INTERPLANETARY SCINTILLATION MEASUREMENTS OF A TRANSIENT SOLAR WIND STREAM ASSOCIATED WITH THE 2003 OCTOBER 28th FULL-HALO CORONAL MASS EJECTION

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ABSTRACT

Observations of interplanetary scintillation (IPS) made with the 327-MHz four-station system of the Solar-Terrestrial Environment Laboratory (STEL) of Nagoya University were analyzed to study the 3-dimensional properties of a transient solar wind stream associated with the 2003 October 28th full-halo coronal mass ejection (CME). As a result, a loop-shaped high-density region propagating at a significantly slower speed than the CME-driven shock was identified. This feature is consistent with the white-light observations made simultaneously. The origin of this loop-shaped structure is considered to be a coronal ejecta confined to the magnetic flux rope.

INTRODUCTION

Interplanetary scintillations (IPS) of natural radio sources serve as effective tools for the remote sensing of solar wind plasma (e.g., [1]). Since IPS observations using many radio sources allow us to probe multiple points of the solar wind in a short time, they are particularly useful for studying the global properties of transient heliospheric phenomena such as coronal mass ejections (CMEs) or interplanetary (IP) shock waves (e.g., [2], [3]). This paper reports our IPS observations of an intensive disturbance event associated with a very fast CME and a powerful solar flare which occurred on October 28th, 2003. In this study, the 3-dimensional features of this event were reconstructed from a deconvolution analysis of our IPS data, and compared with Thomson scattering measurements made simultaneously.

OBSERVATIONS

IPS observations at 327 MHz have been made regularly using the four-station system of the Solar-Terrestrial Environment Laboratory (STEL) of the Nagoya University [4], [5] (see Fig. 1). Nearly 40 sources with solar elongation angle e less than 90 degrees are observed daily between April and December Solar wind speed and the density disturbance factor (so-called g-value [2]) are simultaneously derived from our IPS observations. The g-value represents the relative variation in solar wind

density fluctuations (DNe) integrated along a line-of-sight, and is normalized to the undisturbed level of DNe. Owing to the strong scattering effect near the sun, g-value data for e<11.5 degrees are unavailable from our IPS observations.



Fig. 1. The 327-MHz radiotelescope at Fuji observatory, one of the antennas for the STEL four-station IPS system.

The sun became extremely active between October and November 2003 due to the emergence of eruptive sunspots on the solar disk (e.g., [6]). A spectacular full-halo coronal mass ejection (CME) event occurred on October 28th, 2003, ~11-hr UT in association with the X17/4B solar flare, and the IP shock driven by this CME impacted the Earth's magnetosphere on October 29th ~6-hr UT. The average Sun-Earth transit speed of this IP shock was ~2200 km/s. A traveling disturbance associated with this CME was clearly detected by our IPS measurements between October 28th 22-hr and 29th 7-hr (a comprehensive report of our IPS observations during October-November 2003 has been presented in [7]).



Fig. 2 Sky projection maps of solar wind speed (left) and g-value (right) derived from STEL IPS observations. The center of each map corresponds to the location of the sun. Circles in the map indicate the locations of lines-of-sight. Size and color of the circles represent the magnitude of solar wind speed (left) or g-value (right).

Fig. 2 shows sky projection maps of solar wind speeds and g-values obtained from our IPS observations for this time period. The offset distance given by $R=R_{SE} \sin e$ (where $R_{SE} = 1$ AU) was used in these maps. Owing to the low elevation of the sun during this period, the southern part of the sun-centered sky plane was poorly covered by the IPS observations, which nevertheless, clearly recorded remarkable enhancements in both wind speed and g-value, as shown in the figure. These enhancements are considered as an IP counterpart of the October 28^{th} CME. Our IPS data suggest that the forefront of the high speed flow (>1000 km/s) was well beyond 0.6 AU by the time the IPS observations were obtained, and this is consistent with the average transit speed of the IP shock. The important point to note here is that the majority of g-value enhancements were located much closer to the sun than the expected shock location, suggesting that they may be attributed to a high-density region propagating at a significantly slower speed than that of the IP shock.

RESULTS OF MODEL FITTING ANALYSIS

Using the model fitting method [8], we deconvolved the g-value data to retrieve the 3-dimensional distribution of the IP counterpart of the CME event. The model used here to fit the g-value data was the same as the one used in our previous study [8]. The 3-dimensional feature of the best-fit model obtained by this analysis is illustrated in Fig. 3. As shown in the figure, our result gives the best fit model that has a loop shape spanning from the northeast to southwest of the sun. The center axis of this model was nearly parallel to the sun-earth line. The model represents the slow component of g-value enhancements, and the propagation speed estimated by this analysis was ~1100 km/s at its center axis. Using this model, the mass contained by the IP disturbance was estimated to be 3.2×10^{16} g.

Fig. 3 also illustrates the 3-dimensional reconstruction from Thomson scattered white-light observations made simultaneously for the same CME event by the Solar Mass Ejection Imager (SMEI) [9]. As shown here, the best-fit model deduced from our IPS data was in good agreement with the deconvolved SMEI data. The excess and total mass estimated from SMEI for this event were about 6.7×10^{16} g and 8.3×10^{16} g, respectively.



Fig. 3 Three-dimensional reconstructions from STEL IPS observations (left) and SMEI white-light observations (right). The earth orbit is indicated in each figure by a blue line. Locations of the Sun and Earth are indicated by yellow and blue solid

SUMMARY AND DISCUSSION

Solar wind velocity and density enhancements were clearly identified from our IPS observations for the 2003 October 28th

circles.

halo CME event. The 3-dimensional distribution of this IP disturbance was retrieved from our g-value data using the model-fitting technique. The result of this analysis indicated that the IP disturbance had a loop-shaped structure with an expansion speed of ~1100 km/s, which was much slower than the IP shock speed. This feature was found to be in good agreement with the 3-dimensional reconstruction made simultaneously from SMEI measurements.

The orientation of the loop structure was consistent with that of the magnetic rope deduced from cosmic ray observations for this CME event [10]. Therefore, we consider that the origin of the loop-shaped structure may be a coronal ejecta (such as prominence material) confined to the magnetic flux rope. A comparison with the solar wind speed map derived from our IPS observations revealed that the direction of this loop structure was approximately parallel to the distribution of the slow solar wind on the source surface near the flare site. This finding suggests that the slow wind region may have played an important role in the formation of the coronal ejecta for this event.

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