Search for the Heliospheric Termination Shock (TS) and Heliosheath (HS)

Norman F. Ness[1], Leonard F. Burlaga[2], Mario H. Acuña[2], Edward C. Stone[3], and Frank B. McDonald[4]

[1]Bartol Research Institute, University of Delaware, Newark, DE 19716, USA
[2]NASA-Goddard Space Flight Center, Greenbelt, MD 20771, USA
[3]California Institute of Technology, Pasadena, CA 91109, USA
[4]Institute for Physical Science and Technology, University of Maryland, College Park, MD 20742, USA

Abstract. Voyager 1 continues to measure the very distant Heliospheric Magnetic Field (HMF) beyond 95 AU at ~35 North latitude. The MAG instrument data covers more than a full 22 years solar magnetic cycle. The magnitude of the observed HMF is well described, on average, by Parker's Archimedean spiral structure if due account is made for time variations of the source field strength and solar wind velocity. The V1 magnetic field observations do not provide any evidence for a field increase associated with entry into a subsonic solar wind region, such as the heliosheath is expected to be, nor an exit from this regime. We see no evidence for crossing of the Termination Shock (TS) as has been reported at ~85 AU by the LECP instrument [1]. Merged Interaction Regions are identified by an increased HMF and associated decreases in the flux of >70 MeV/nuc cosmic rays which are then followed by a flux recovery. This CR-B relationship has been identified in V1 data and studied since 1982 when V1 was at 11 AU. The variance of HMF, a direct measure of the energy**1/2 in the HMF fluctuations, shows no significant changes associated with the alleged TS crossings in 2002-2003. Thus, the absence of any HMF increase at the entry into the heliosheath appears not to be due to the onset of meso-scale turbulence as proposed by Fisk [2]. The TS has yet to be directly observed in-situ by the V1 MAG experiment in data through 2003.

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INTRODUCTION

This paper presents a status report on the continuing search for the Termination Shock (TS) theorized to be associated with the complex interaction of the Solar Wind (SW) with the Local Interstellar Medium (LISM). This study concentrates on observations of the very weak Heliospheric Magnetic Field (HMF), generally less than 0.2 nT by the dual magnetometer experiment [3,4] on the Voyager 1 (V1) spacecraft during the 2 year period 2002-2003. At that time, V1 was located at a heliographic latitude of ~35 degrees North and moved radially from 83 to 91 AU from the Sun.

An earlier report by Burlaga et al. [5] showed that the two reported crossings of the TS by the V1 Low Energy Charged Particle experiment [1] were inconsistent with the expected changes in average field magnitude at both the alleged entry 2002 into and 2003 exit from the subsonic and sub-Alfvenic SW Heliosheath (HS). Higher energy

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particles on V1 were studied by McDonald et al. [6] and their interpretation did not confirm any crossings of the TS.

INSTRUMENT ACCURACY AND IN-FLIGHT CALIBRATION

The most important basis of the V1-MAG interpretation is the accuracy of the data. We briefly describe and demonstrate the method which has been in standard use for several decades and discussed in a limited treatment in the Appendix A in Burlaga et al. [7]. The tri-Axial vector fluxgate magnetometer sensors are not absolute instruments in that their calibration does not depend upon atomic constants such as used in the proton precession or alkali-vapor self-oscillating scalar instruments [8].

Periodic sensitivity calibrations of all the dual triaxial sensors on both the V1 and V2 attitude controlled spacecraft occur by the traditional technique of temporarily imposing additional external fields on each sensor axis by use of carefully calibrated electrical currents.

For determination of possible zero level shifts of each sensor axis and contaminating contributions of spacecraft generated fields, both V1 and V2 are periodically placed in a roll-calibration maneuver about the S/C z axis, which is Earth pointed. There are 10-programmed complete rolls of the S/C during a period of approximately 6 hours. These are scheduled to be done every 3 months and during those periods when the S/C are being tracked and data recorded by the JPL-Deep Space Network (DSN) tracking system.

