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NASA Grant NAGW-249

Semiannual Progress Report No. 7

For the period 1 November 1984 through 30 April 1985

Principal Investigator

George L. Withbroe

April 1985

Prepared for
National Aeronautics and Space Administration
Washington, D. C. 20546

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1. INTRODUCTION

The objective of the current grant is the study of selected problems concerned with important physical processes that may occur in the corona and solar wind acceleration region, particularly time-dependent phenomena. We are studying both the physics of the phenomena (e.g. effect of transient momentum deposition on the temporal and spatial variation of the temperature, density and flow speed of the solar wind, formation of shocks, etc.) and the resultant effects on observational signatures, particularly spectroscopic signatures. Phenomena under study include (1) wave motions, particularly Alfven and fast mode waves, (2) the formation of standing shocks in the inner heliosphere as a result of momentum and/or heat addition to the wind and (3) coronal transient phenomena where momentum and/or heat are deposited in the corona to produce transient plasma heating and/or mass ejections. The study also includes theoretical investigation of spectroscopic plasma diagnostics for the inner heliosphere and the analysis of existing Skylab and other relevant data.

During the current reporting period our efforts were directed primarily toward studies on the physics of solar wind flow in the acceleration region (Section 2) and on impulsive phenomena in the solar corona (Section 3). These studies, and others that we are planning to undertake, have relevance not only to improving knowledge concerning the physics of the solar wind acceleration region, but also to defining scientific objectives and requirements for instrumentation for the Solar Coronal Diagnostics Mission, Solar and Heliospheric Observatory and Pinhole Occulter Facility.

During the current reporting period two scientific papers were presented at meetings and four were submitted for publication. Several papers submitted earlier have now appeared in the literature. A summary of papers published, submitted and in press as well as presentations at scientific meetings and colloquia are listed in Section 5.

Student involvement in the program in the past year includes R. Esser, a visiting scientist and student of E. Leer (Norway), who is working on the physics of Alfven driven solar winds, and A. Cowell and R. Ronan, Harvard undergraduates, who have been working as research assistants--Ronan at a sufficiently high level that he has been coauthor on several papers and principal author on a paper delivered at an AAS meeting.

2. PHYSICS OF SOLAR WIND FLOW IN THE ACCELERATION REGION

An important aspect of our theoretical program has been the study of MHD wave propagation in the corona and the study of solutions for steady-state and time-dependent solar wind equations. The objective is to gain insights concerning the physics of the solar wind acceleration region, plasma heating and plasma acceleration processes there and the formation of shocks. The objective is not only to improve the understanding of the physics of the region where the solar wind is generated, but also to provide guidance in the development of experimental techniques for probing this important region of the solar atmosphere.

A parameter study on the influence of Alfven waves on the solar wind is being carried out in a collaboration with R. Esser and E. Leer (Norway). The objective is to determine the effects of Alfven waves on solar wind models and observable parameters such as densities and effective temperatures (temperatures measured with line profiles). The theoretical model was developed by E. Leer and R. Esser, who is currently a visiting scientist at the CfA. This two fluid model has four adjustable parameters, the density, electron temperature, Alfven wave velocity amplitude and magnetic field strength at the base of the corona. In addition the geometry can be specified (e.g. radial or non-radial). In order to obtain a baseline model we derived a set of parameters which gave the best fit to the empirical electron densities and hydrogen temperatures (from Lyman alpha profiles) reported in the paper by Withbroe et al. (1985). The resulting theoretical model was in good agreement with the semi-empirical model derived from the observations. Of particular interest is the finding that the outflow velocity at 4 solar radii in the theoretical model is 60 km/s--well within the limits imposed by the Doppler-dimming constraints of the observations [V(4r) < 160 km/s, with a most likely value of 100 km/s]. The solar wind velocity at 1 AU predicted by the theoretical model is consistent with that predicted by the semi-empirical model. The adopted velocity amplitude for the Alfven waves in the theoretical model is also in good agreement with that inferred from the observations. In short, the theoretical and empirical results are in good agreement about the magnitude of the effects of Alfven waves in the 1980 polar region observed by the rocket coronagraph. A paper describing these results is in progress. In the future we plan to compare the theoretical Alfven-driven wind model with other empirical results from the rocket coronagraph program. We also plan to expand the study to include time-dependent effects of Alfven waves.

