CORONA AND SOLAR WIND
(Invited)

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ABSTRACT

The Pinhole/Occulter Facility is a powerful tool for studying the physics of the extended corona and origins of the solar wind. Spectroscopic data acquired by the P/OF coronal instruments can greatly expand empirical information about temperatures, densities, flow velocities, magnetic fields, and chemical abundances in the corona out to $r \gtrsim 10\ R_{\odot}$. Such information is needed to provide tight empirical constraints on critical physical processes involved in the transport and dissipation of energy and momentum, the heating and acceleration of plasma, and the acceleration of energetic particles. Because of its high sensitivity, high spatial and temporal resolutions, and powerful capabilities for plasma diagnostics, P/OF can significantly increase our empirical knowledge about coronal streamers and transients and thereby advance the understanding of the physics of these phenomena. P/OF observations can be used to establish the role in solar wind generation, if any, of small-scale dynamical phenomena, such as spicules, macrospicules and coronal "bullets," and the role of the fine-scale structures, such as polar plumes. Finally, simultaneous measurements by the P/OF coronal and hard X-ray instruments can provide critical empirical information concerning nonthermal energy releases and acceleration of energetic particles in the corona.

I. INTRODUCTION

Improved knowledge of the physical conditions throughout the solar corona is critical to the development of an understanding of the physical state of the corona and the physical mechanisms responsible for plasma heating, solar wind acceleration, energetic particle acceleration and the transport of mass, momentum, and energy. The Pinhole/Occulter Facility (Hudson et al., 1981; Tandberg-Hanssen et al., 1983) can be a very powerful tool for acquiring this knowledge. Because the P/OF occulting disk is large and located much farther (~50 m) from the telescope than for any previous externally occulted coronagraphic instrument, it is possible to employ telescopes of large aperture (~0.5 m). This gives the P/OF coronal instruments sufficient collecting area to have several orders of magnitude more sensitivity than any coronagraphic instrument previously flown on sounding rockets or orbiting spacecraft. As a result the P/OF coronal instruments can provide measurements with high spatial resolution (~1 arc s, an order of magnitude or more better than more conventional instruments) and good time resolution for studying transient phenomena, as well as providing a capability for measuring weak coronal lines at large distances from the Sun (out to $r \gtrsim 10\ R_{\odot}$). The P/OF occulter also serves as a multi-pinhole array for high resolution ($\lesssim$1 arc s) hard X-ray imaging. This gives P/OF a means of detecting signatures of nonthermal energy releases and energetic electrons. These capabilities yield an instrument package with unprecedented power for probing the extended corona, investigating the origins and physics of the solar wind, and studying energetic particle acceleration in the corona.

The purpose of this paper is to briefly discuss the role that P/OF can play in addressing a few scientific problems in the above areas. Section II discusses spectroscopic plasma diagnostics and coronal physical processes. Sections III and IV deal with the structure and physics of streamers and coronal holes, while Section V considers coronal transients and mass ejections.

II. SPECTROSCOPIC PLASMA DIAGNOSTICS AND CORONAL PHYSICAL PROCESSES

Plasma diagnostic information derived from spectroscopic measurements can provide critical empirical constraints on mechanisms for transport and dissipation of energy and momentum in the corona, acceleration of energetic particles, and production of differences in coronal chemical composition. For example, information on temperatures and flow velocities is important for studying mechanisms for plasma heating and solar wind acceleration and for separating mechanisms that depend upon driving the solar wind thermally and those driving it through wave-particle interactions. At the present time there are very few measurements of most basic plasma parameters (other than electron densities) beyond a few tenths of a solar radius above the solar surface. New spectroscopic techniques made possible by the use of coronagraphic instrumentation with reflecting optics are being developed and proven using instruments flown on sounding rockets and Spartan (cf., Kohl et al., 1980, 1983, 1985). These are small instruments with limited collecting area, spatial resolution, and wavelength coverage. The P/OF instruments with their large collecting areas, high spatial and spectral resolutions, and broad wavelength range, spanning the visible to the XUV, offer a means of implementing a wide variety of plasma diagnostic techniques that can provide information of a number of critical plasma parameters.

