X-693-71-107
PREPRINT

NASA TM X- 65484

A U-TYPE SOLAR RADIO BURST ORIGINATING IN THE OUTER CORONA

R. G. STONE
JOSEPH FAINBERG

MARCH 1971

GSFC
GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

A U-TYPE SOLAR RADIO BURST ORIGINATING IN THE OUTER CORONA

by

R. G. Stone and Joseph Fainberg
Radio Astronomy Branch
Laboratory for Extraterrestrial Physics
Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

The observation of a U-type solar radio burst with a reversing frequency of approximately 0.7 MHz suggests the presence of a magnetic bottle extending out to about 35 solar radii. A possible model of this loop structure is developed from the data. The occurrence of low-frequency U bursts seems to be extremely rare although magnetic bottles may develop frequently during solar maximum.

I. INTRODUCTION

The dynamic spectra of U-type solar radio bursts, as the name implies, are characterized by a drift to lower frequencies and a subsequent return drift to higher frequencies. The initial drift rate $|^{df}/_{dt}|$ is similar to that of type III bursts, but decreases as the reversing frequency f_{min} is approached. U-type bursts were first reported by Maxwell and Swarup (1958) and Haddock (1958). Although far less abundant than type III's, U bursts are nevertheless not uncommon at meter wavelengths. Their occurrence at longer wavelengths does seem to be rare, although one with a reversing frequency of 35 MHz has been reported (Sheridan et al., 1959).

The U burst is frequently considered to be a variant of a type III in which the exciter is constrained after the initial outward motion to return to lower coronal heights. This would occur if the exciter were forced to travel along a magnetic arch structure produced by a bi-polar field configuration. Directive measurements show that the positions of the two branches of the burst differ appreciably (Wild et al, 1959). As noted by Fokker (1970), the more descriptive classification of "J-like" bursts would be more appropriate in those instances where the second branch (frequency increasing) is less developed or almost absent.

In this paper we discuss the very rare occurrence of a U-like burst observed between 5 and 0.7 MHz by the

Radio Astronomy Explorer satellite (RAE-1). In terms of a model in which the exciter moves along a magnetic loop, the present observations suggest that such loops or magnetic bottles can extend out to the order of 35 solar radii.

II. OBSERVATIONS

The observations reported here were obtained with the Radio Astronomy Explorer Satellite (RAE-1) over the frequency range from 5.4 to 0.2 MHz. Since launch in mid-1968, the RAE-1 has observed an enormous number of type III (fast drift) bursts occuring individually, in groups, and as storms (Fainberg and Stone, 1970a,b, 1971a). During such storms of type III events, a continuum component of solar origin has also been detected (Fainberg and Stone 1971b). Conservatively estimated, more than 10^5 storm type III's have been observed in addition to approximately 10^3 intense individual type III events. Because of the large burst occurrence rate during storms and the subsequent confusion that would result in looking for reverse structure, only intense individual and groups of type III's have been examined for signs of reverse drift structure. In only one instance, that reported here, has a clear example of a hectometric U burst been identified.

Figure 1 shows the U burst observed on November 23, 1968 at approximately 1933 UT (time of occurrence at 5.4 MHz). These data are obtained with a set of fixed-frequency radiometers which are each sampled twice per second. Figure 2 is a computer developed contour diagram of the output from the swept frequency radiometer system which samples 32 frequencies in 8 sec. The contours in Figure 2 are separated by 3db. The antenna system for both radiometers is an electric dipole. There is a system calibration near 1940 hours which lasts for 38 sec and results in the loss of some data points. The lower frequency limit of the observations is determined by the position of the satellite in the plasmapause; at the time of these observations the limit was about 600 KHz which turns out to be close to the reversing frequency as discussed later.

The decreasing frequency branch of the burst is not unlike other type III's seen in this frequency range. On the other hand, the increasing frequency branch, which is of comparable intensity, appears to cut off rather abruptly around 3 MHz. The instrument would have been able to detect a signal 20 db less intense above this high frequency cutoff, but none was observed.

