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TITLE: WORKING GROUP 1: CORONAL STREAMERS

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WORKING GROUP 1: CORONAL STREAMERS

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Abstract. The working group on coronal streamers convened on the first day of the 2nd SOHO Workshop, which took place in Marciana Marina, Isola d'Elba, 27 September - 1 October 1993. Recent progress in streamer observational techniques and theoretical modeling was reported. The contribution of streamers to the mass and energy supply for the solar wind was discussed. Moreover, the importance of thin electric current sheets for determining both the gross dynamical properties of streamers and the fine-scale filamentary structure within streamers, was strongly emphasized. Potential advances to our understanding of these areas of coronal physics that could be made by the contingent of instruments aboard SOHO were pointed out.

Key words: Sun: corona - Sun: streamers - Sun: solar wind

1. Introduction

Coronal streamers are by far the most striking feature of the "quiescent" solar corona, their wispy forms having dominated the hand drawings of eclipse observers long before the advent of photography. It is fair to say that, by virtue of the sometimes-Herculean efforts of observers and theoreticians alike, there exists today an enormous wealth of knowledge regarding the morphology and evolution of streamers, the physical conditions within these structures, and the probable role of streamers within the larger context of heliospheric physics.

Unfortunately, not all of this knowledge is self-consistent, and it can certainly stand to be improved upon in many respects. Nevertheless, the reader must not be left with the mistaken impression that we are envisaging the SOHO project as starting from scratch in investigating the above topics. Rather, the goal of SOHO is to refine our perception of certain processes at work on the Sun (such as the mass and energy balance of the corona), thereby adding to the pre-existing storehouse of information. Because of their relative brightness and longevity, coronal streamers comprise a particularly attractive type of solar structure to observe and analyze for this purpose.

In addition, there are important gaps in our knowledge, and the enhanced spectroscopic capabilities of SOHO may make it possible for the first time to fill in these gaps by allowing us to ascertain the detailed properties of the coronal plasma close to the Sun.

2. Basic Streamer Configuration

The classical form of a coronal streamer consists of a bright dome-shaped structure in the inner corona, usually best seen at or near the solar limb at the time of a total solar eclipse; above the top of the dome, or "helmet", a region of enhanced brightness extends outward more-or-less radially, narrowing somewhat with increasing elongation from the Sun. The distance into space at which streamers can be detected seems to be limited only by the observing technique employed: see the streamer review article in this Proceedings by Poletto. It is in fact generally accepted that streamers have distinct signatures in the properties of the solar wind at, and probably well beyond, 1 A.U.

The simplest three-dimensional model that one implicitly assumes when discussing streamer physics is that of a magnetically closed bipolar region comprising the helmet, surrounded on both sides and above by a region of "open" field lines extending far out into space. The boundary between the open and closed field regions is believed to consist of a system of extremely thin sheet currents - the "magnetic separatrices".

As simple as it is, it should be stressed that this conceptual picture of a magnetized streamer structure is based more on conjecture than on fact. There are as yet no direct measurements of the magnetic field strength at coronal heights and only a few indirect inferences of the direction of the field in streamers based on coronal emission line polarization.

It is within the context of the above scenario that most of the talks and posters of the working group were presented.

3. Density and Temperature in Streamers

Except for ballpark figures, there seems to be no universal agreement on the temperature and density distribution within streamers - not to mention the values of these quantities at the streamer base. This is understandable when one considers that no two streamers are exactly alike, and there no doubt exists a natural dispersion of the physical properties of streamers as a class. Moreover, it is rare indeed that a given streamer has been analyzed extensively by two entirely different observing techniques. The Workshop presentations and discussions illustrated clearly that there is no single method of temperature determination that yields a completely unambiguous value of the kinetic (electron or ion) temperature at a fixed point within a streamer. For example, the oft-quoted "scale-height" temperatures are suspect because they are based on the assumption of dynamical stationarity, or hydrostatic equilibrium, of the coronal plasma and they ignore the possible contribution of magnetic stresses in the pressure balance. Moreover, one usually assumes a (locally) isothermal medium in approximating the observed density lapse

rate by an exponential function.

