

ULYSSES/GALILEO OBSERVATIONS OF TYPE III RADIO BURSTS AND ASSOCIATED IN-SITU ELECTRONS AND LANGMUIR WAVES

M. J. REINER¹, K. A. ANDERSON², E. ROELOF³, T. ARMSTRONG⁴,
G. B. HOSPODARSKY⁵, J. FAINBERG⁶, R. G. STONE⁶, L. LANZEROTTI⁷,
D.A. GURNETT⁵, J. L. PHILLIPS⁸, R. FORSYTH⁹

¹Hughes STX, Lanham, MD, 20706, USA

²Space Science Lab., Univ. of Cal., Berkeley, CA, 94720, USA

³Johns Hopkins Univ./APL, Laurel, MD, 20723, USA

⁴Dept. of Phys. & Astron., Univ. of Kansas, Lawrence, KS, 66045, USA

⁵Dept. of Phys. & Astron., Univ. of Iowa, Iowa City, IA, 52242, USA

⁶NASA/GSFC, Greenbelt, MD, 20771, USA

⁷ATT, Bell Labs., NJ, 07974, USA

⁸Los Alamos National Lab., Los Alamos, NM, 87545, USA

⁹The Blackett Lab., Imperial College, London, SW7 2BZ, UK

Abstract. Both the Ulysses and Galileo spacecraft detected energetic electrons and Langmuir waves that were associated with a type III radio burst on 10 December 1990. At the time of these observations, these spacecraft were in the ecliptic plane and separated by 0.4 AU, with Galileo near the Earth at 1 AU and Ulysses at 1.36 AU. From the measured electron arrival times, the propagation path lengths of the electrons to both Ulysses and Galileo were estimated to be significantly longer than the length of the Parker spiral. These long path lengths are interpreted as due to draping of the interplanetary magnetic field lines around a CME. The onset times of the Langmuir waves at Ulysses and Galileo coincided with the estimated arrival time of the 9 keV and 14 keV electrons, respectively.

1. Introduction

Type III solar radio bursts are produced by streams of suprathermal electrons that propagate along open magnetic field lines into the interplanetary medium. Most analyses of these electrons have been restricted to measurements made by a single spacecraft located within the electron stream (Lin, 1985). Observations of series of flare associated electron events, originating from a common solar active region, indicate that the longitudinal width of electron streams is $\geq 60^\circ$ (Lin, 1970a). Propagation path lengths and solar injection times of electrons were deduced from measured electron velocity dispersive onsets (Potter *et al.*, 1980). The derived path lengths were often consistent with the length of the Parker spiral, suggesting scatter-free propagation.

The onset of type III associated Langmuir waves is directly correlated with the formation of a "bump-on-tail" in the measured electron distribution function (Lin *et al.*, 1981; 1986). The Langmuir waves generate radio emissions at the fundamental and harmonic of the local plasma frequency (Reiner *et al.*, 1992). The remotely observed type III radio emission is characterized by increasing onset times with decreasing frequency due to the fall off of the interplanetary density with heliocentric distance.

During November-December 1990 the relative configuration of Ulysses and Galileo was such that both spacecraft were often simultaneously located within electron streams associated with western solar flares. This unique configuration permits the characteristics of the electrons and associated Langmuir waves to be simultaneously measured and compared at two spatially separated points.

2. Ulysses/Galileo Observations of a Type III Radio Burst

We examine a type III radio burst on 10 December 1990 that was previously analyzed by Gurnett *et al.* (1993) using the Galileo data alone. Both Ulysses and Galileo observed the frequency-drifting radio emission from this type III burst, which was associated with a western 2F flare (N15°W47°). Figure 1 shows a dynamic spectrum of the radio emission observed by Ulysses. Many type III radio bursts were observed during this time. The one of interest is the intense burst beginning at ~07:45 UT at 940 kHz. The onset of the ~5 MHz radio emission observed at 07:42 UT at Galileo suggests that the type III associated electrons were injected into the interplanetary medium at ~07:34 UT. The frequency-drifting radiation was observed to very low frequencies (~20 kHz).