With the identification of this U burst, a more detailed search was conducted of the time period November-December 1968 to find similar events. One other possible U burst, and a number of what should more appropriately be called "J bursts" have been tentatively identified. In the latter case, the normal type III, upon reaching some minimum frequency, ceases to drift and at the same time becomes very intense. In still another case, the dynamic spectrum shows an intensification, but after a delay of the order of a minute, the burst again starts to drift to still lower frequencies. We cannot at this time be sure that such structure is really related to U-like phenomena.

No flare or radio burst activity which could be related to the occurrence of the U burst was reported in the ESSA Solar-Geophysical Data. This may indicate that the active center was located just around the limb and was not observable optically, although radio emission originating at much higher altitudes could be seen.

THE POSSIBLE TRAJECTORY

In the absence of position observations of the source of emission, it is necessary to develop a model of the exciter trajectory. Fokker (1970) utilizes a model for the density enhancement through which the exciter moves to derive a trajectory from his dynamic spectra. If we utilize the radial density profile determined from previous work (Fainberg and Stone, 1971a) the radial extent of the U burst as estimated from the reversing frequency is the order of 35 solar radii.

However assuming a constant average exciter speed (Fainberg and Stone, 1970b) along the loop, the distance corresponding to the time required for the exciter to move between the same plasma level on the two branches of the burst may be determined. The path length between the same radial points on the two branches of the loop can be determined by using different frequencies. By combining these two constraints, the radial distance scale and the total distance along the path between the same plasma level, the model shown in Figure 3 is obtained. The magnetic bottle is placed near the (east) limb for the following reasons: (1) as noted previously, the absence of an associated flare suggests the possibility of an event behind the limb; (2) as discussed below, the abrupt cutoff of the return branch of the burst at the higher frequencies can be explained by refraction if the event occurs at or near the limb. However, we also find a small difference in the observed drift rate for the two branches, which is quite consistent with the light time corrections necessary for events occuring at large radial distances (Fainberg and Stone, 1970b). To account for the slightly faster observed drift rate along the return branch, the trajectory must be placed near the (east) limb. Accepting the constraints discussed above, there is surprisingly little choice in the model trajectory.

The location of the active region near either limb will satisfy these conditions. Our selection of the east limb is discussed later.

III. RETURN BRANCH CUTOFF

The fact that U-like bursts display a less developed return branch has been considered by Fokker (1970), who attributes this characteristic to radiation directivity and by Smith (1970), who argues against this and suggests instead that defocusing of the exciter accounts for the less developed return branch. The interaction of the field and the exciter was considered in connection with other U-burst characteristics by Zheleznyakov (1965). Although such processes undoubtedly play an important role in the characteristics of U bursts, it is difficult in our case to account for the rather abrupt disappearance of the high-frequency end of the return branch in this way. Figures 1 and 2 show that the observed section of the return branch is as intense as the outgoing branch.

In view of the abrupt cutoff of the return branch and the absence of an associated flare, as well as the discussion above, we are inclined to believe that the event occurs at or slightly behind the (east) limb. Radiation leaving that branch of the burst at a greater distance behind the disc will fall within the limit of the refraction escape cone at a higher altitude. Many ordinary type III bursts observed at these low frequencies exhibit such behavior, i.e. only the lower-frequency end of the burst can be observed. These also show no association with observed flares, presumably for the same reason.

IV. RELATED OBSERVATIONS

Levy et al. (1969) noted large-scale transient phenomena during their Faraday rotation measurements of a radio source (Pioneer 6) occulted by the solar corona. Schatten (1970) interprets these events observed on November 4, 8, and 12, 1968 as evidence for a coronal magnetic bottle at 10 solar radii. He argues that a flare resulted in the heated coronal plasma expanding to produce the extended magnetic field configuration.