As part of our continuing investigation of coronal plasma diagnostics we undertook, in collaboration with E. Avrett, a study of the formation of He I lines in the corona. Because of the large intensity of the photospheric radiation field we speculated that it might be possible to probe the physical conditions in the low corona using the resonantly scattered radiation from the

He I λ10830 line. We hoped that the large number of photons available for optically pumping the λ10830 line might be able to compensate for the unfavorable (compared to hydrogen) ionization properties of He I under coronal conditions. If so, it would be possible to probe the low corona with a light atom at heights accessible with ground-based coronagraphs, a few tenths of a solar radius above the surface. Another motivation for the study was the possible potential of using EUV He I lines for probing the corona with future satellite instruments. Results of preliminary calculations performed with the PANDORA program and a 13 level atom indicate that the strength of the 10830 line is a couple of orders of magnitude too weak to be readily observable from the ground. The He I λ584 resonance line, although very weak, should be observable with a large aperture instrument such as POF. Given the expected strength of the He II λ304 line, it appears that measurements of λ304 offer the best prospects for achieving a helium diagnostic in the extended corona. As a result of this and our studies of XUV resonance lines from iron ions, we have concluded that development of a coronagraphic instrument operating in the XUV would be worthwhile.

We have been working on the development of several new codes for future theoretical studies of the physics of the solar wind acceleration region and possible spectroscopic diagnostics for the physical conditions and the responsible physical processes operating in this critical region of the heliosphere. One of the new codes under development is a 2 fluid hydrodynamic time-dependent code which includes thermal conduction--an important process not included in our present 1 fluid time-dependent code. This code will be used, among other things, for studying the effects of thermal conduction on the development of standing shocks in the solar wind acceleration region. The aim is to determine, among other things, whether the formation of a standing shock in the inner solar wind is merely a property of isothermal or polytropic winds, or a more general phenomenon. We have also been working on the development of codes for the study of the time-dependent ionization of the solar wind. We expect to use these codes in future theoretical studies of spectroscopic diagnostic techniques for transient phenomena in the solar wind acceleration region.

We also have developed a computer code for determining the effective "temperature" of the corona from empirical electron density distributions using the formulation given by Munro and Jackson (1977, Astrophys. J., 213, 874). The effective temperature is defined as the temperature needed to maintain the pressure balance in the solar wind and includes both thermal and non-thermal pressures (due for example to wave-particle interactions). This code has been applied to existing data for comparison with temperatures determined by other means, for example, from Lyman alpha measurements. We also used the code to determine the uncertainty in "temperatures" inferred from electron density gradients. These are not true temperatures because of the possible effects of wave-particle interactions. In addition, as shown by Munro and Jackson, a wide range of solutions are possible because of the uncertainty in the pressure at the upper boundary. However, the effective temperature can provide information on the possible existence of significant non-thermal pressures. A comparison of measured (Lyman alpha) temperatures and inferred effective temperatures for the region observed in the 1980 rocket coronagraph flight suggests that there were no significant nonthermal pressures present in the observed region at the south solar pole. The results are discussed in a paper ("Coronal Temperatures, Heating and Energy Flow in a Polar Region of the Sun at Solar Maximum" by G. Withbroe, J. Kohl, H. Weiser and R. Munro). This paper has been accepted for publication by the Astrophysical Journal.