There have been a number of papers published recently which have discussed various spectroscopic plasma diagnostic techniques that can be used in the extended corona (cf., Beckers and Chipman, 1974; Kohl and Withbroe, 1982; Bommier and Sahal-Brechot, 1982; Withbroe et al., 1982a; Kohl, et al., 1983); hence, we will discuss them only briefly here. We consider first the measurement of temperatures. In the outer corona, $r \gtrsim 1.5\ R_\odot$, the temperatures of particle species such as electrons, protons, and heavy ions can differ (because the collisional exchange of energy among particles of different masses is slow at low density). Coronal temperatures can be determined from measurements of the widths of spectral lines. The line width $\Delta\lambda \sim T_W^{1/2}$, where the temperature T_W includes the effect of line broadening by thermal and nonthermal motions along the line of sight. Nonthermal motions can be produced, for example, by MHD waves propagating through the corona. The temperature determined from the line width is related to the thermal temperature T_t by $T_W = (T_t + M\xi^2/2k)^{1/2}$, where M is the mass of the particles species producing the spectral line and ξ is the rms velocity component due to plasma motions along the line of sight that occur on a spatial scale much larger than the particle mean free path, but smaller than the path length over which the spectral line is formed. Additional information about the plasma in the line of sight can be obtained if the shape of the profile is measured as well as its width, since the shape depends upon the velocity distribution of the particles along the line of sight. By observing lines from ions of different masses one can obtain empirical constraints on the magnitude of mass-dependent and mass-independent motions.

An example of how widths of line profiles can be used to test theoretical models for the solar wind is shown in Figure 1. One of the problems with current solar wind models is satisfactorily accounting for the flow speeds in high speed solar wind streams originating from coronal holes. Additional energy over and above that calculated using models with thermally driven winds is needed to yield solar wind speeds of the magnitude measured. In addition, unless one invokes a mechanism for heating protons far from the Sun, the proton temperatures predicted by the theoretical models are too low. Because signatures of MHD waves are detected with in situ measurements of the solar wind far from the Sun, there is speculation that Alfvén waves may play a significant role in driving the solar wind and heating the protons (see reviews by Hollweg, 1981, Leer et al., 1982). Since the velocity amplitude of Alfvén waves is expected to vary as $N^{-1/4}$ in the corona, the amplitude of these waves increases rapidly with increasing distance (and therefore decreasing density N) from the solar surface. By measuring spectral line profiles from atoms and ions of different masses (and thus different thermal widths) one can obtain tight empirical constraints on the flux of Alfvén waves propagating outward from the Sun in coronal holes and other solar regions.

Figure 1 compares some existing measurements of Lyman alpha with widths calculated for a theoretical two fluid solar wind model which includes the effects of Alfvén waves on line broadening. (The resonantly scattered hydrogen Lyman alpha line is expected to be the strongest emission line in the extended corona; see Kohl and Withbroe, 1982.) The solid line gives the predicted behavior for a model with no Alfvén wave flux, the dashed line shows how the introduction of an appropriate amount of broadening by Alfvén waves yields a better fit to the Lyman alpha measurements (Esser et al., 1985). Although the fit is better, the evidence for the presence of Alfvén waves is not compelling because of the magnitude of the uncertainties in the measured widths. However, if measurements of a heavy ion such as Fe XII are available, one obtains a much tighter constraint on the Alfvén wave mechanism, as illustrated by the curves calculated for the Fe XII λ 1242 line. With P/OF one could not only observe profiles of Fe XII and other heavy ions, one could also obtain much better Lyman alpha profiles (hence smaller uncertainties in the line widths) for $r < 4\ R_{\odot}$ and observe them much farther out where the amplitude of the Alfvén waves is expected to become very large. One also obtains constraints on the energy spectrum of the waves from the shape of the spectral line profiles, particularly from profiles of heavy ions such as Fe XII λ 1242.