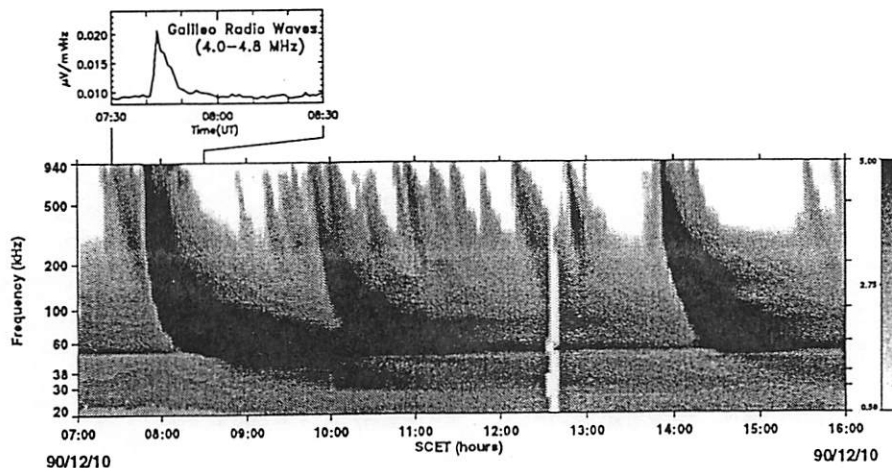


Fig. 1. Dynamic spectrum of the radio emission from 20 to 940 kHz observed at Ulysses from 07:00 to 16:00 UT on 10 December 1990. The intensity-time profile of the radio emission observed at Galileo at ~5 MHz is shown in the insert.

At this time, Galileo was passing near Earth at 1 AU and Ulysses was about 7° west of the Earth-Sun line and 1.36 AU from the Sun. The distance between Ulysses and Galileo was 0.4 AU and both spacecraft were located in the ecliptic plane. Their relative configuration is illustrated in Figure 2.

Figure 3 shows the energetic electrons and Langmuir waves observed at Ulysses and Galileo that were associated with this type III radio burst. An impulsive electron event was detected between ~08:10 and 8:30 UT at Galileo (Figure 3a) and between 08:30 and

08:40 UT at Ulysses (Figure 3c). In both cases, the pitch angle distributions (not shown) indicate field-aligned beaming of the electrons in the antisunward direction. This is characteristic of a prompt electron event (Lin, 1970b; Anderson *et al.*, 1981) and implies essentially scatter-free propagation. Due to the relative separation of Ulysses and Galileo, these electrons must have propagated along interplanetary field lines that originated at different heliographic longitudes (separated by $\sim 20^\circ$) near the Sun. The electron fluxes observed at Galileo in the $\sim 42\text{-}60$ keV energy range were significantly (~ 30 times) higher than those observed at Ulysses. This may be due to the fact that, for electrons ejected from a $W47^\circ$ flare site, Galileo should lie nearer the centroid of the electron stream.

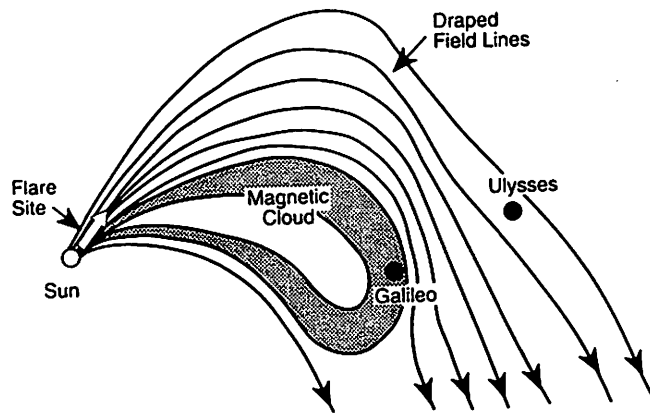


Fig. 2. Relative location of Ulysses and Galileo on 10 December 1990. This cartoon illustrates the possibility, discussed in the text, that Ulysses was located in the region of magnetic field lines draped around a coronal mass ejection.