3. IMPULSIVE PHENOMENA IN THE SOLAR CORONA

One of the objectives of our research program is the development of techniques for placing constraints on the mechanisms responsible for coronal heating. We have undertaken several studies of Skylab EUV observations in order to exploit existing data for this purpose and to gain insights as to what types of observations should be acquired in the future from ground-based instruments, from SMM and from proposed future experiments such as SOT and its co-observing instruments. We discuss below the results of several recently completed studies made using Skylab data and preliminary results of new VLA observations acquired in order to determine the desirability of making simultaneous VLA and space (e.g. from SMM) observations in the future.

We completed a detailed study of the EUV emission from an active region in which several EUV subflares and surges occurred. We obtained the following results: The emission measures and radiative outputs at maximum brightness of the subflares were approximately 20% of the corresponding values for the active region. Multiple surges were observed during and following each subflare, with surge material being ejected in a variety of directions, including toward a coronal bright point located outside of the active region. The total energy of the surges appears to be comparable to that radiated by the subflares, a few times 10^{28} erg. As reported in previous studies of surges, we find that there was no significant emission from these features in spectral lines formed at temperatures $T > 10^6$ K. The ejection of surges in several different directions and nearly simultaneous flaring of various areas of the active region suggest that the primary site of the subflares was magnetically connected to a variety of different areas in the active region and the surrounding quiet region. A paper discussing these results "EUV Observations of Subflares and Surges" by G. Withbroe has been submitted for publication in Solar Physics.

We completed a study of the temporal and spatial variations of the EUV emission from the coronal loops in an active region observed on the limb by the Harvard Skylab instrument. The results obtained are as follows: Both cool ($T < 10^6$ K) and hot ($T > 10^6$ K) loops were observed in the active region. For the hot loops the observed intensity variations were small, typically a few percent over a period of 30 min. The cool loops exhibited stronger variations, sometimes appearing and disappearing in 5 to 10 min. Most of the cool material observed in the loops appeared to be caused by the downward flow of coronal rain and by the upward ejection of chromospheric material in surges. The frequent EUV brightenings observed near the loop footpoints appear to have been produced by both in situ transient energy releases (e.g. subflares) and the infall/impact of coronal rain. The physical conditions in the loops (temperatures, densities, radiative and conductive cooling rates, cooling times) were determined. These results are discussed in a paper submitted to Solar Physics ("Spatial and Temporal Variations of Solar Coronal Loops" by S. Habbal, R. Ronan and G. Withbroe). Preliminary results were presented earlier at an AAS meeting in a paper by Ronan, Habbal and Withbroe (1984).

As a consequence of our findings that the EUV emission from coronal bright points frequently exhibits short term temporal and spatial variations characteristic of impulsive heating, we acquired VLA observations of coronal bright points in order to determine whether such phenomena could be detected at radio wavelengths. Preliminary results indicate that significant fluctuations in the intensity and degree of polarization are present on temporal scales of a few minutes. Furthermore, the results show an anticorrelation in the variation of the intensity and degree of polarization. At both wavelengths observed, 6 and 20 cm, the brightness temperature of the coronal bright points was in the range 3 to 5 x 10^5 K. On the basis of these results it appears highly desirable to acquire simultaneous VLA measurements with both SMM and Spacelab 2. A paper on the VLA results was presented at the January 1985 meeting of the American Astronomical Society ("Temporal and Spatial Variations of Solar Coronal Bright Points with the VLA by S. Habbal, A. Cowell, R. Ronan, G. Withbroe, R. Shevgondar and M. Kundu). A more detailed paper is being prepared for publication.

Work on temporal variations in the EUV emissions from active regions continues. Of particular interest is the continued study of McMath region 12628 for which a particularly extensive time series of observations are available.

4. FUTURE WORK

We plan to continue our collaboration with E. Leer and R. Esser (Norway) on the study of Alfven wave driven solar winds. The current effort is directed toward the study of steady-state winds. We hope to expand the investigation to include time-dependent effects. This study is expected to yield predictions that can be tested with observations to be obtained in the Spartan program. We also plan to continue (1) other theoretical work on time-dependent and steady-state phenomena in the solar wind acceleration region, (2) studying temporal variations in the low corona using existing Skylab and radio observations and (3) investigating the formation of XUV iron lines in the outer corona and their use as plasma diagnostics.

