HECTOMETER AND KILOMETER SOLAR OBSERVATIONS

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ABSTRACT. Three dimensional "snapshots" of the large scale solar magnetic field topology as well as the solar wind electron density distribution from about 0.1 to 1 AU are obtained by tracking traveling solar radio bursts at hectometer and kilometer wavelengths with instruments aborad the ISEE-3 satellite and the HELIOS-2 solar probe. Both instruments observe in the frequency range from 30 kHz to 1 MHz and both are equipped with dipole antennas located in the vehicle spin plane. ISEE-3 also has a dipole along the spin axis and the signals from the two ISEE-3 antennas are combined to give the azimuth and elevation angles of the radio source. Triangulation between HELIOS-2 and ISEE-3 provides the additional observation necessary to uniquely determine the position of the radio source in space at each observing frequency. The techniques will be outlined, and illustrated by an example of the three dimensional field geometry and electron density distribution determined by the observations.

1. INTRODUCTION

The strong inhomogeneity of solar surface conditions is reflected in the flow structure in a way which cannot yet be accounted for in the present state of solar wind physics: Statistical studies of solar wind parameters at the Earth's orbit show evidence of strong gradients in velocity as one moves out of the ecliptic, at least in the accessible range of heliocentric latitudes ($\pm$ 7°) (Hundhausem, 1977). The latitude variation in the magnetic sector structure has been studied on Pioneer 11, which reached a latitude of 16°, where little evidence of sector structure was found (Smith et. al., 1978). Radio tracking of solar type III bursts has clearly shown the existence of large meridional deviations of the magnetic field from the average Archimedean spiral (Fitzenreiter et. al., 1977). These results complement, on an intermediate scale, magnetometer results which show a very tangled field structure on a short time scale and the classic spiral structure after averaging, and can be extrapolated to the Sun only in a statistical way. Therefore, a global description of the heliosphere is necessary to reach two major objectives; to investigate as a function of latitude the

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properties of the solar corona, the corona-wind interface, and the heliospheric magnetic field; and to understand the microscopic mechanisms controlling the overall pattern.

Improving our understanding of the physics of charged particle propagation in the heliosphere also require such a global description. The observed particle intensities and their time profile depend not only on small scale irregularities in the magnetic field that cause diffusion; but also on the large-scale structure of the field, the location of acceleration sites on the Sun, and the geometry of the field lines that are open into the solar wind.

An understanding of solar-wind physics and propagation of energetic particles in the heliosphere requires a three-dimensional description over as large a volume as possible of the overall magnetic field topology, the solar-wind velocity, and the electron density distribution. The tracking of solar type III radio bursts provide just such three-dimensional snapshots of the large-scale magnetic field topology and the spatial distribution of the elctron density N_e. A sequence of these will show the development and evolution in time and space of many important structures on a time scale of days.

2. TRACKING OF TYPE III RADIO BURSTS

Fast drift (type III) traveling solar radio bursts are produced by streams of electrons (10-100 keV) which are injected onto and travel outward from the Sun along open magnetic field lines (see review by Steinberg, 1980). Tracking the radio source is equivalent to mapping the magnetic field lines on which these exciter electrons are guided and propagate. The radio emission frequency f_R is directly related to the ambient plasma density in the vicinity of the exciter stream ($f_R = 2f_{pe}$) so that two-spacecraft observations of the source position as a function of radio frequency yields directly both three-dimensional magnetic field structure and electron density. If a dipole is mounted in the spin plane XY of a spacecraft, perpendicular to the spin axis Z (Figure 1a) the signal received from a discrete radio source will be modulated (Figure 1b) with two equal depth minima A_{min} per spin period whose position over the spin cycle will yield the aximuth ϕ_s (around the spin axis) of the source. It is possible to extract from the modulated signal the angular direction of the radio source to a precision of one degree. Therefore, a spin plane dipole mounted on a spinning spacecraft will allow the determination of the meridian plane (containing the spin axis) where the source lies. The 180° ambiguity can be removed by continuity considerations.