Active centers associated with plage numbers 9747, 9754 and 9740 were believed to be responsible for the Faraday rotation transient events. In particular, plage 9747 reappears on the east limb as 9789 on November 23, 1968, the day of the observed U burst. It is possible that the same active region again produced a magnetic bottle shortly before the observed U burst. The magnetograms for 9747 show a simple bipolar magnetic region oriented with the positive flux following (eastward of) the negative flux.

If the magnetic field pressure is sufficient to overcome the gas kinetic pressure, the coronal plasma will be prevented from expanding into interplanetary space. If the expansion exceeds the Alfvén point at the order of 30 $R_{\odot}$, the coronal plasma and the imbedded field will escape into the interplanetary space.

Schatten (1970) has also suggested that the occurrence of such extensive magnetic bottles may not be unusual. The background field at distances of 1 AU is essentially constant between solar minimum and maximum, and yet close to the sun there is evidence of open magnetic structure which must extend out into the corona. The additional field lines which do not reach 1 AU at solar maximum must reside in magnetic bottles extending to distances less than the Alfvén Point.

CONCLUSION

The observations of U-type bursts appear to be extremely rare at hectometric wavelengths, although the occurrence of extensive magnetic bottles may occur more frequently during the years of maximum solar activity. From the observations of the U-type burst of November 23, 1968, a model of the trajectory has been developed. The inferred loop extends out to the order of 35 solar radii and is believed to occur near the east limb of the sun. It appears that the active region responsible for such loops earlier in November may have also produced the magnetic bottle inferred from the present observations. The occurrence during this period of time of type III bursts resembling "L-like" structures are suggestive of at least partial confinement of an exciter by a magnetic field.

ACKNOWLEDGEMENTS

The authors wish to thank J. K. Alexander and H.H. Malitson for their helpful comments on this problem.

REFERENCES

Fainberg, J. and Stone, R.G.: 1970a, Solar Physics, 15, 222

.: 1970b, Solar Physics, 15, 433

.: 1971a, Solar Physics (in press)

.: 1971b, Ap. J. , 164, L123

Fokker, A.D.: 1970, Solar Physics, 11, 92.

Haddock, F.: 1958, Proc. I.R.E. 46, 1.

Levy, G.S., Sato, T., Seidel, B.L., Stelzried, C.T., Ohlson, J.E., and Rusch, W.V.T.: 1969, Science 166, 596.

Maxwell, A. and Swarup, G.: 1958, Nature 188, 36.

Schatten, H.: 1970, Solar Physics 12, 484.

Sheridan, K.V., Trent, G.H., and Wild, J.P.: 1959 Observatory 79, 51.

Smith, D.F.: 1970, Solar Physics 13, 444.

Wild, J.P., Sheridan, K.V., and Trent, G.H.: 1959 Paris Symposium on Radio Astronomy (R.N. Bracewell, ed.) Stanford University Press.

Zheleznyakov, V.V.: 1964, Radio emission of The Sun and Planets (English Translation, 1970, Pergamon Press N.Y.)

