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Comment on "Comment on the abundances of rotational and tangential discontinuities in the solar wind" by M. Neugebauer

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1. Introduction

[1] *Neugebauer* [2006] has very nicely reviewed the current status of work done on identifying the abundance of rotational discontinuities (RDs) and tangential discontinuities (TDs) occurring in interplanetary space. This has been a topic of great interest and heated debate since the 1970s [*Smith*, 1973; *Belcher and Solodyna*, 1975; *Burlaga et al.*, 1977; *Lepping and Behannon*, 1980] (see also discussion by *Neugebauer et al.* [1984]). *Neugebauer* [2006] has also reexamined jump conditions across discontinuities and has ended up with inconclusive answers.

[2] We wish to make some suggestions that may help clarify the apparently conflicting results of the RD/TD occurrence ratio existing in the literature. We will argue that in many cases discontinuities are "contaminated" by overlying plasma and induced magnetic fields (see also discussion by *Sonnerup and Scheible* [1998], *Horbury et al.* [2001], and *Knetter et al.* [2004] concerning contamination by electromagnetic plasma waves), leading to errors (in interpretation) of results using the *Sonnerup and Cahill* [1967] minimum variance method (MVA). We also will argue that the establishment of pure (or nearly pure) solar wind convection of discontinuities does not necessarily lead to the conclusion that they are TDs.

[3] *Tsurutani et al.* [1994] have argued that interplanetary discontinuities are (often) the phase steepened edges of nonlinear Alfvén waves as *Neugebauer* [2006] notes. Another feature detected in interplanetary space are decreases in the interplanetary magnetic field magnitude. These have been given the name magnetic holes (MHs), magnetic decreases (MDs) and other descriptive names in the literature [*Turner et al.*, 1977; *Winterhalter et al.*, 1994, 2000; *Tsurutani and Ho*, 1999]. These magnetic field magnitude (pressure) decreases are supplanted by enhanced, anisotropic plasma [*Fränz et al.*, 2000; *Neugebauer et al.*, 2001]. The total pressure is constant across these structures, to first order [*Winterhalter et al.*, 1994]. It has recently been shown that these MHs/MDs are (often) collocated with the discontinuities/phase steepened edges of Alfvén waves [*Tsurutani et al.*, 2002a, 2002b]. *Dasgupta et al.* [2003] and *Tsurutani et al.* [2002b, 2005a] have argued that the ponderomotive force associated with the steepened Alfvén wave edges (the discontinuities) accelerate solar wind ions (and electrons) perpendicular to the ambient magnetic field and thus create the MHs/MDs by plasma diamagnetic effects. In this scenario, the plasma blobs and their resultant magnetic decreases are external features to the discontinuities and not parts of the discontinuities/Alfvén waves themselves. From this viewpoint, MHs/MDs can thus be thought of as byproducts of the Alfvén wave dissipation process.

[4] We view MH/MD plasma and induced field decreases which are collocated with the discontinuities as possible contaminants to the intrinsic discontinuity structures. In some cases the MHs/MDs can appear to be bounded by a pair of TD-like structures as well [*Tsurutani and Ho*, 1999]. Minimum variance analysis results of this very complex region of multiple discontinuities will be difficult, if not impossible to interpret.

[5] *Tsurutani et al.* [2005b] have examined several (7) events from the *Knetter* [2005] Cluster discontinuity data set where the discontinuities were collocated with MHs/MDs. All of the discontinuities were associated with Alfvén waves. The same discontinuities were identified at ACE, ~0.01 AU upstream of Cluster, by their similar field rotational characteristics. The time delay from detection at ACE to that at Cluster was measured. It was found that the discontinuities/MHs/MDs propagated at almost the solar wind convection speed (determined by plasma measurements), within measurement uncertainties. *Tsurutani et al.* [2005b] speculated that the low wave propagation speed relative to the ambient solar wind was due to a "slowing" of the wave phase speed through the high-density plasma (the MHs/MDs), oblique wave propagation, or a combination of both factors.

[6] As to why most directional discontinuities (DDs) in the solar wind have small values of B_N [*Knetter et al.*, 2004;

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0148-0227/07/2006JA011973$09.00

Neugebauer, 2006], one possibility is that the DDs are not purely MHD structures and the kinetic effects make them susceptible to some type of modulational instability that limits B_N. The evidence that there is ion and electron heating occurring inside the DDs strongly suggests that these are kinetic structures rather than MHD ones. Other possibilities for low values of B_N have been discussed by *Knetter et al.* [2004] and other references given in this paper.

2. Intermediate Shocks?

[7] There is not only evidence for perpendicular ion heating at discontinuities/MHs/MDs as discussed previously, but evidence for electron heating as well. *Lin et al.* [1995, 1996] have reported the presence of enhanced whistler mode and Langmuir waves in these structures, indicative of the presence of strong electron anisotropies. These plasma waves must be locally produced. Such dissipation would not be expected at static TDs. For all of these reasons *Tsurutani et al.* [2005a] have surmised that these phase steepened edges of Alfvén waves are some form of intermediate shocks. Intermediate shocks can have properties of both RDs and TDs.

3. Future Progress

[8] One thought is that some progress could be made by reexamining "pure" discontinuities (using the MVA technique) that have essentially no magnetic magnitude variations (less than 5%?) either within or near the discontinuities. It is possible that the best events to study would be those that are "thick," where the phase-steepening and wave dissipation processes have not developed much. Overlaying contamination would be expected to be at a minimum for these cases.

[9] Another approach would be to perform numerical simulations of large amplitude arc-polarized Alfvén waves. *Medvedev and Diamond* [1996], *Medvedev et al.* [1997], *Vasquez and Hollweg* [2001] and *Buti et al.* [2001] have shown that nonlinear Alfvén waves are both dispersive and compressive. *Vasquez and Hollweg* [2001] have noted the formation of discontinuities in their simulation runs. Long temporal runs to identify the nonlinear feedback of the Alfvén wave dissipation process would be highly instructive.

[10] It has also been noted that MDs/MHs/discontinuities evolve very rapidly within ~0.01 AU distance [*Tsurutani et al.*, 2005b]. It would be interesting to determine how they evolve over longer distances and periods of time. This could be performed by multisatellite studies and/or modeling.

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