Remote Sensing Measurements of the Corona with the Solar Probe

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Abstract. Remote sensing measurements of the solar corona are indispensable for the exploration of the source and acceleration regions of the solar wind which are inaccessible to in situ plasma, particles and fields experiments. Furthermore, imaging the solar disk and corona from the unique vantage point of the trajectory and the proximity of the Solar Probe spacecraft, will provide the first ever opportunity to explore the small scale structures within coronal holes and streamers from viewing angles and with spatial resolutions never attained before. Imaging will also provide the essential context for the in situ measurements. The scientific advantages of different proposed imagers are summarized here. Both disk and limb observations are recommended. Given the power, weight and telemetry limitations. of the Solar Probe, the optimal choice of imagers could not be provided at the time of the workshop. Further concentrated studies were highly recommended.

INTRODUCTION

With the advent, of Yohkoh, Ulysses, Spartan and very recently SOHO, our knowledge of the corona has improved considerably since the first serious considerations of a Solar Probe mission were made (e.g, [9], [4]). These new results are providing strong compelling reasons for remote sensing measurements of the source and acceleration regions of the solar wind. The current consensus is that such measurements are indispensable for the inference of the plasma characteristics, such as density, temperature, magnetic field distribution and strength, and flow speed, in the coronal space which is inaccessible to in situ plasma, particles and fields experiments. Imaging the solar disk and corona from the unique vantage point of the trajectory and the proximity of the Solar Probe spacecraft, is essential for placing the in situ measurements within the context of the morphology of the solar corona. It will also provide the first ever opportunity to explore the small scale structures within coronal holes and streamer-s from viewing angles and with spatial resolutions never attained before.

From white-light coronagraph and ground-based radio occultation measurements, it is now clear that the outer and inner corona are closely connected through an extensive hierarchy of raylike structures. If Solar Probe is going to achieve its goals, the urgency and feasibility of imaging both the source region of the solar wind directly observed by Solar Probe, and the solar corona along the spacecraft trajectory, can not be overlooked. The existence of such an hierarchy of raylike structures also suggests the presence of an underlying constraint which might be utilized to causally correlate the remote imaging and in situ measurements, enhancing the ability of the Solar Probe to meet the mission objectives.

'This summary resulted from presentations and discussions made by a number of participants. Given the complexity and advantages of the different imagers discussed, the participants in this group felt that no specific recommendation for an optimal context instrument could be made at the time of the workshop, They also shared a common view that several viable options could be accommodated within the power and mass limitations of the Solar Probe. Further concentrated studies including model computations were strongly recommended.

SCIENTIFIC GOALS

One of the primary goals of the Solar ~'robe mission is to achieve an understanding of the coronal heating and solar wind acceleration processes. Such understanding is intimately related to the understanding of the morphology of the different source regions of the solar wind. There are several outstanding questions at present that could be resolved with a near Sun flyby. Among these are (1) the identification of the filamentary nature of the corona in the source regions of the fast and slow solar wind; (2) the filling; factor of the coronal plasma; (3) the expansion factor of the flow tubes carrying the solar wind flow; and (4) the activity in the magnetic network, believed to be the source of the coronal heating processes, and the energy and momentum addition to the solar wind. By taking advantage of the unprecedented spatial resolution and unique vantage point of the Solar Probe trajectory, these measurements are also expected to *discover* new and faint structures not seen before, as has proven to be the case for the preceding solar missions such as Skylab, Yohkoh and SOHO.

CLASSES OF REMOTE SENSING MEASUREMENTS

Nadir and limb pointing offer two complementary and essential measurements of the corona between the solar surface and the trajectory of the spacecraft. When made in conjunction with in situ measurements, these observations will provide the context for the latter which cannot be achieved by an earthbound spacecraft in an equatorial orbit.

Disk Imagers

As described in [1], the imaging instrumentation is required to sample a range of heights in the solar atmosphere as a function of solar latitude. The most challenging technical aspect of disk imagers is the nadir viewing.