A second remote spacecraft determines a second plane containing the source; its itersection with the first would determine a direction in space. A three-dimensional position could then be determined only if a third piece of information is available; e.g. that the electron density distribution is equivalent to a set of surfaces where all events

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observed at a given frequency are supposed to be located. One way to avoid the need for such a model is to use a dipole which is neither perpendicular nor parallel to the spin axis (Figure 1c). Then

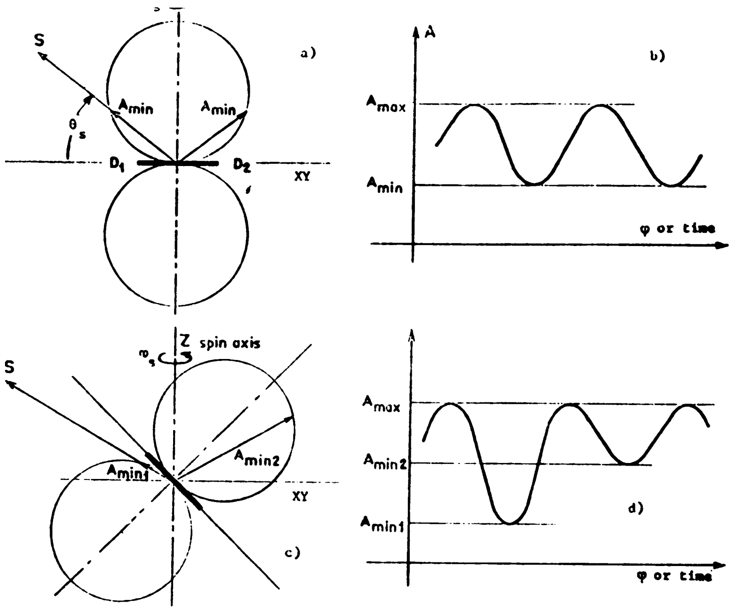

Fig. 1. (a) Reception and (b) Modulation Pattern for Dipole Mounted in Spin Plane; (c) Reception and (d) Modulation Pattern for "Tilted" Dipole

the modulation pattern shows two minima $A_{min\ 1}$ and $A_{min\ 2}$ which are in general different (Figure 1d). We synthesize a tilted dipole by correlating the signals from spin plane and spin axis electric antennas.

3. OBSERVATIONS

The upper panel of Figure 2 (Fainberg et al, 1972) shows part of the dynamic spectrum for a type III solar burst observed by IMP-6. The insert figure shows the actual spin modulation at 250 kHz. Since the spin plane was parallel to the ecliptic,azimuth angles are measured in a plane parallel to the ecliptic. The lower sequence of panels show the trajectories at five minute intervals. The intersection of the measured type III arrival direction with the RAE spherical emission level is determined and a radial line segment with length proportional to intensity is plotted.

Observations from a single spacecraft do not uniquely fix the

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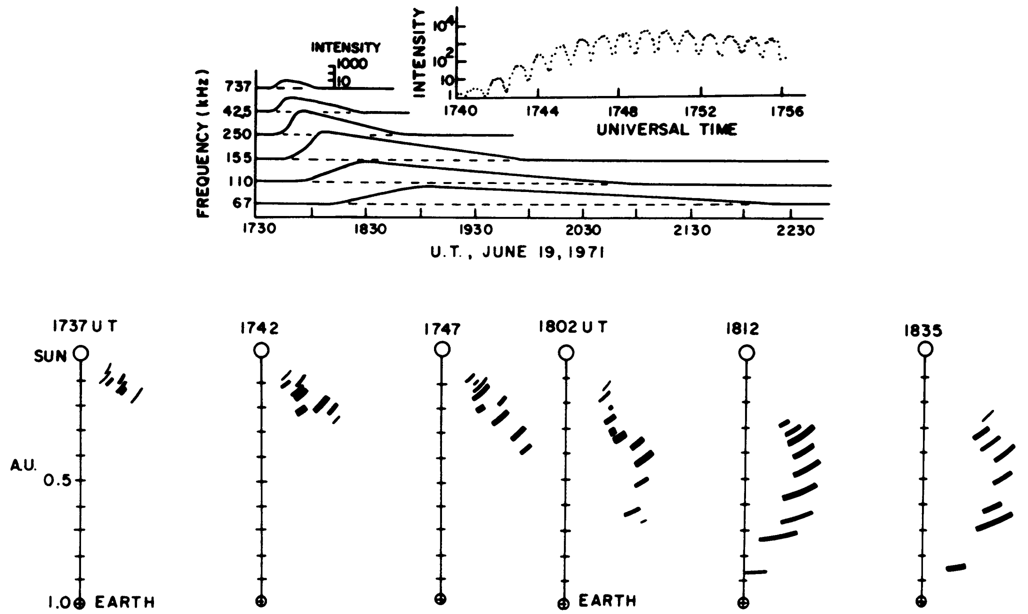

