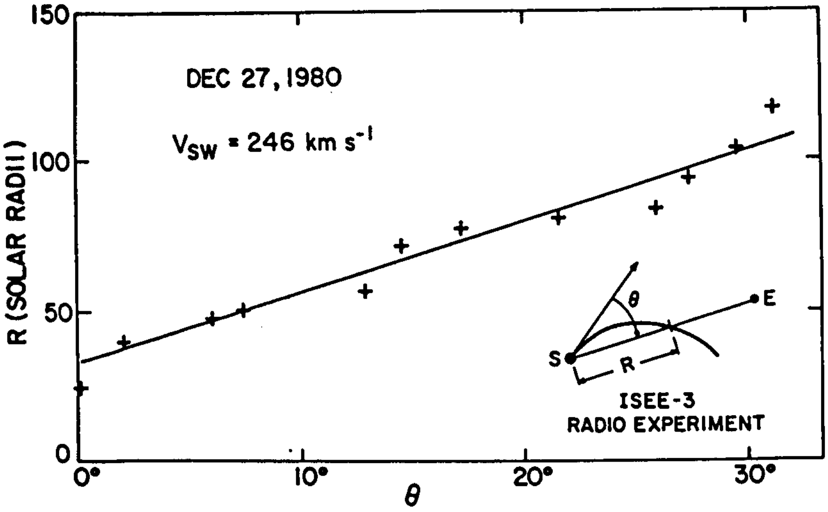


Figure 4 - Outward movement of the IP storm region in a fixed Sun-Earth coordinate system.

Figure 5 - Emission levels of 4 IP storms observed by ISEE-3. The RAE model is also shown (heavy line), as well as observations of type III and type I storms at higher frequencies and in-situ measurements by HELIOS 1 and 2 (after Bougeret et al., 1982b).

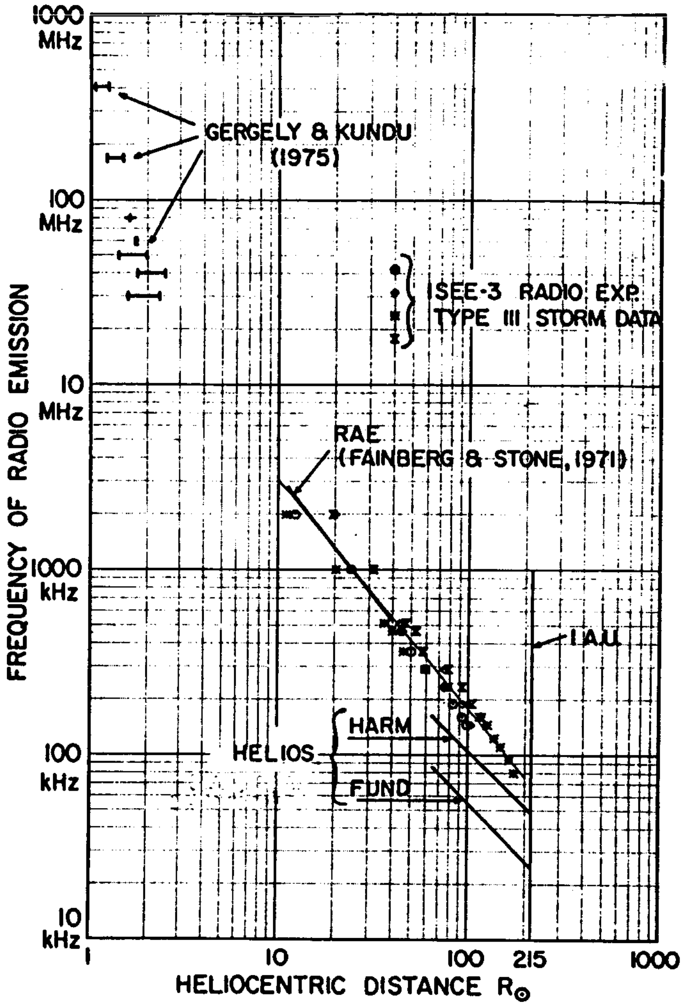
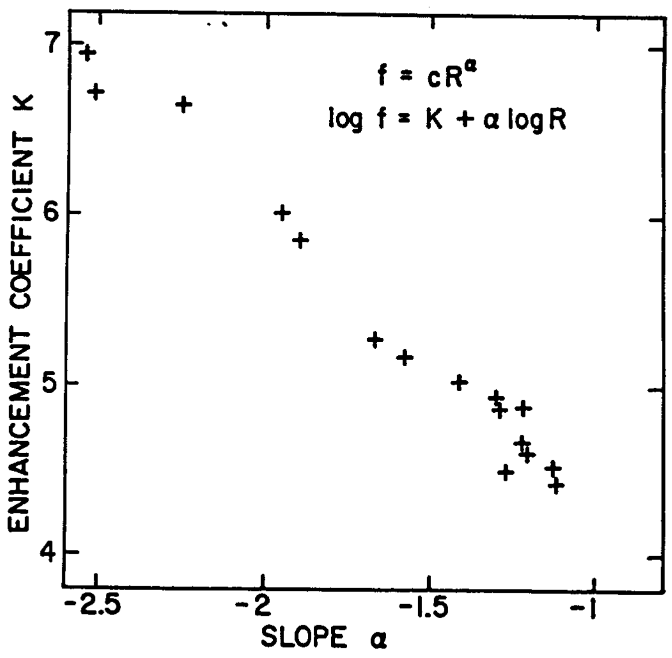


Figure 6 - Diagram of log k vs. alpha for 16 IP storms. The frequency scale of each IP storm was fitted to :
log f = log k + (alpha) log R .
A slope of -1 in this frequency scale corresponds to -2 in density.



the interplanetary medium. We have also shown (Figure 2) that they correlate with solar active regions and especially with the type I and type III storm activity in the lower corona (Bougeret et al., 1982a). Type III bursts are produced by packets of energetic electrons which propagate along open field lines. There is some direct evidence that they are associated with white light streamers (Kundu et al., 1983). Hence we suggest that the IP storms trace the extension of streamers into the interplanetary medium.

Our findings can be summarized as follows. The IP storm radiation occurs in regions of enhanced density at levels of 10-170 solar radii (0.05-0.8 AU). These regions are most likely the extension of streamers into the interplanetary medium. The density in these enhancements falls off faster than R^{-2}. Regions of higher density fall off faster, so that there is apparently a merging to the average solar wind density by about 60-100 solar radii. We have also measured the velocity of the solar wind in these regions, and our technique actually follows the same region of solar wind plasma during its transit outward. Finally, in cooperation with R.P. Lin (University of California experiment on-board ISEE-3), we find that these IP storms are usually associated with fluxes of low energy electrons observed at 1 AU.

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