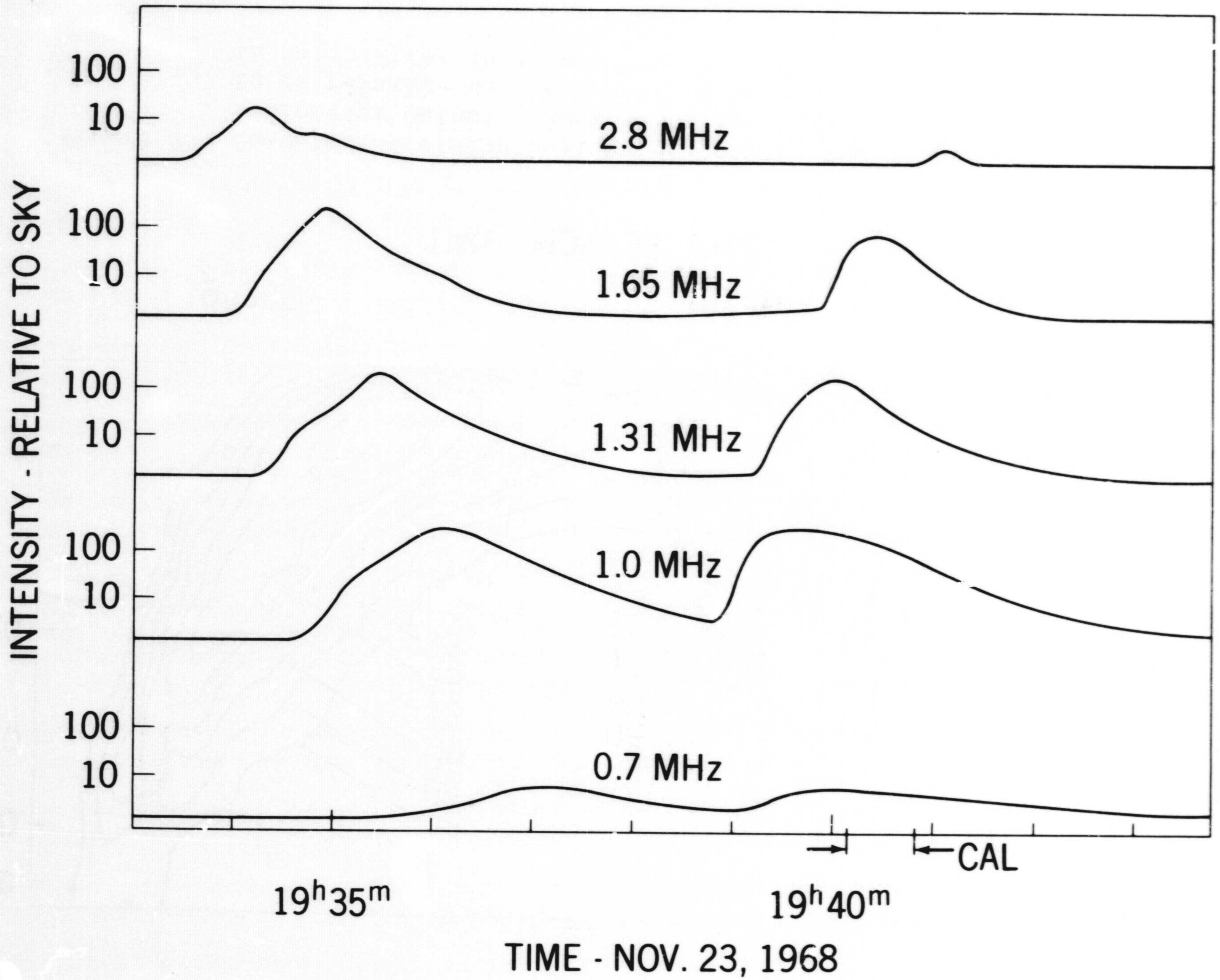

Figure 1 - Fixed frequency scans of the solar U burst. Note the abrupt decrease in intensity above 3 MHz on the return branch. Data was not obtained below 700 Khz for this event. "Cal" refers to calibration interval.