Figure 2. Dynamic spectrum of a type III radio burst and antenna spin induced modulation are shown. With a density model, and the directions determined from the spin modulation, the spiral trajectory is mapped at five minute intervals as shown (after Fainberg et al, 1976)

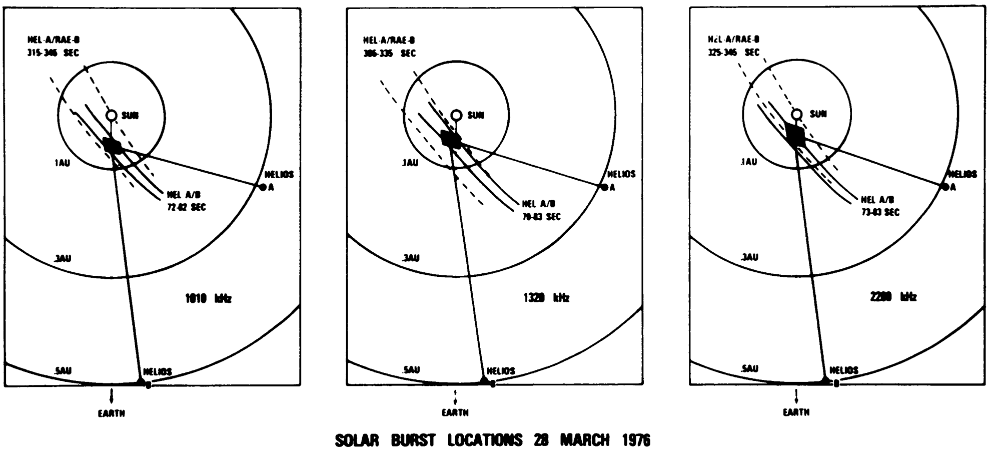

Fig. 3. Radio burst location obtained from both triangulation and arrival time differences between HELIOS-A and HELIOS-B. Direction finding and arrive time results are in agreement (after Weber et al,1977)

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source radial distance from the sun. This restriction can be removed by triangulation with two widely separated spacecraft as demonstrated by observations from HELIOS A and B shown in Figure 3 (Weber et al, 1977). The locations of the two probes and the observing frequencies are shown in each panel. The shaded rhombics illustrate the source locations and estimated errors.

Initially RAE-2 was operated with its dipole spinning in a plane perpendicular to the ecliptic. RAE then could measure elevation angle instead of azimuth angle relative to the ecliptic. The simultaneous observations of a type III radio burst by RAE and IMP-6 led to the three dimensional trajectory shown in Figure 4 (Fitzenreiter et al, 1977). It was still necessary to employ the RAE emission level scale to fix the source distance at each frequency.