5. PAPERS PRESENTED, SUBMITTED FOR PUBLICATION OR IN PRESS

Barnes, A., Goldstein, M., Hollweg, J., Mariska, J., Matthaeus, W., Smith, C., Smith, E., Stein, R., Withbroe, G. and Woo, R., 1984, "MHD Waves and Turbulence in the Sun and Interplanetary Medium", in Solar Terrestrial Physics: Present and Future, NASA Reference Publication 1120, ed. D. M. Butler and K. Papadopoluos, p. 4-3.

Doyle, J. G., Raymond, J. C., Noyes, R. W. and Kingston, A. E. 1984, "The EUV Spectrum of Sunspot Plumes. II. Spectral Diagnostics and Implications for Cooling", Astrophys. J, in press.

Ferrari, A., Habbal, S. R., Rosner, R. and Tsinganos, K., 1984, "A Wind Type Model for the Generation of Astrophysical Jets", Astrophys. J., **277**, L35.

Fla, T., Habbal, S. R., Holzer, T. E. and Leer, E. 1984, "Fast Mode MHD Waves in Coronal Holes and the Solar Wind", Astrophys. J., **280**, 382.

Habbal, S. R. 1984, "The Formation of a Standing Shock in a Polytropic Wind Model within 1 - 10 R_s", Bull. Am. Astron. Soc., **16**, 533.

Habbal, S. R. 1984, "Temporal Evolution of the Solar Wind and the Formation of a Standing Shock", talk presented at the Naval Research Laboratory, June, 1984.

Habbal, S. R. 1985, "Formation of a Standing Shock in a Polytropic Solar Wind Model Within 1-10 R_s", 1984 Chapman Conference on Collisionless Shocks in the Heliosphere, Napa Valley, California. J. Geophys. Res., **90**, 199.

Habbal, S. R., Cowell, A., Ronan, R., Withbroe, G. L., Shevganokar, R. and Kundu, M., 1984, "Temporal and Spatial Variations of Solar Coronal Bright Points Observed with the VLA", Bull. Amer. Astron. Soc., **16**, 929.

Habbal, S. R., Ronan, R. and Withbroe, G. L. 1985, "Spatial and Temporal Variations of Coronal Loops", submitted to Solar Phys..

Habbal, S. R. and Rosner, R. 1984, "Temporal Evolution of the Solar Wind and the Formation of a Standing Shock", J. Geophys. Res., **89**, 10645.

Habbal, S. R. and Tsinganos, K. 1982, "Stellar Winds with Multiple Critical Points and Shock Transitions", presented at 160th meeting of American Astronomical Society, Troy, June, Bull. Amer. Astron. Soc., **14**, 608.

Habbal, S. R. and Tsinganos, K. 1983, "Multiple Transonic Solutions and a New Class of Shock Transitions in Steady Isothermal Solar and Stellar Winds", J. Geophys. Res., **88**, 1965.

Habbal, S. R., Tsinganos, K. and Rosner, R. 1983, "Time Evolution of the Solar Wind Flow and the Formation of Standing Shocks", Bull. Amer. Astron. Soc., **15**, 939.

Habbal, S. R., Tsinganos, K. and Rosner, R. 1983, "Multiple Transonic Solutions and a New Class of Shock Transitions in Solar and Stellar Winds", paper presented at Solar Wind V conference, Woodstock, VT, November 1982. In Solar Wind V, NASA Conference Publication 2280, ed. M. Neugebauer, p213.

Owocki, S. 1982, "Interpreting the Solar Wind Ionization State", talk presented at University of Maryland Space Physics Group, Goddard Space Flight Center High Energy Astrophysics Group, Massachusetts Institute of Technology Space Physics Group, and Los Alamos National Laboratory Solar Wind Group, October.