Broadband Visible Disk Imager

Observations of the topology of the magnetic field and the surrounding flows, and the determination of the size and temporal evolution of magnetic flux elements in a coronal hole, a quiet sun and an active region, can be achieved with a broadband visible telescope with a resolution of a few kilometers when the spacecraft reaches 4 R_s. Such an imager will be the first to measure the *polar* magnetic field. It will resolve the fundamental size and distribution of the photospheric magnetic field (A. Title, K. Strong, private communication). Because of the limited telemetry rate, much of the scientific data will depend on image processing in the spacecraft computer of long time sequences of images.

EUV/X-ray Disk Imager

A coronal disk imager in the extreme ultraviolet (EUV), such as proven by the revolutionary results from Skylab, and SOHO, will be able to determine the dynamics of structures in the transition region and corona, hence to determine the energy and momentum addition to the solar wind. Such an imager will be the only tool to define characteristic spatial scales which cannot be attained from earthbound observations. As discussed by [3], with a judicious choice of spectral lines characteristic of transition and coronal emission, the fundamental causal correlations between transition region and corona can be derived. This will require extensive modeling of the transport and distributions of various non-hydrogenic species in order to interpret the imager data and an understanding of how each of the magnetic topologies identified are related to the in situ measurements made on the Solar Probe ("J'. Evans, private communication). In addition, such an imager will determine the tomography of the transition region and corona, and the chemical composition, if a number of spectral lines can be accommodated. As described by [5], such a scheme can be accommodated with present technology (also, O. Siegmund, private communication). With the use of data compression schemes, a reduction of data rate and increase in number of images can be achieved. The choice of wavelength range for such an imager, whether in the ultraviolet, extreme ultraviolet or x-rays, should be such that the spectral lines selected are individually resolved to provide the necessary plasma diagnostics.

Limb/Coronagraph Imagers

Limb observations are essential to sample the space between the solar surface and the spacecraft trajectory which is inaccessible to the in situ measurements. At the same time these measurements also provide the context for the in situ measurements. Several options exist. The obvious technical advantages of limb imagers is the use of the spacecraft shield as a natural occulter.

White Light Coronal Imager

As described by [6 8] for example, white light observations will yield the tomography of structures in the corona and their distribution function, the expansion factor of the solar magnetic field, and the aspect ratio of structures: i.e. whether these structures are in the form of sheets or more thread-like. In addition to morphology, white light observations will yield plasma characteristics of the coronal space inaccessible to in situ measurements, such as the density distribution in the corona, and the static versus wave associated structures. From these observations a map of the flow speed in the inner corona can be determined (see [6-8,1 O]).

EUV/X-ray Coronal Imager

While the white light is sensitive to the electron density, an EUV/X-ray coronal imager will be able to distinguish between the different temperature plasmas that thread the corona. Such an imager will sample the outward extension of the coronal plasma from its source region on the Sun. Similarly to the white light imager, an EUV/X-ray imager can also determine the filling factor of the coronal plasma and its morphology. In addition, it can yield inferences of temperature and density of the extended corona with a judicious choice of spectra] lines. An example of such an instrument was provided try [5] (also, O. Siegmund, private communication). A concept using a special algorithm was proposed by [3] to study the causal relationship between events in the transition region and corona with an EUV coronal imager.

Another very powerful diagnostic imager is the in-cqmscd back scattered Lyman α coronagraph which will yield Doppler shifts in the inner corona [1 2]. Such an instrument will yield the species temperatures of neutral hydrogen, helium and oxygen.

Radio observations

The path-integrated density measurements that essentially come free with the Solar Probe communications link will serve to complement the in situ plasma measurements in an important way. These radio measurements will observe mainly the plasma nearest the spacecraft and at a sampling rate that can be much higher than that of the in situ measurements. While the sampling rate of the in situ measurements will be severely limited by telemetry rates, there is no limit on the radio measurements because it is a matter of raising the sampling rates of the received signal at the DSN station. The radio measurements will, therefore, observe spatial structures that are much smaller than those inferred from the proposed imagers. At the same time, they will allow for comparison and calibration with the direct measurements of the common larger scales [1 3].