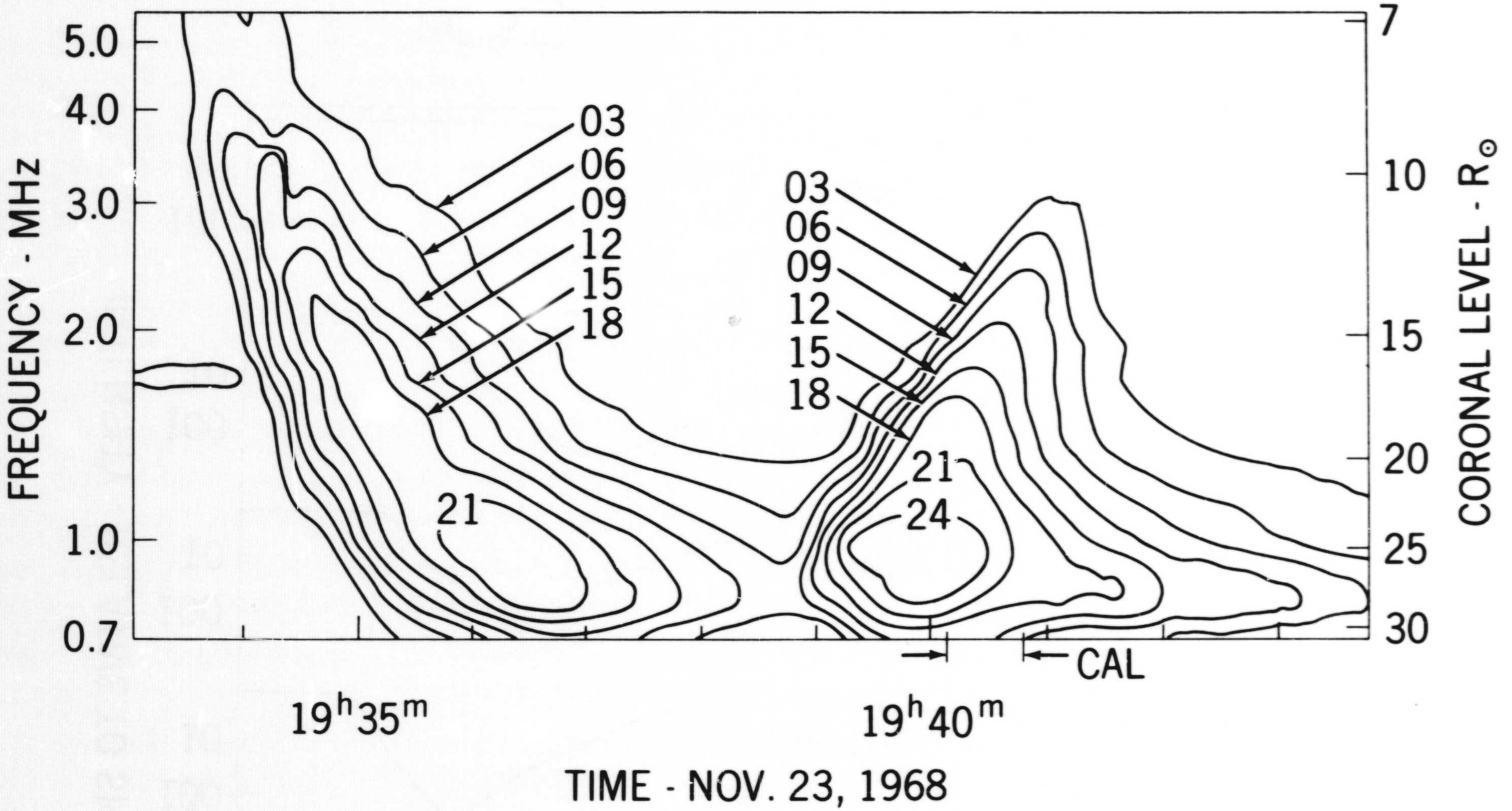

Figure 2 - Computer developed contour diagram of the swept frequency radiometer output. Numbers on the figure represent intensity in db relative to the cosmic noise background. "Cal" refers to calibration interval.