Although a velocity dispersion in the electron onset times at both spacecraft is suggested by the data, it is not particularly well-defined. This makes a precise quantitative analysis of the beam dynamics somewhat ambiguous. Spatial structures in the interplanetary medium may be partly responsible for these ill-defined electron onsets. Our "best" estimate for the arrival times for the electrons in the five energy channels shown in Figure 3 are plotted in Figure 4 versus $1/\beta$, where $\beta=v/c$. If it is further assumed that the electrons detected at both spacecraft were injected into the interplanetary medium at 07:34 UT (as determined from the radio data), then the "best" straight line fits to these data give a propagation path length of ~ 1.7 AU to Galileo and of ~ 3.4 AU to Ulysses. These lengths are significantly longer (~ 1.4 times for Galileo; ~ 2 times for Ulysses) than the length of the Parker spirals (~ 1.15 AU for Galileo; ~ 1.7 AU for Ulysses) that correspond to the measured 400 km/s solar wind speed at Ulysses.

The onset time of the Langmuir waves at Galileo (Figure 3b) at 08:36 UT corresponds to the time that it would take ~ 14 keV electrons (assuming no pitch angle scattering), propagating along the same path length, to arrive at Galileo. The

maximum intensity of these Langmuir waves was estimated by Gurnett *et al.*, (1993) to be ~ 1.7 mV/m. The 14 keV electrons were expected to arrive at Ulysses along the inferred 3.4 AU path at $\sim 09:38$ UT, but no Langmuir waves were observed at this time. Langmuir waves at Ulysses (Figure 3d) were not observed until $\sim 10:10$ UT (~ 30 minutes later), corresponding to the estimated arrival time of ~ 9 keV electrons. The maximum intensity of the Langmuir waves at Ulysses was ~ 7 mV/m, i.e., 5 times higher than at Galileo.

