A STUDY OF THE STRUCTURE OF THE SOURCE REGION OF THE SOLAR WIND IN SUPPORT OF A SOLAR PROBE MISSION

NASA Grant NAGW-4381

Final Report

For the Period 1 March 1995 through 30 September 1997

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February 1998

Prepared for

National Aeronautics and Space Administration

Washington, D.C. 20546

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Final Report

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Introduction

Despite the richness of the information about the physical properties and the structure of the solar wind provided by the Ulysses and SOHO observations, fundamental questions regarding the nature of the coronal heating mechanisms, their source, and the manifestations of the fast and slow solar wind, still remain unanswered. The last unexplored frontier to establish the connection between the structure and dynamics of the solar atmosphere, its extension into interplanetary space, and the mechanisms responsible for the evolution of the solar wind, is the corona between 1 and 30 R_s.

A Solar Probe mission offers an unprecedented opportunity to explore this frontier. The uniqueness of this mission stems from its trajectory in a plane perpendicular to the ecliptic which reaches within 9 R_s of the solar surface over the poles and 3 - 9 R_s at the equator. With a complement of simultaneous in situ and remote sensing observations, this mission is destined to have a significant impact on our understanding of the fundamental processes that heat the corona and drive the solar wind. The Solar Probe should be able to detect remnants and signatures of the processes which heat the corona and accelerate the solar wind.

The primary objective of this proposal was to explore the structure of the different source regions of the solar wind through complementary observational and theoretical studies in support of a Solar Probe mission. Listed below are the topics and tasks accomplished during the funding period.

Report of the Minimum Solar Mission Science Definition Team

As a member of the Minimum Solar Mission Science Definition Team, S. Habbal participated in the study conducted by the Team over the Spring and Summer of 1995 at JPL. S. R. Habbal played a critical role in pointing out that model computations and recent IPS and Spartan observations strongly indicated that the acceleration of the solar wind could be happening a lot closer to the Sun than expected from earlier solar wind models. Subsequently, the technological implications of such a finding were discussed in length, and recommendations for holes in the shield to get a full description of the plasma distribution function were made. S. R. Habbal also strongly advocated the scientific need for an EUV imager for such a mission. The results of the study appeared in the *Report of the Minimum Solar Mission Science Definition Team.*

The Eclipse expedition to India in October 1995

A discussion of the importance of observing the Sun simultaneously with a series of iron lines in the visible wavelength range, and the feasibility of such observations, was presented at the Solar Wind Eight conference in June 1995. The first experiment to carry out such observations during a total eclipse was performed in October 1995 in India. There were several factors that rendered this eclipse experiment extremely timely: (1) the coincidence with solar minimum, and (2) the closeness of the apparent diameter of the Moon to that of the Sun. Both factors made the conditions ideal to carry out observations of structures of coronal holes in wavelengths sensitive to different temperature plasmas.

Funds were used to purchase CCD cameras for the eclipse observations, 300 mm lenses, a set of four filters for multiwavelength observations, and a laptop to acquire and display the images recorded by the CCD cameras. Filter mounts were designed to enable us to switch filters half way through the observations. A sequence of exposure times was selected for each filter. Despite the short duration of the eclipse (40 seconds), images with different exposure times were acquired with each filter.

Conference on *Robotic Exploration close to the Sun: Scientific Basis*

The conference was held on 15-18 April 1996, at the NYNEX conference center in Marlboro, Massachusetts with 75 attendees. The emphasis in the program was on an open exchange of ideas pertaining to the current status of our knowledge of the solar wind, and what the requirements would be for a meaningful advance in our knowledge. The program included a few overview talks, and discussions carried out in the separate meetings of the three working groups, as well as in plenary sessions. The Proceedings of the workshop were published by AIP in January 1997. These proceedings continue to provide the foundation for ongoing efforts in the planning of a Solar Probe mission.

Modeling of the acceleration region of the solar wind

While the mechanisms responsible for the solar corona and the high-speed solar wind streams are still unknown, model computations offer means of predicting the properties of such mechanisms in light of the empirical constraints currently available. Modeling and data analysis efforts were aimed at understanding the plasma properties of the acceleration of the solar wind, its filamentary nature, and the conditions needed to account for a rapidly accelerating solar wind, reaching its terminal speed within 10 R_s. Studies of two and three fluid solar wind models concentrated on the effects of heating, momentum addition and Alfvén waves, on the flow of electrons, protons, minor ions and neutral hydrogen. In addition, a study was focused on the role of proton temperature anisotropy on the energy balance requirements for the solar wind, and the implications for coronal heating processes. Also the implications of current inferences of high proton and minor ion temperatures in the inner corona for the interpretation of spectral lines were explored.

Model computations complemented by data analysis played a key role in the realization that

- the fast solar wind undergoes very rapid acceleration in the inner corona and reaches its asymptotic speed by 10 R_s (Habbal et al. 1995, Esser and Habbal 1995, Esser et al. 1997). These studies also established the necessary requirements for coronal heating mechanisms to produce such profiles;
- heavy ions play a role in the solar wind flow (Li et al. 1997);
- significant temperature anisotropies in the protons and minor ions develop in the inner corona in the presence of Alfvén waves (Allen et al. 1997, Hu et al. 1997);
- high proton temperatures in the inner corona can have a significant impact on the formation of some spectral lines there (Brickhouse and Esser 1996);

Characteristics of the inner heliosphere between 1 and 10 R_s

Analyses of coordinated radio occultation measurements with white light and ultraviolet observations provided the first evidence that

- the filamentary nature of structures in the solar wind are much smaller in streamer axes than in coronal holes (Woo and Habbal 1997b);
- the quiet Sun is also very likely to be a source for the fast solar wind (Woo and Habbal 1997a);
- the fast wind is ubiquitous in the inner corona, the streamer axes are the locus of the slowest solar wind, and a velocity shear exists between the fast and slow solar wind at the boundaries of streamers and along their axes (Habbal et al. 1997).

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