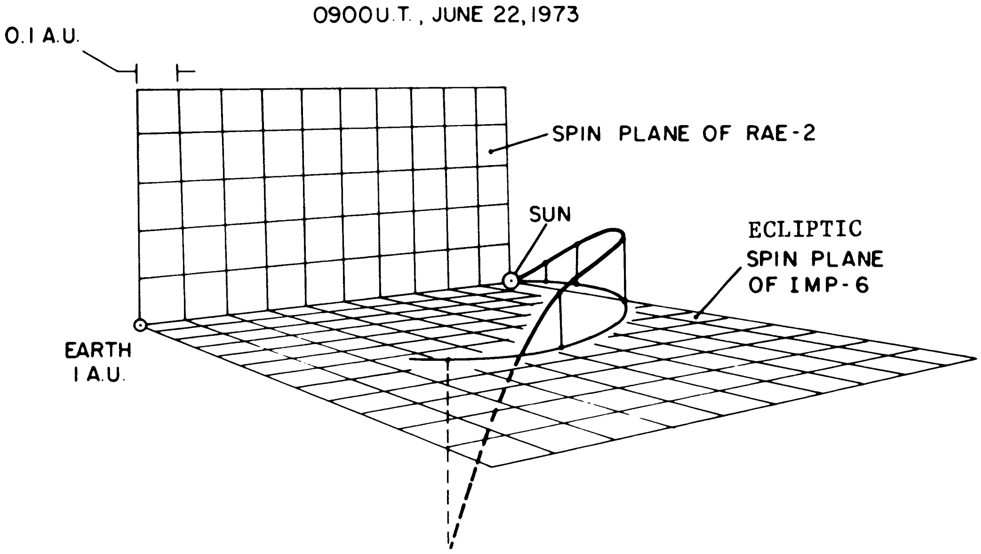

Fig. 4. Out of Ecliptic Observation of a type III Trajectory on June 1973 by RAE-2 and IMP-6 (after Fitzenreiter et al. 1977).

The ISEE-3 spacecraft is situated in a "Halo" orbit about the libration point located ~ 240 R_E upstream between Earth and Sun. The experiment (Knoll et al, 1978), observes on 24 frequencies between 30 kHz and 2 MHz. The antenna system consists of a 90 m dipole in the spin plane, which is parallel to the ecliptic and a 10 m dipole perpendicular to the spin plane. Azimuth angle is determined from the spin plane antenna observations while a comparison of intensity received by the two dipole systems gives the elevation angle of the source with an accuracy depending on the value of elevation. The sign of this elevation angle is obtained from the phase comparison of the signals received from both antennas.

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The HELIOS instrument consists of a 30 m dipole in the spin plane and covers the frequency range from 30 kHz to several MHz (Weber et al, 1977). HELIOS is in a heliocentric orbit and is often in an excellent position relative to ISEE for triangulation on solar burst trajectories. Several events show typical spiral patterns with the trajectories occurring within a few degrees of the ecliptic plane. Figure 5 is the trajectory derived from analysis of one of several type III events occurring close in time at 2000 U.T., Dec. 11, 1978. The Figure is the plane of the ecliptic, and the positions of HELIOS, ISEE, and the Earth are shown. The associated flare event was at S19 W52 and is shown with a tick mark on the figure. Each triangle represents the intersection of azimuth vectors derived from the two sets of observations. The corresponding source elevation is shown alongside these positions. Thus it appears from this preliminary analysis that the field lines along which this event propagated originated at latitudes of south 19°, are at south 7° at 0.2 A.U., cross the ecliptic at about 0.5 AU and thereafter remains at northern latitudes. The second type III events associated with this same active region displayed a similar spiral trajectory but appeared to be totally at northern latitudes. This may be a further manefestation of type III emission along narrow lanes resulting possibly from neutral plane geometry (McLean, 1970).

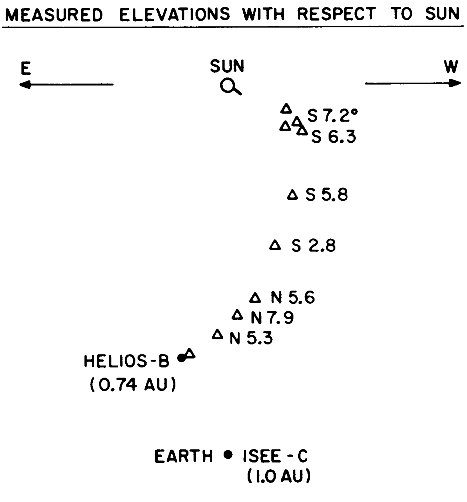

Fig. 5. Trajectory of the Event of 2000 UT Dec. 11, 1978 Derived from the Simultaneous ISEE-1 HELIOS observations. Flare location was S19 W52. Triangles represent position in ecliptic, adjacent numbers are corresponding elevation angles.