Similarly, the observed intensity ratio of coronal emission lines of different ionization stages of a single element has been widely used over the years as a sensitive temperature indicator. Most recently, this technique has been applied to a large body of green- and red-line data by Guhathakurta and co-workers (this Proceedings) to infer the large-scale pattern of coronal temperature variations over a sunspot cycle. Combined with K-coronameter and photospheric magnetic field data, they were able to determine the spatial correlations of coronal density and temperature with the large-scale distribution of surface magnetic fields (see also Guhathakurta et al., 1993).

These "ionization equilibrium" temperatures implicitly assume that both of the lines used to form the intensity ratio always originate in the same coronal volume element(s) along the line of sight. Considering the large amount of fine structure likely to be present in streamers and, indeed, throughout the corona (see below), this assumption must be difficult to justify in general. A strong argument in its favor could nevertheless be made if a careful examination of similar data taken at high angular resolution were to reveal that the same fine-scale features are visible in both lines. Alternatively, to render the "identical volume" assumption less controversial, one might select line pairs arising from nearby ionization stages - or ideally even from the same stage of ionization (e.g., a resonance-line doublet in the XUV spectral region); this, however, would most likely decrease the temperature sensitivity of the technique somewhat.

The least controversial method of coronal temperature determination appears to be that of observing the spectral profile and intensity of the resonant-scattered *Lyman- α* line of neutral hydrogen. (Combined with other data, such as that from white-light coronagraphs, these observations can provide information on coronal electron densities and plasma bulk motions as well.) This method depends on only a single spectral line, whose formation mechanism is relatively simple and well-understood; moreover, that being a line of a light element, its width is fairly insensitive to turbulent motions of the coronal plasma. Of course, high in the corona there could be a large difference between the electron and proton temperatures, but this is not likely to be the case in the dense cores of streamers over the range covered by SOHO (UVCS) observations.

Interesting results using this technique were presented by the Harvard group (presentations by J. Kohl and L. Strachan). These were obtained during the April 1993 Space Shuttle deployment of the Spartan 201 instrument package containing both a white-light coronagraph and an ultraviolet coronal spectrometer. Proton kinetic temperatures were determined at a number of heights between 1.35 and 3.5 $R_{\odot}$, both along the axis of a large coronal streamer and in the polar coronal holes. Whereas the Spartan 201 spatial coverage was not sufficiently complete to establish a systematic trend of

temperature with position in these structures, it did provide a tantalizing preview of possible things to come from the UVCS experiment on SOHO.

4. Fine-Scale Structure in Streamers

As with any other structural component of the solar atmosphere, coronal streamers exhibit a wealth of filamentary detail when observed with sufficient spatial resolution. This is not particularly new or surprising: some of the best examples of fine structure date from the early years of the present century (e.g., Campbell, 1923), when it was common practice to photograph the corona at total eclipse with very long focal-length telescopes (large plate scale). Structures of all spatial scales down to the resolution limit of the observations (typically a few arc seconds) are present on broadband eclipse photographs (Koutchmy, this Proceedings), and presumably even smaller features exist. It has long been supposed that this filamentary structure delineates the magnetic field lines imbedded in the coronal plasma. Although the brief coverage provided by eclipses does not directly reveal much evidence for plasma motions, such flows must certainly exist and these, too, should largely be aligned with the ambient magnetic field. The earliest attempt to estimate on purely theoretical grounds the effect of filamentary structure on the dynamics of the coronal plasma was made by Parker (1964).

More recently the beautiful X-ray images of the corona being returned by instruments such as NIXT and Yohkoh's SXT have sparked renewed interest in the subject of small-scale inhomogeneities, particularly within streamers. Several examples were shown during the streamer session. Perhaps the most outstanding of these were the SXT images of both bright and (relatively) dark cusp-like structures within streamer complexes (presentations by K. Strong and C.-C. Cheng). These transient brightenings may well be the long-searched-for signature of magnetic reconnection in the corona. Alternatively, they may simply reflect the plasma filling from below of a pre-existing cusp structure at the top of an arcade of loops. Detailed analyses of these fascinating observations are just now getting underway, and substantial progress in this area can be anticipated in the near future.

5. Coronal Source Regions of the Solar Wind

In the mid-1970's it became generally recognized, on the basis of kinematic mapping of the interplanetary magnetic field back to the Sun, that the large high-speed streams (HSS; $v \geq 400 \text{ km/s}$) observed to recur every 29 days in the solar wind emanate primarily from long-lived coronal hole (CH) regions as the latter rotate with the Sun (Hundhausen, 1977). HSS's account for a substantial fraction of the solar wind at 1 A.U. ($\approx$ half, depending upon the number of streams present and thereby upon phase in the solar cycle); the

remainder is characterized as "slow" or "background" wind ($v < 400 \text{ km/s}$).