Figure 1 presents V1 calibrated data from the primary magnetometer (outboard) for a typical 2-day interval in 1991 including a roll calibration. These data also indicate the data gaps, which occur due to a lack of JPL-DSN continuous tracking. The effective zero level calibration has been determined and folded into the final data plot (see Ness [8] for a discussion of fluxgate sensor performance characteristics on a spinning S/C). The data plot includes field magnitude (B) and 2 heliographic angles, latitude (δ) and azimuth (λ), at the top. The three field components in heliographic coordinates of the magnetic field R, T and N are presented at the bottom. It is clear that the two components T and N reflect the roll modulation by the ambient external magnetic field. It is from such data that the effective zero levels of each sensor axis, which is the combined S/C field and zero level offset, is derived by least square analyses of the roll modulation of each.

As discussed by Burlaga et al. [7] the effective zero level of the z axis of the dual triaxial sensors, which is the R component in the heliographic coordinate system, is determined by assuming that the average of the R component observations for the period of 2 solar rotations, one on either side of the roll maneuver, are zero. (Note that at distances >80 AU, the R component direction is within 1° of the S/C z axis.) That is a reasonable assumption since in any theoretical model of the extrapolated heliographic field, the typical field magnitude of the R component at >50 AU is <0.001 nT and essentially zero, below the quantization step size of the digital data system of the MAG [9].

