Progress Report NAG 5-11623: Propagation of Interplanetary Disturbances in the Outer Heliosphere

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Summary of Work in 2002

1. Finished a multi-fluid solar wind model.
2. Determined the solar wind slowdown and interstellar neutral density.
3. Studied shock propagation and evolution in the outer heliosphere.
4. Investigated statistical properties of the solar wind in the outer heliosphere.
5. Two papers have been accepted by J. Geophys. Res. and two by Astrophys. J. Four additional papers have been submitted, one to Astrophys. J., one to Adv. Space Res, and two to SW10.

Work completed

In the first year of this study we have had four papers accepted in refereed journals (JGR and ApJ) in collaboration with J.D. Richardson at MIT and L.F. Burlaga at NASA-Goddard Space Flight Center.

We have developed a one-dimensional, spherically symmetric, multi-fluid MHD model that includes solar wind protons and electrons, pickup ions, and interstellar neutral hydrogen. This model advances the existing solar wind models for the outer heliosphere in two important ways: one is that it distinguishes solar wind protons from pickup ions, and the other is that it allows for energy transfer from pickup ions to the solar wind protons. Model results compare favorably with the Voyager 2 observations.

The solar wind in the outer heliosphere is fundamentally different from that in the inner heliosphere since the effects of interstellar neutrals become significant. The magnitude of the solar wind speed decrease from the inner to the outer heliosphere provides important information about the interaction of the heliosphere with the local interstellar medium (LISM), leading to better estimates of the size and shape of the heliosphere and of the LISM density. Using our newly developed model, we take advantage of the observations from multiple spacecraft (ACE, Ulysses and Voyager 2) in 1999 near solar maximum to examine the solar wind slowdown. [C. Wang and J. D. Richardson, J. Geophys. Res., in press, 2002]. We find a decrease in speed of 53-62 km/s at Voyager 2 (~60 AU) with respect to ACE and Ulysses measurements, or a 12-14% slowdown, the largest yet reported. The interstellar neutral hydrogen density is estimated to be 0.09 cm^{-3} at the termination shock, which is consistent with the estimations from other investigations.

During the current solar maximum (Cycle 23), several major CMEs associated with solar flares produced large transient flows and shocks which were observed by widely-separated spacecraft such as Wind at Earth and Voyager 2 beyond 60 AU. Using data from these spacecraft and our model, we study shock propagation and interaction in the outer heliosphere. We demonstrate that a strong shock in the distant heliosphere could be an outer heliospheric remnant of a strong shock in the inner heliosphere (``one to one" relationship), or it could be an outcome of the successive interaction and merging of a series of interplanetary shocks (``one to many" relationship). [C. Wang and J. D. Richardson, Proceedings of the Tenth International Solar Wind Conference, in press, 2002.]

In a collaboration with L.F. Burlaga of GSFC, it is shown that the basic statistical properties of the solar wind in the outer heliosphere can be well produced by our model.

Future work

Our 1-D multi-fluid MHD model in the outer heliosphere has been proved to be relatively accurate and useful in interpreting solar wind observations in the other heliosphere, however a full understanding of the propagation and evolution of the interplanetary disturbances requires 2-D and 3-D model. Significant efforts will put into extensions to 2-D and 3-D code during the following years.

Shocks are an important component of the interplanetary disturbances. In addition to case studies single events, we plan to investigate the statistical characters of shocks, their occurrence rats, strengths, etc. during the second year.

We will also search interplanetary coronal mass ejections (ICMEs) events observed by multiple spacecraft, study the propagation and evolution of the ICMEs in the outer heliosphere, and use them as testbed for our 2-D or 3-D numerical models.

Publications

1. Wang, C., and J. D. Richardson, Determination of the solar wind slowdown near solar maximum, J. Geophys. Res., in press, 2002.
2. Burlaga, L. F., J. D. Richardson, and C. Wang, Speed fluctuations near 60 AU on scales from 1 day to 1 year: Observations and model, J. Geophys. Res., 10.1029/2002JA009379, 2002.
3. Burlaga, L. F., C. Wang, J. D. Richardson, and N. F. Ness, Large-Scale Magnetic Field Fluctuations and Development of the 1999-2000 GMIR: 1 to 60 AU, Astrophys. J., in press, 2002.
4. Wang, C., and J. D. Richardson, The interaction and evolution of interplanetary shocks from 1 to beyond 60 AU, submitted to Solar Wind 10 proceedings, 2002.
5. Burlaga, L. F., N. F. Ness, F. B. McDonald, J. D. Richardson, and C. Wang, Voyagers 1 and 2 Observations of Magnetic Fields and Associated Cosmic Ray Variations from 2000 through 2001; 60- 87 AU, Astrophys. J., in press, 2002.
6. Richardson, J. D., and C. Wang, The Solar Wind in the Outer Heliosphere at Solar Maximum, submitted to Solar Wind 10 proceedings, 2002.
7. Richardson, J. D., C. Wang, and L. F. Burlaga, The solar wind in the outer heliosphere, submitted to Adv. Sp. Res., 2002.
8. Burlaga, L.F., C. Wang, N.F. Ness, and J.D. Richardson, Evolution of magnetic fields in corotating interaction regions from 1 to 95 AU: Order to chaos, submitted to Astrophys. J., 2002.