Today the association of HSS's with CH's is established beyond a reasonable doubt. This scenario is presently being played out in real time by incoming solar wind data from the Ulysses mission (presentation by M. Neugebauer): as the spacecraft moves to ever-higher southern heliographic latitudes, it appears to be spending an increasing fraction of each successive solar rotation immersed in the "simpler" HSS flow pattern associated with the south polar coronal hole region.

The origin of the *slow* wind, on the other hand, is still a matter of debate, there being no obvious candidates for its source region(s) among known features on the solar surface. Some years ago it was suggested (Borrini et al., 1981) that the low-velocity, high-density, helium-poor solar wind plasma in the vicinity of the "sector boundaries" at which the interplanetary magnetic field reverses polarity abruptly, maps back to the high-density cores of coronal streamers. According to this picture, a sector boundary is nothing more than the outward extension of the current sheet postulated to lie along the symmetry axis of an underlying streamer, and the slow wind near the sector boundary originates within the body of the streamer - i.e., on the first open field lines encountered as one moves away from the streamer axis. These field lines are rooted in the solar surface at the edges of the helmet, in regions occupied by relatively high coronal density (albeit perhaps not quite as high as that within the helmet itself). Thus the slow-wind source regions would be described as being of high density at the Sun compared with, for example, a coronal hole.

On the other hand, we have heard described in the streamer session some recent work that ascribes the slow wind to the outflow of plasma near the edges of, but still within, coronal hole regions (presentation by Y.-M. Wang). On the basis of numerical simulations of coronal expansion in various types of prescribed non- r^2 geometries, in which the energy transport (like the flow itself) is assumed to be channeled along the flow tubes, Wang concludes that the (relatively) faster divergence of field lines issuing from the edges of coronal hole regions results in lower wind speeds there.

Judging from the ensuing discussion of this work, there appears to be some real confusion at present as to the slow-wind source regions. This confusion may turn out to be simply a matter of semantics; nevertheless, it should be resolved. Is the slow-wind source region near the "edge" of a (low density) coronal hole in Wang's scenario synonymous with the high density region envisaged by Borrini et al. (1981) and others to be situated at the edge of an adjacent helmet streamer? If so, should the coronal source region be considered to be part of the CH or part of the streamer? The answers to these questions ultimately revolve around a more precise operational definition of the "border" between coronal holes and streamers, as well as that of the effective boundary separating the high- and low-speed wind flows in

interplanetary space.

In addition, most likely not *all* of the low-speed wind comes from these relatively narrow boundary regions between streamers and holes. The feeling that I (and I'm sure that others) have had for many years, is that the above division of the outer solar atmosphere into "streamers" and "coronal holes" is overly simplistic. A cursory glance at any high-resolution image of the X-ray corona, such as the beautiful examples from Yohkoh that were shown in this working group, reveals that there are many large regions of diffuse emission that belong neither to coronal holes nor to large-scale streamer regions. Some of these regions appear to contain faint loop-like structures, whereas others seem to be completely featureless. What is the magnetic topology of the latter? Seen with enhanced contrast and sufficient spatial resolution, they may consist of complex groupings of closed loops interspersed with "open" flux tubes extending far out into space. Such open tubes, and the plasma flowing along them, might account for much of the solar wind outside high-speed streams. However, the obvious observational difficulties associated with tracing a given parcel of low-speed wind back to a well-defined feature in one of these amorphous regions of the low corona, need not be belaboured here.

6. Theoretical Streamer Models

Early attempts to build coronal models containing streamer structures, and to predict the spatial modulation of solar wind properties by these structures, were based on the assumption of ideal magnetohydrodynamics (MHD). These proceeded by solving directly for the steady state by an iterative process (Pneuman and Kopp, 1971; Robertson, 1983). This approach is currently being pursued by Y.-M. Wang in developing a self-consistent MHD model for the solar wind outflow from CH regions, including the effects of heating and conductive energy transport. We look forward to seeing the first results from this ambitious effort at the next SOHO Workshop.