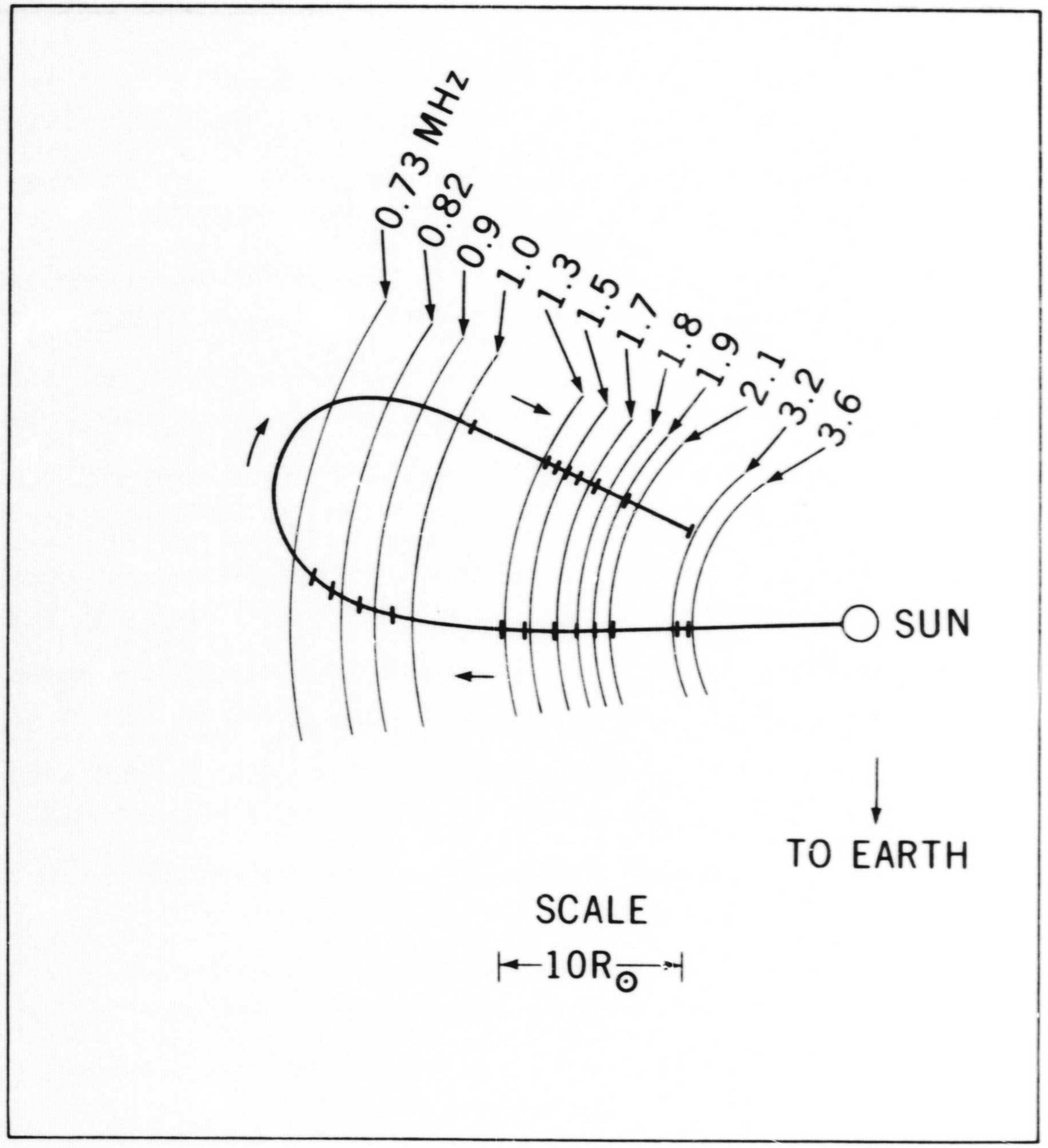

Figure - The model trajectory for the exciter obtained from the dynamic spectrum of the U burst. Plasma levels (Fainberg and Stone, 1971a) are labeled in the figure. The turning point is about 35 solar radii. Bars on the trajectory indicate the positions determined from the observed burst drift times relative to the start of the burst assuming a constant exciter speed of .3c.