In order to place the maximum empirical constraints on theoretical mechanisms for plasma heating and for energy and momentum transport, it is desirable to measure profiles from a wide variety of particle species. P/OF is ideally suited for accomplishing this, because of the high sensitivity and wide wavelength coverage that can be achieved, spanning visible through XUV wavelengths. P/OF can measure profiles of numerous spectral lines, including very weak lines such as the electron-scattered component of hydrogen Lyman alpha, over a wide range of heights. With such data one can determine the electron temperature (electron-scattered component of Lyman alpha) and either determine or place upper limits (depending on the nature of the non-thermal broadening and plasma heating mechanisms present) on proton temperatures (from resonantly scattered Lyman alpha) and heavy ion temperatures (from ions such as O VI, Ne VII, Ne VIII, Na IX, Mg X, Al XI, Si XII, and ions of iron from Fe VIII to Fe XVI).

The second important class of plasma parameters are particle densities. The densities of the two most abundant particle species, the electrons and protons, can be measured using the electron-scattered component of the coronal white-light emission (for determining N_e) and resonantly scattered hydrogen Lyman alpha (for determining N_p). Densities of various heavy ions can be measured using the intensities of appropriate spectral lines. By measuring densities of several stages of ionization of an element and/or temperatures and densities of critical particle species (e.g., one or more stages of ionization of a given element and the electrons which are responsible for collisional excitation and ionization), one can either measure or place tight empirical constraints on chemical abundances of the heavier particles such as He, N, O, Ne, Na, Mg, Al, Si, S, Fe, and Ni (cf., Kohl and Withbroe, 1982,; Withbroe et al., 1982a). Such information is needed to obtain insights and empirical constraints on mechanisms for production of the variations in chemical composition of the solar wind which are measured in the solar wind far from the Sun (cf., Hirshberg, 1975).

The third critical plasma parameter is the flow velocity. P/OF can measure flow velocities through use of "Doppler-dimming" of the intensities of spectral lines. In the outer corona where the densities are low, many coronal lines have a strong resonantly scattered component. This component is produced by resonant scattering of the line radiation from the solar disc and low corona. The intensity of the scattered radiation depends on the number of particles in the line of sight capable of scattering radiation in the line and on the intensity of the incoming radiation from the solar disk and lower levels of the corona. The number of scatterings is a function of the outflow velocity of the solar plasma. In a static atmosphere the central wavelength in the coronal scattering profile is identical to that of the disk profile. However, in a region with solar-wind flow the scattering profile is Doppler-shifted with respect to the disk profile and hence there is less efficient scattering, resulting in a reduction in intensity of the scattered radiation. Examples of this effect, known as Doppler-dimming, are illustrated in Figure 2 for hydrogen Lyman alpha λ 1216 and O VI λ 1032 (Kohl and Withbroe, 1982). The Lyman alpha line is sensitive to flow velocities greater than about 100 km/s, while the O VI line is sensitive to flow velocities above 30 km/s. By comparing the intensity of a spectral feature that is affected by Doppler-dimming with the intensity of a spectral feature that is not (e.g., electron-scattered white-light radiation), one can determine the amount of Doppler-dimming and hence the outflow velocity.

Measurements of Doppler-dimming acquired on several sounding rocket flights have been used to demonstrate that the outflows in some regions are subsonic for $r \lesssim 4\ R_\odot$ (cf., Withbroe et al., 1982a, 1985). The most recent data provide evidence for supersonic flow in a polar coronal hole at smaller radii, $r \approx 2\ R_\odot$ (Kohl et al., 1984). Much more extensive observations are needed, particularly measurements made with high sensitivity in a wide variety of spectral lines over a wide range of heights in order to place constraints on solar wind acceleration mechanisms for particles of different masses as well as to determine the role of different types of coronal structures, such as streamers and coronal holes of different sizes and geometrical configurations, in the generation of the solar wind.

Another critical parameter is the vector magnetic field. Current work suggests that measurements of the Hanle effect may provide a very useful tool for placing empirical constraints on coronal magnetic fields (Bommier and Sahal-Brechot, 1982; Kohl and Strachan, 1985). Measurements of magnetic fields via the Hanle effect make use of the influence of magnetic fields on the polarization of spectral lines. It has been used, for example, to measure magnetic fields in prominences (see references cited in Bommier and Sahal-Brechot, 1982). Because of the high sensitivity of the P/OF coronal instruments, it will be possible to measure polarization of a variety of spectral lines and thereby obtain constraints on coronal magnetic fields.