An alternative technique which seems to be more widely used nowadays is to integrate the time-dependent MHD equations with artificially enhanced resistivity, starting from an arbitrary assumed initial state and following the temporal evolution of the plasma-field system until a dynamically relaxed steady state is reached, corresponding to the assumed (invariant) boundary conditions. This "relaxation method" was first used to construct 2-D streamer models by Endler (1971).

The relaxation technique is presently being used by, among others, the Huntsville group to build composite steady state models of streamers flanked on both sides by CH regions (presentation by S. Suess). The aim is to make a direct connection to SOHO observations of the spatially resolved plasma properties (temperature, density, and bulk flow velocity) within a streamer.

To this end, G. Poletto (Arcetri) has made quantitative predictions of the intensity and shape of the hydrogen $Ly-\alpha$ line for these models, including the effects of Doppler dimming, for comparison with UVCS observations of the actual line profile as a function of position. Perhaps the major limitation of these simulations is that imposed by assuming polytropic flow in and around the streamer. This necessitates assigning unreasonably high temperatures to the CH field lines, in order to obtain low densities there. The next logical refinement to this model will presumably be the use of a realistic energy equation in the flow calculation. If nothing else, this should facilitate an arbitrary specification of boundary conditions at the coronal base - thereby accommodating almost any observed variation of density and temperature as one proceeds outward from a streamer to the neighboring open-field regions.

7. Streamer Evolution and the Global Corona

That streamers are intrinsically dynamical phenomena of the solar corona has been well-established by observations from Skylab, Solwind (P78-1), and SMM. Major changes are known to occur on time scales ranging from many months down to a few tens of minutes. Even the largest, most stable-appearing streamers do not persist for more than a few solar rotations (although this may be an effect of changing perspective of the streamer belt relative to the ecliptic plane). Most dramatic, of course, are instances in which a streamer is disrupted entirely by the occurrence of a nearby coronal mass ejection (CME). Many of the gradual, more subtle changes in streamer morphology manage to slip by unnoticed in day-to-day synoptic observations, being largely masked by the effects of solar rotation (Kopp, 1992). At the present time it is impossible to state with any precision what fraction of the global restructuring of the corona is caused by these slow changes, and what fraction should be ascribed to transient events (including CME's).

Again, the recent Yohkoh observations have been a boon to revealing many of the short-term changes in streamer configurations. The SXT has provided many fine examples of both the plasma filling (brightening) of pre-existing helmet shapes and the reformation of streamers following major disruptions (presentation by K. Strong). Important in themselves for depicting the various time scales on which significant changes occur, these examples and others await in-depth analysis and interpretation, which hopefully will be forthcoming in the not-too-distant future.

When it comes to modeling these transient changes in coronal streamers, we appear to be close to possessing the requisite theoretical tools. The time-dependent MHD relaxation method described in the previous section for generating steady-state streamer configurations, can in principle also be used to simulate large-scale transient phenomena in the corona, *as long as the specifics of reconnection phenomena (e.g., time scales) are not an issue:*

the inherently low resolution of existing numerical MHD codes, and the associated unrealistically large values of resistivity (small magnetic Reynolds number), have thus far precluded a physically correct treatment of magnetic dissipation in global reconnection scenarios. Notwithstanding this caveat, time-dependent simulations have been used quite successfully to illustrate the outward disruption of streamers (a convective, rather than a dissipative, process) under the action of externally generated disruptive forces in the corona (presentation by R. Steinolfson). The applications have thus far been to two-dimensional configurations, whereas in reality streamers are three-dimensional objects - probably extending in longitude not a great deal more than in latitude; thus ultimately 3-D MHD codes will have to be brought to bear on the streamer-simulation problem.

The obstacles confronting a more comprehensive modeling of streamer disruptions apparently stem more from the incomplete observational coverage of these events than from the lack of adequate computational tools. To carry out conclusive tests of our coronal-transient modeling capabilities, precise temporal and spatial knowledge of the plasma and magnetic state of streamers and their surroundings is badly needed, extending from the base of the corona (for specifying boundary conditions) out to several solar radii (for defining the initial state of an event as well as for documenting its subsequent evolution). Such thorough coverage will only be possible through a combination of coordinated observations from the SOHO instruments and correlative observations from an extensive ground observing network (e.g., high-resolution vector magnetographs).

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