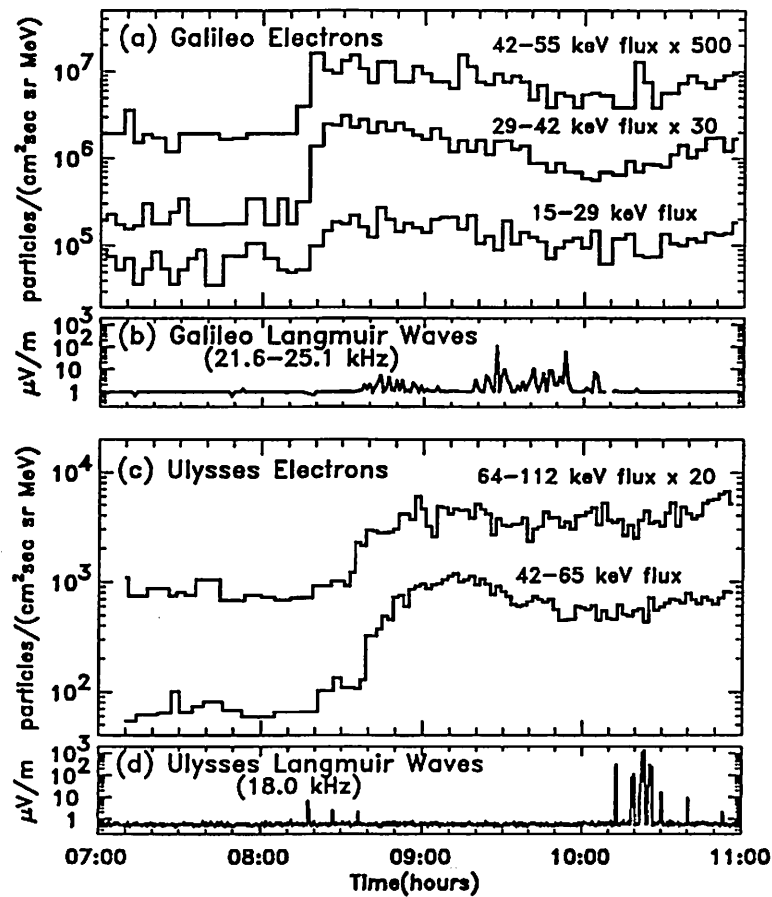


Fig. 3. (a) 15 - 55 keV peak electron fluxes at Galileo from 07:00 to 11:00 UT. (b) Langmuir waves detected near the local plasma frequency at Galileo. (c) Two minute averaged 42 - 112 keV background subtracted electron fluxes at Ulysses. (d) Langmuir waves observed near the local plasma frequency at Ulysses.

3. Discussion

Simultaneous observations by longitudinally separated spacecraft provide a direct measure of the longitudinal extent of a type III burst associated electron stream. The

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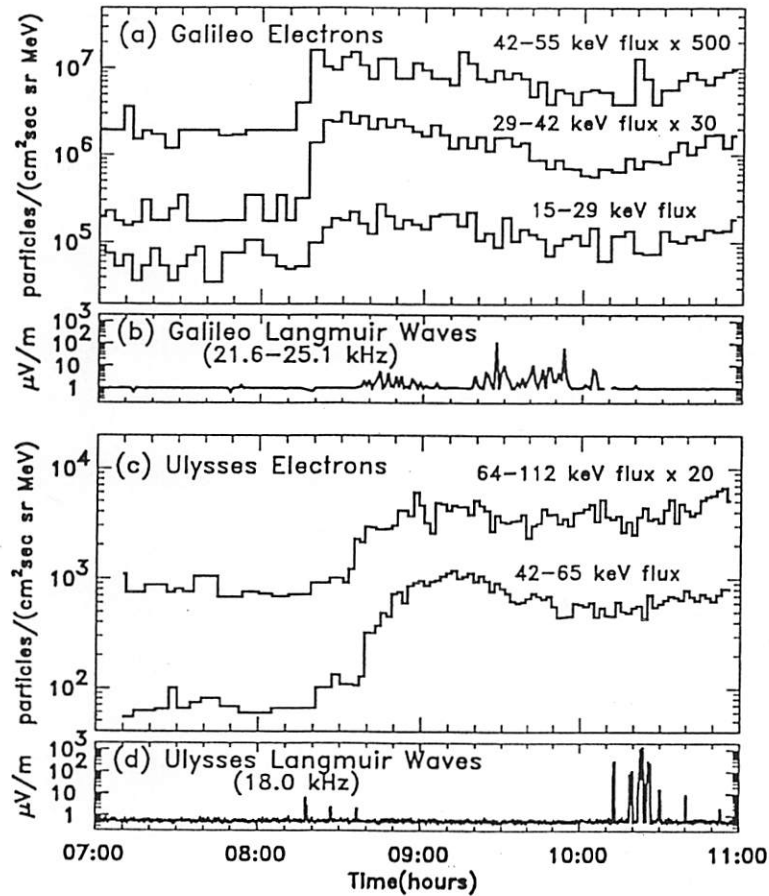


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observations for the 10 December event imply that this electron stream extended over at least a $\sim 20^\circ$ heliographic longitudinal range of field lines above the solar active region.

There is *a priori* no reason that solar electrons at different heliographic longitudes should be injected simultaneously onto open interplanetary magnetic field lines or that the length of the field lines to longitudinally separated spacecraft should be the identical. Simultaneous electron observations by two spacecraft offers the unique opportunity for independently measuring both the injection times of the suprathermal electrons at the Sun and their respective propagation path lengths to each spacecraft by the analysis suggested in Figure 4. Because of the imprecise onset times for the electron events considered here, however, we were not able to utilize the full potential of this technique.