Owocki, S. P. 1983, "Intepreting the Solar Wind Ionization State", invited paper presented at Solar Wind V conference, Woodstock, VT, November 1982, in Solar Wind V, NASA Conference Publication 2280, ed. M. Neugebauer, p623.

Owocki, S. and Hundhausen, A. 1983, "The Effect of a Coronal Shock Wave on Time-Dependent Solar Wind Ionization State", Astrophys. J., 274, 414.

Owocki, S. P., Holzer, T. E. and Hundhausen, A. J. 1983, "The Solar Wind Ionization State as a Coronal Temperature Diagnostic", Astrophys. J., 275, 354.

Owocki, S. and Scudder, J. 1983, "The Effect of a Non-Maxwellian Electron Distribution on Oxygen and Iron Ionization Balance in the Solar Corona", Astrophys. J., 270, 758.

Noyes, R. W., Raymond, J. C., Doyle, J. G. and Kingston, A. E. 1984, "The EUV Spectrum of Sunspot Plumes. I. Observations", Astrophys. J., in press.

Ronan, R., Habbal, S.R. and Withbroe, G. L. 1984, "Spatial and Temporal Variations of Solar Coronal Loops", Bull. Amer. Astron. Soc., 16, 528 (abstract).

Tsinganos, K., Habbal, S. R. and Rosner, R. 1983, "Formation of Standing Shocks in Stellar Winds and Related Astrophysical Flows", paper presented at Solar Wind V conference, Woodstock, VT, November 1982. In Solar Wind V, NASA Conference Publication 2280, ed. M. Neugebauer, p289.

Withbroe, G. L. 1981, Spectroscopic Probing of the Solar Wind Acceleration Region", colloquium presented at University of New Hampshire, December.

Withbroe, G. L. 1983, "The Role of Spicules in Heating the Solar Atmosphere, Implications of EUV Observations", Astrophys. J., 267, 825.

Withbroe, G. L. 1983, "Probing the Solar Wind Acceleration Region", colloquium presented at Naval Research Laboratory, Washington, D. C., February.

Withbroe, G. L. 1983, "Evidence for Temporal Variations in Polar Plumes", Solar Phys., 89, 77.

Withbroe, G. L. 1983, "Solar Wind and Coronal Structure", review paper presented at National Academy of Sciences--European Science Foundation Workshop on Solar and Space Physics, Hilton Head, S. C. In ESA Journal, 7, 341.

Withbroe, G. L., 1985, "The Solar Wind", invited paper presented at the Conference on Soft X-rays, XUV and EUV Observations of the Solar Atmosphere with the ASO", Carmel, CA, January.

Withbroe, G. L., 1985, "EUV Observations of Subflares and Surges", submitted to Solar Phys..

Withbroe, G. L., Habbal, S. R. and Ronan, R., 1984, "Impulsive Phenomena in a Small Active Region", Bull. Amer. Astron. Soc., 16, 528 (abstract).

Withbroe, G. L., Habbal, S. R. and Ronan, R., 1984,"Impulsive Phenomena in a Small Active Region", Solar Phys., in press.

Withbroe, G. L. and Kohl, J. L. 1982, "Spectroscopic Diagnostics for the Solar Wind Acceleration Region", invited paper presented at Theory Conference in Solar-Terrestrial

Withbroe, G. L., Kohl, J. L., Weiser, H. and Munro, R. H. 1982, "Probing the Solar Wind Acceleration Region Using Spectroscopic Techniques", invited paper, Space Sci. Rev., 33, 17.

Withbroe, G. L., Kohl, J. L., Weiser, H. and Munro, R. H., 1985, "Coronal Temperatures, Heating and Energy Flow in a Polar Region of the Sun at Solar Maximum", Astrophys. J.., in press.

Withbroe, G. L. and Raymond, J. C. 1984, "Plasma Diagnostics for the Outer Solar Corona: UV and XUV Fe XII Lines", Astrophys. J., 285, 347.