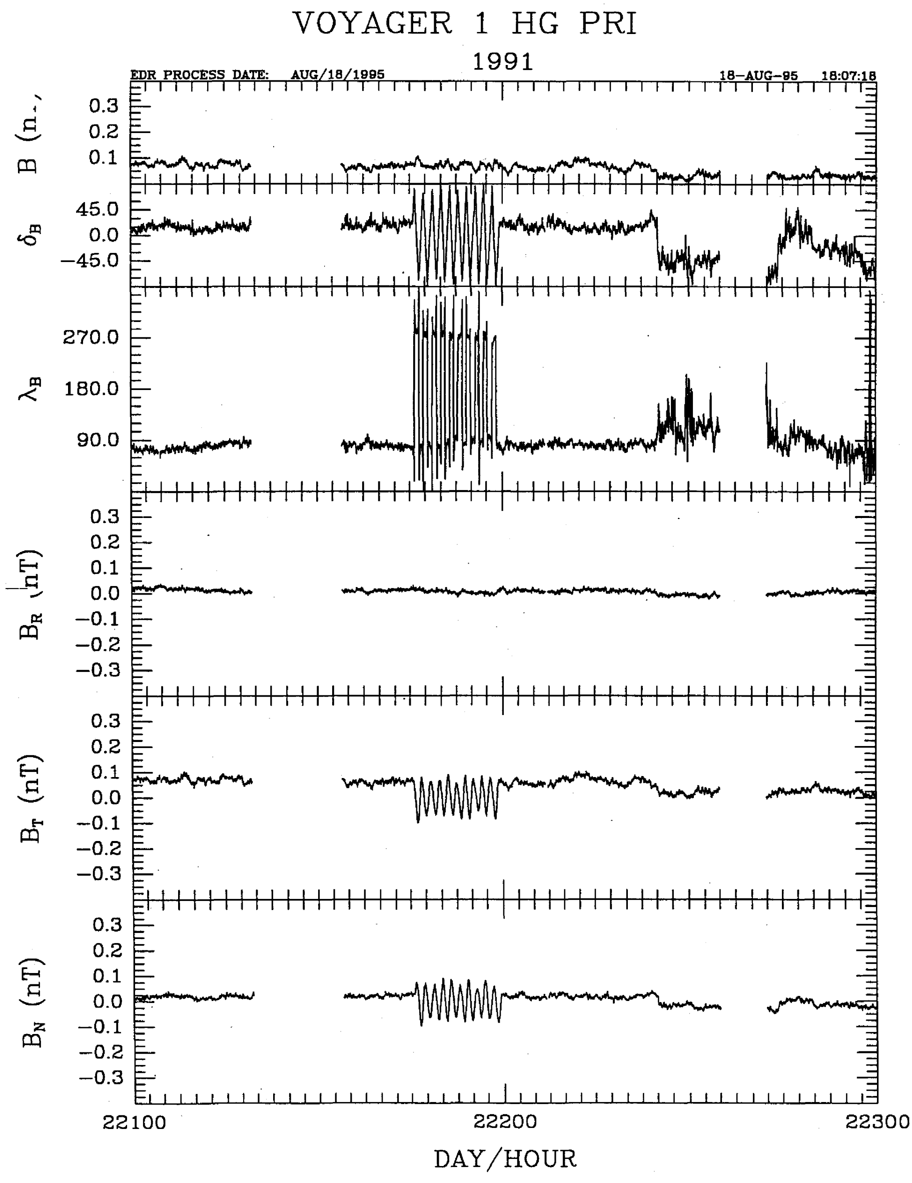

FIGURE 1. Primary triaxial fluxgate magnetometer data in 1991 during a roll calibration maneuver.

OBSERVATIONS

Figure 2 presents the daily average of the magnetic field (B) for the two years 2002-2003 along with the daily average of the 16-minute Pythagorean mean Standard Deviation (SD) or variance of the 1.92 second sampled magnetic field triaxial components. This SD quantity is a direct measure of the three-dimensional field fluctuations and is independent of coordinate system used; SD is proportional to the square root of the fluctuation energy. The lower panels in each year's plots presents the simultaneous 5 day running average of the observations of the particle flux of >70Mev/nucleon detected by the V1 Cosmic Ray System experiment.

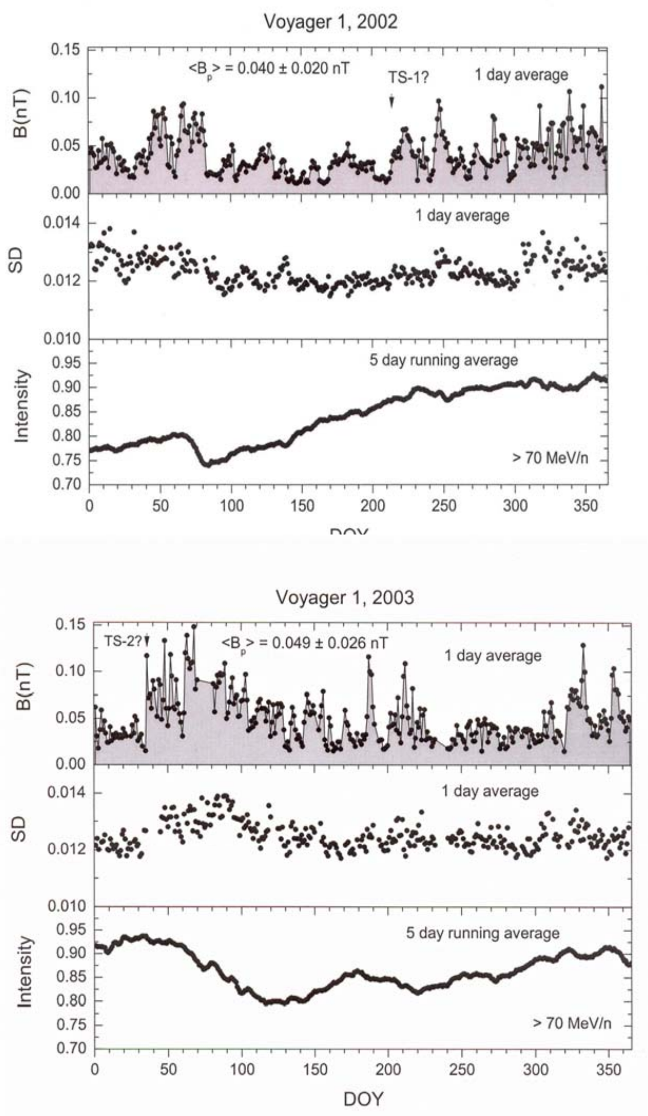

FIGURE 2. V1 magnetic field magnitude, and standard deviation, variance, in 2002 to 2003 along with cosmic ray flux of >70 Mev/nucleon particles.