The depth of modulation may be used to estimate source size without the ambiguity resulting from not knowing source latitude. For the event in Figure 5 the half angle subtended by the source is found to be about 45° at all heights.

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Figure 6 is the electron density gradient between 0.15 AU and 0.75 AU derived for the December 1978 burst. This event, typical of those analysed thus far, indicates that the density gradient often differs significantly from a simple power law distribution.

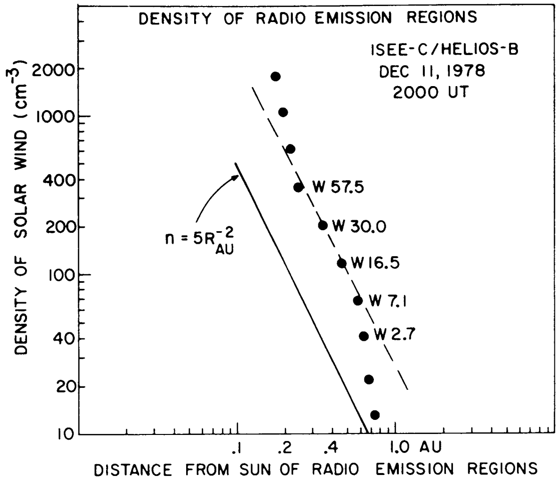

Fig. 6. Electron density distribution (●) for the Dec. 11, 1978 event. A simple inverse square model is also shown.

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DISCUSSION

Maxwell: There appears to be a benign neglect of type II's. Can you tell me for example how many type II bursts have you seen? Have you seen the fundamental and the harmonic? Did you deduce the velocity from the Stone model of electron denisty?

Stone: Indeed we have not as yet tackled the investigation of type II's because we have spent our time developing the programs and analysis routines required to determine source directions. We anticipate that when this is completed, and it is a highly sophisticated problem, we will be able not only to analyze the spectra of II's but their positions. We have observed about 6-12 type II's with perhaps 2 showing harmonics. I hope that observers interested in type II's will contact us for specific events. Bear in mind that ISEE is observing the sun 100% of the time.

Fainberg: The analysis of type II radio events on ISEE-3 has reached only very preliminary stages. At this point, we have identified many events lasting for periods over 12 hours, and some exhibit clear harmonic structure. In one case, following the Sept. 23, 1978 flare, the radiation from the interplanetary shock was visible over its entire transit out to 1 AU.

Steinberg: It is true that we have had no time to analyze type II's in detail on ISEE data. This is being done now.

Dulk: Using some of your measurements of source sizes together with higher frequency measurements from the ground, one can conclude that sources occupy a large cone ($\gtrsim$ 60° with apex in the active region) that extends all the way to and beyond 1 AU. Would you agree that such a picture is correct?

Stone: The event just shown does suggest that the source size, calculated between one sigma points of a gaussian distribution is of the order of 45° at all heights we observe. I do recall (Gergely's thesis) that the source size was narrow at frequencies above 100 MHz and showed an abrupt increase in angular size below 100 MHz. At 1 AU Lin's data shows particle beam widths consistent with a 45-60° angle.

Gergely: The source size seems to open up at $\sim$ 100 MHz frequency if my memory is correct. This refers to storm continuum, however, I'm not sure about type III bursts being the same.

Lin: The electron streams appear to fill regions of $\gtrsim$ 60° extent, approximately the same size as the low frequency type III radio sources.

Kayser: Some of apparent source diameter at $\lesssim$ 150 kHz is probably due to broadening by scattering.

Takakura: Why is the intensity of radio bursts with Z antenna so low?

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Stone: Yes, the spin axis data shown in the dynamic spectra for ISEE is less intense because that antenna is much shorter than the spin plane dipole. To make the situation even more obvious, the dynamic spectra I have shown were from the first few months of operation when the spin axis dipole antenna was only partly deployed.

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