P/OF is a powerful tool for studying the acceleration of energetic particles in the corona, because of its unique capability for spectroscopically probing the coronal plasma with high spatial and temporal resolutions while simultaneously observing signatures of energetic electrons. The P/OF hard X-ray instruments can observe the location of the region where the electrons are accelerated and the number, energy spectrum, and trajectory of the accelerated electrons. The P/OF coronal instruments can observe the spatial and temporal variations of the coronal structure, density, and temperature of the thermal electrons, and provide empirical constraints on ion temperatures, magnetic field strengths, and flow and turbulent velocities at the acceleration site and in the surrounding medium. Clearly, P/OF offers rich prospects for the study of energetic particle acceleration in low density plasmas in an astrophysical source.

In summary, the P/OF coronal instrument can provide a wide variety of plasma diagnostics for determining the physical conditions in the corona and inner heliosphere where the solar wind originates and is accelerated. It can provide empirical information on electron, proton, and ion temperatures, densities, and flow velocities as well as information of chemical abundances and nonthermal velocities produced by wave motions. This information can be used, for example, with the solar wind equations to determine and/or place limits on the magnitude of the non-radiative energy deposited as a function of distance from the solar surface – separately for electrons, protons, and heavy ions. This would provide critical insights concerning possible heating mechanisms which can have different characteristic dissipation lengths and may preferentially heat particles of a specific mass or charge-to-mass. For example, in coronal holes fast-mode MHD waves preferentially heat electrons (Habbal and Leer, 1982). Precise measurements of spectral line shapes made possible by the high sensitivity of the P/OF coronal instruments can provide additional constraints on processes for energy transport and dissipation. Measurements by the hard X-ray instruments can provide information on in situ energy releases, nonthermal energy deposition, and the acceleration of energetic electrons.

III. STRUCTURES AND PHYSICS OF STREAMERS

Streamers are the most prominent bright features observed in white-light photographs of the corona (see Figure 3). These large structures extend far out into the heliosphere from the Sun, often to distances greater than 10 solar radii. Because streamers extend beyond the heights readily accessible with traditional spectroscopic instruments operating at visible, EUV, and X-ray wavelengths, relatively little is known about the physical conditions in these features other than information about geometry and electron densities derived from white-light observations. There is little or no information about critical parameters such as temperatures, chemical composition, magnetic field strengths, and outflow velocities. For example, although streamers clearly contribute mass to the solar wind, it is not known how much. There is evidence from in situ measurements of the solar wind far from the Sun that streamers are sources of slow speed solar wind (cf., Gosling et al., 1981). However, until measurements of the outflows in streamers are acquired, there will be uncertainty as to the nature of their contribution to the outflow of coronal plasma into the heliosphere.

P/OF will have the capability to greatly expand our empirical knowledge about the physical conditions in streamers. It will have the high spatial resolution required to probe in detail the structure of these features and obtain the plasma diagnostic information required to investigate the physics of these prominent structures of the solar corona. P/OF can provide empirical information to address questions such as: What are the differences in the temperatures, densities, mass flows, and plasma heating in the magnetically open and closed regions of streamers and between streamers and the surrounding areas? What are the physical conditions in the outermost extensions of streamers where we expect there are current sheets separating regions of oppositely directly magnetic fields? What are the physical conditions in the region near the top of the "helmet" where the magnetic field lines make a transition from closed to open? Do magnetic reconnection, plasma heating, nonthermal energy releases, and/or particle acceleration occur here? Are MHD waves present in various regions of the streamer?

Streamers are also a laboratory for studying interactions between magnetic fields and plasmas in open and closed configurations and in the transition regions between these configurations. Skylab and SMM observations show that streamers are dynamic structures which can move about (Illing et al., 1981; Munro and Fisher, 1985), presumably in response to changes in the large scale magnetic field of the Sun. These observations also indicate that the amount of material contained in a given structure can vary with time. Because of their very high spatial resolution, the coronal instruments on P/OF are particularly well suited to studying temporal variations in streamers. With P/OF it will be possible to observe the structure of a streamer (on both large and small spatial scales) and monitor the physical conditions in the streamer and its surroundings as a function of time. It should be possible to obtain, for example, insights as to whether observed changes in the shape or orientation of a streamer are in response to magnetic forces or changes in plasma heating. Streamers are an ideal place to search for signatures of magnetic reconnection with P/OF because of (1) the high spatial resolution of the P/OF instruments, (2) the capability for simultaneously monitoring plasma properties and detecting the release of nonthermal energy and the acceleration of energetic electrons, and (3) the large scale (compared to the P/OF resolution) structure of streamers.