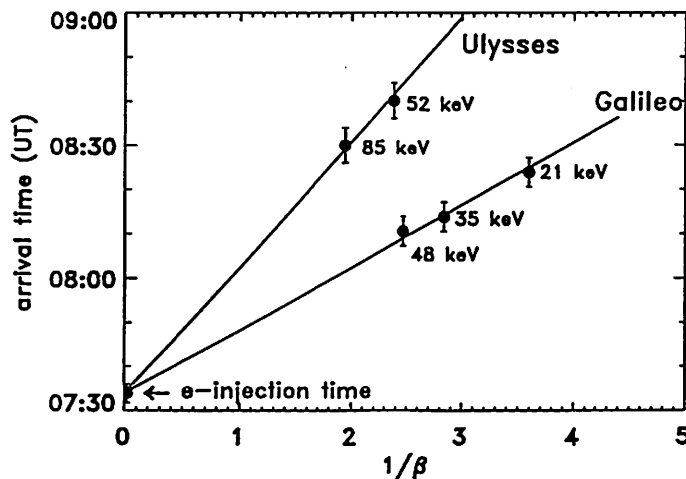


Fig. 4. Plot of arrival time versus $1/\beta$ for the energetic electrons detected at Galileo and at Ulysses. The values for β were obtained using the geometric mean energy in each channel. The straight lines assume a common injection time at the Sun. The slopes of the lines are proportional to the length of the propagation path.

The chronology of the *in-situ* observations at Ulysses and Galileo for the December 10 type III radio burst differed significantly from expected. The analysis suggests that the effective electron path lengths to both Ulysses and Galileo were significantly longer than the nominal Parker spiral. The electron anisotropies observed at both Ulysses and Galileo suggest that pitch angle scattering alone cannot account for such large path lengths. Although interplanetary spatial structures may have influenced the dispersive onsets for some of these electrons, our analysis does not depend critically on this. It is unlikely that spatial structures would have significantly delayed the electron arrival times at both spacecraft simultaneously. It is therefore reasonable to conclude that the derived path lengths represent the approximate length of the field lines from the Sun to each spacecraft. On the other hand, the Ulysses plasma and field data indicate that a CME, with field characteristics identifying it as a magnetic cloud, passed Ulysses on 11 December 1990. Thus, at the time of these observations, Ulysses was antisunward from

the CME in the region of the draped magnetic field lines (Gosling and McComas, 1987), as illustrated schematically in Figure 2. The significantly longer path length to Ulysses (and possibly also to Galileo) may therefore correspond to "lengthening" of the field lines that were draped around the CME (McComas *et al.*, 1989).

There was also a difference in the expected Langmuir wave onset times at the two spacecraft. The Langmuir waves observed at Ulysses involved lower energy electrons (9 keV) than those at Galileo (14 keV). One possible explanation for this delay at Ulysses is that the Langmuir waves were not produced uniformly across the electron stream. Thus, although 14 keV electrons may have been present at Ulysses at 09:38 UT, the bump-on-tail in the velocity distribution function may not have formed in this region of the interplanetary medium at this time. This may be consistent with the observations of Reiner *et al.* (1992), that local radio emissions and associated Langmuir waves are produced only in localized regions of the interplanetary medium. Another possibility is that the effective electron exciter speed to Ulysses (near the stream edge) was lower than for Galileo (near the stream centroid) (Reiner and Stone, 1989). Unfortunately, since the low-energy electrons (2- 40 keV) were not detectable at either spacecraft, the parallel velocity distribution function, which would directly reveal the onset time of the beam instability, could not be determined.

4. Conclusion

Simultaneous *in-situ* observations of electrons at Ulysses and Galileo, at longitudinally separated points within a suprathermal electron beam, provide direct information on the longitudinal extent of the electron stream associated with a type III radio burst on 10 December 1990. The measured velocity dispersion in the electron arrival times suggest that the propagation path lengths to Ulysses and Galileo were significantly larger than the length of the nominal Parker spiral. These observations may represent the first direct evidence for lengthening of field lines due to the presence of a CME. The observed Langmuir waves were also significantly delayed at Ulysses compared to those observed at Galileo.

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Edited by

R. G. Marsden

*Solar System Division,
Space Science Department of ESA, ESTEC,
Noordwijk, The Netherlands*

M. J. Reiner

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