OTHER SCIENCE OPTIONS

Since the spacecraft will be traveling in a plane at 90° to the ecliptic, an unprecedented opportunity for stereoscopic imaging and diagnostic can be achieved between 0.5 AU and 0.2 AU when power requirements are not limited to the batteries. Coupled with ground-based observations, the spatial resolution at that distance is comparable to that attainable at Earth from an orthogonal direcction. At a distance of 0.5 AU, a 3° field of view of an instrument will subtend 6 R_s above the solar surface. Without the need for any scanning at this phase of the mission, this field of view and vantage point will offer a unique imaging opportunity of the large-scale corona. In addition to *approach* science, stereoscopic views of the corona can be obtained during the cruise phase by combining images from near-Earth-based imagers with those from the Solar Probe situated approximately 90° from the Earth-Sun line.

The proposed imagers are also ideally suited to be part of the proposed Russian probe which reaches a perihelion of 10 R_s (see [11]). The increased scientific return provided by simultaneous measurements from the possible configuration of two probes is complemented by a reduced cost increase. Because of the less stringent constraints of weight, power and telemetry on the Russian probe, the instruments on the latter could have more capabilities without dramatic cost impact.

TECHNICAL CHALLENGES

The power, weight and telemetry limitations, discussed in []], as well as the technical challenges imposed by nadir viewing (see [1], and [1 1]) are not prohibitive for any of the imagers proposed. To achieve the scientific goals of Solar Probe, namely of exploring the different source regions of the solar wind, it is essential to acquire a number of images with a high sampling rate in three critical regions: the polar coronal hole, the transition) from the corona hole to the quiet Sun, and in the stalks of the streamers, With the development of data compression schemes and onboard processing, images with high sampling rate can be achieved.

CONCLUSIONS

Remote sensing measurements of the corona between the solar surface and the trajectory of the Solar Probe will address the fundamental questions about the solar corona and the solar wind in the following way:

1) The fundamental energy source of coronal heating and momentum, and the difference between the steady and bursty energy sources will be determined. These measurements will be directly linked to temporal and spatial variations in the in situ measurements.

2) With the option of a broadband visible disk imager, the determination of the polar magnetic field can be made. By comparison with the in situ measurements, the evolution of the magnetic field can be inferred.

3) Remote sensing measurements will characterize the differences and transition from the fast to the slow solar wind, and the boundary region between these two types of flows. These measurements will provide the structure, dynamics and plasma parameters through imaging and spectroscopy. By comparing with in situ measurements, the remnants of these structures and their dynamic evolution can be made.

4) These measurements will provide for the first time the three dimensional imaging of the corona and will distinguish large from small scale structures. They will yield the expansion factor and filamentary nature of the structures. Through inferences of filling factors and field divergence, the connectivity between the source region and the in situ plasmas can be made. These measurements can be achieved with broadband visible, EUV and X-ray disk and limb imaging. These will be particularly powerful during cruise science and with a two spacecraft option.

5) The spatial structure of the solar corona as a function of energy can be determined through measurements of the plasma temperature. High resolution images at transition region and coronal temperatures will yield the information necessary to make a direct connection to the distribution functions.

6) The requirements of high time sampling rates and high spatial resolution of a few images can be met with onboard processing algorithms.

The consensus of the remote imaging panel was that data from a variety of remote imaging sensors are critical to achieving the mission objectives as stated in [1]. Further, the panel discussed at length the need for causally correlating remote imaging data with the in-situ measurements. Several approaches (W. Feldman images and particles [private communication], M. Guhathakurta and R. Fisher limb images [6], and T. Evans, et al., transition region structures [3]) for achieving such causal correlation were discussed. The panel did not reach a consensus on the feasibility, within the Solar Probe mission scope, of these approaches for achieving causal correlations, but there was significant interest in developing such techniques further. Concentrated efforts including model computations were strongly recommended.

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This summary reflects the consensus reached by the participants in this group after a number of rounds of often spirited discussions. We thank all those who shared their ideas and energies so generously.

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