In short, P/OF will provide the first opportunity to probe in detail the physical conditions in streamers and obtain empirical information needed to provide insights for developing realistic physical models for these features and for testing theories for various physical processes occurring in them. Figure 4 summarizes in "cartoon" or schematic fashion some of the questions discussed above.

IV. STRUCTURE AND PHYSICS OF CORONAL HOLES

The discovery that coronal holes are sources of recurrent, high-speed, solar wind streams has generated much interest in these low density regions of the outer solar atmophere. Coronal holes are the only unambiguously identified source of steady-state solar wind. Figure 3 shows a particularly large coronal hole observed during the 1973 solar eclipse. From white-light observations, such as illustrated in Figure 3, and He I λ 10830, XUV, and X-ray observations of coronal holes on the disk (e.g., Figure 5) we have been able to obtain information about the geometries and densities of coronal holes, their lifetimes (often many solar rotations), and mean temperatures ($\sim 10^6$ K) at their coronal bases (see Zirker, 1977, 1981). From limited spectroscopic observations acquired by a combined UV/white-light coronagraphic payload flown several times on a sounding rocket we have also obtained some empirical constraints on temperatures and flow velocities out to several solar radii in several polar regions where coronal holes were located (Kohl et al., 1980, 1984; Withbroe et al., 1985). These measurements suggest that the temperatures, densities, and coronal outflow velocities can be different for different coronal holes, possibly because of differences in size and geometry.

Existing instruments have insufficient sensitivity, spatial resolution, and spectroscopic diagnostic capabilities for addressing several fundamental questions concerning the physics of coronal holes. The high spatial resolution of P/OF (~1 arc s as compared to several arc min for existing UV coronal spectrometer and 8 to 10 arc s for white-light instruments) is of particular importance for determining the role of small-scale structures in the generation of the solar wind outflow from coronal holes. The high sensitivity of P/OF (several orders of magnitude beyond that of existing instruments) and access to spectral lines over a wide range of the spectrum (current instruments are limited to measuring intensities of a few spectral lines and profiles of only hydrogen Lyman alpha) is needed for performing extensive plasma diagnostics in the low density regions such as coronal holes. As summarized in Section II, these diagnostics are required for placing tight empirical constraints on processes for energy transport and dissipation and for solar wind acceleration.

The most prominent fine-scale structures observed in polar coronal holes are polar plumes, ray-like structures often visible in white-light eclipse photographs (e.g., lower pole in Figure 3). These features, which have widths of a few times 10^4 km, are believed, in many cases, to trace open magnetic field lines. Skylab observations in the EUV and XUV showed that coronal bright points are found at the bases of polar plumes (cf., Bohlin, 1977). This is illustrated in Figure 6, which contains several spectroheliograms acquired by the NRL Skylab spectroheliograph. The arrows point to several plumes which are best seen in the Mg IX λ 368 image. It appears that plumes can contain 10 to 20% of the coronal mass in polar coronal holes and may contribute a comparable fraction, perhaps more, of the solar wind mass flux originating in polar regions of the

Sun (Ahmad and Withbroe, 1977; Ahmad and Webb, 1978). A determination of whether or not this is the case requires new high resolution measurements of the type that can be acquired by the coronal instruments on P/OF.

The high sensitivity of the P/OF instruments will be important for studying the temporal behavior of polar plumes. There is evidence from Skylab data that there are short term variations (minutes to tens of minutes) in the EUV emission from these features, variations which could result from dynamical phenomena (Withbroe, 1983b). One possible source of the variations are flares in the coronal bright points which underlie plumes. Coronal bright points are often the site of flare-like phenomena (cf., Golub et al., 1974); hence, it is possible that they may also be the source of small-scale coronal transients or mass ejections. Often 50% or more of the energy in flares in active regions is carried away in the form of mass ejections. It would be interesting to determine whether or not similar phenomena occur for the smaller "flares" observed in coronal bright points. It would also be interesting to determine whether or not acceleration of energetic particles occurs during bright point flares and, if so, whether these particles escape into the heliosphere, for example, along the open magnetic field lines in plumes overlying the bright points. Hence, observations of polar plumes and coronal bright points with the entire complement of P/OF instruments could lead to significant discoveries concerning the physics of solar wind flow, transient phenomena, and possibly particle acceleration in coronal holes.