A persistent long-term relationship between the HMF and cosmic ray flux has been observed since V1 was >11 AU [10, 11]. Whenever the magnetic field magnitude increases, the flux tends to decrease and when the field decreases to lower levels, the flux recovers to either a constant level or continues a recovery to a higher level. This pattern of behavior also is seen clearly in these 2 years of V1 data.

The times of the putative crossings of the TS by the LECP are shown as TS1 in 2002 and TS2 in 2003. As Burlaga et al. [5] have noted, there is no increase in field magnitude upon the claimed entry of V1 into the Heliosheath (HS) at TS1. At the claimed exit from the HS, following TS2, the field actually increases rather than decreases. Indeed, upon closer examination of the detailed data around the period following TS2, a shock might have occurred (the discontinuous data complicate identifying exactly when). That increase is followed by stronger fields along with a decreased cosmic ray flux, which is characteristic of the passage by V1 of a merged interaction region having passed by V1 [12].

ALTERNATIVE EXPLANATIONS FOR ABSENCE OF FIELD INCREASE AT TS1

Fisk [2] has recently suggested that the basic physical processes at the termination shock are altered from those typical of interplanetary propagating shocks at distances >20 AU and at planetary bow shocks due to the presence of LISM neutrals approaching the termination shock. He proposes that a turbulent HS exists in which the stronger magnetic fields are eliminated by a process of dissipation associated with macro-scale turbulence.

Fluctuating magnetic fields of all scales are observed in the HMF from seconds to minutes to hours. Frequency spectra of magnetic fluctuations in the plasmas in interplanetary space have been studied for many years. Correlated with variations in SW plasma speed and density, they indicate the presence of predominantly outwardly propagating Alfven waves. There is now no plasma data available from the PLS instrumentation on V1 to measure the SW so such a study is not possible.

Careful inspection of the HMF fluctuation data presented in Fig. 2 indicates that there is no noticeable change in the level of fluctuations associated with the alleged termination shock crossing at TS1.

The increases in field magnitude B and the fluctuation level that is evidenced in the SD data post TS2 can be understood as being associated with a propagating Merged Interaction Region (MIR) [9, 10, 11, 12]. These disturbances in the heliosphere are often preceded by a shock and the sudden spike in field magnitude seen at dcy 35 2003 is a prime candidate for that event.

This MIR interpretation is buttressed by the leveling and then decreasing flux of >70 Mev nucleons which begins near dcy 35 2003 and continues to dcy ~125 when the field magnitude decreases. The correlated field increases and flux decreases that occur thereafter are simply a manifestation of the cosmic ray/field relationship already observed and studied since V1 was at distances >11 AU.

SUMMARY

A careful study of the V1 HMF observations in 2002-2003 provides no persuasive evidence that the Termination Shock has yet been observed, as alleged by interpretation of Low Energy Charged Particle observations [1]. So the search will continue for the Heliosheath and its characteristics.

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Note added in proof: Conclusive evidence of the observation of the Termination Shock Crossing by the magnetometer experiment occurred on December 16, 2004 when V1 was at 94.0 AU. The compression ratio of the magnetic field from before to after the crossing ranges between 2 to 4 with an average best estimate of 3.0. The field increases from 0.045 to 0.136 ± .035 nT across the shock as V1 enters the heliosheath. (See Burlaga, et al [13] and associated V1 papers).

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