Another prominent feature in polar coronal holes are the large spicules known as macrospicules (cf., Bohlin, 1977). These features are most clearly seen in the He II λ 304 image in Figure 6 as narrow ($\lesssim 10^4$ km) jets of emission extending above the solar limb. Macrospicules have lifetimes of 10 to 20 min and appear to be jets of cool ($\lesssim 10^5$ K) material ejected from the chromosphere with velocities up to 150 km/s, velocities comparable to the sound speed in the corona. Skylab EUV observations indicate that most, perhaps all, of the mass appears to fall back into the chromosphere (Withbroe et al., 1976; Withbroe, 1983a). It is possible that macrospicules, and the more numerous, less energetic spicules found in the quiet chromosphere, are associated with upward-propagating waves or shocks (cf., Hollweg et al., 1982; Shibata, 1982).

A less frequent, but much more energetic phenomena that may or may not be related to spicules and/or macrospicules are the high-energy jets, sometimes called coronal "bullets," observed by the NRL HRTS rocket experiment (Brueckner and Bartoe, 1983), especially in the C IV spectral lines formed at temperatures $\sim 2 \times 10^5$ K. The velocities associated with these energetic events are typically of the order of 400 km/s. Their role in the acceleration of the solar wind is unknown. It is interesting to note that the upward flux of mass and energy flows associated with these features is comparable to that in the solar wind. New high resolution spectroscopic measurements at chromospheric and coronal heights are required to determine the effects of these phenomena (spicules, macrospicules, and high-energy jets) on mass and energy flows in the overlying corona. It would also be interesting to determine whether or not significant numbers of energetic particles are accelerated in conjunction with these small-scale dynamical phenomena. This requires simultaneous observations by the P/OF coronal and hard X-ray instruments and the Solar Optical Telescope and/or the NRL HRTS instrument. The latter instruments could provide the chromospheric and transition region observations needed to complement the P/OF coronal and hard X-ray measurements. Figure 7 summarizes schematically some of the questions concerning the physics of small-scale phenomena which can be addressed with P/OF.

Another type of structure that may be found in coronal holes are standing shocks. Theoretical investigations of the solar wind indicate that standing shocks can develop in coronal holes under appropriate conditions depending on the geometry and momentum deposition (cf., Habbal and Rosner, 1984). The P/OF coronal instruments have the sensitivity, spatial resolution, and spectroscopic diagnostic capabilities to detect standing shocks and establishing whether such phenomena actually occur in solar coronal holes as predicted.

V. CORONAL TRANSIENTS AND MASS EJECTIONS

One of the most spectacular forms of solar activity is the coronal mass ejection, the most common type of coronal transient disturbance (see reviews by MacQueen, 1980; Sheeley et al., 1982; Wagner, 1984; Michels et al., 1984). Figure 8 shows a coronal transient photographed by the Skylab white-light coronagraph. Although we have learned a great deal about coronal transients from the extensive series of observations obtained by white-light coronagraphs on spacecraft such as Skylab, SMM, and P-78, there is much we do not know. White-light observations have provided a wealth of information about the forms, frequencies, masses, and apparent velocities of these phenomena. The rate of production of coronal transients appears to be about one to two per day (MacQueen, 1980; Sheeley et al., 1982, 1985). From measurements of the rate of outward propagation of regions of enhanced brightness, assumed to be caused by the outward flow of coronal material associated with the transient, it appears that coronal transients often exhibit acceleration out to five or six solar radii and reach velocities of 200 to 1000 km/s. Because of the presence of accelerating forces over large distances above the solar surface and frequent association of coronal transients with loop structures, proposed models for these phenomena often invoke magnetic forces (MacQueen, 1980). The amount of mass involved generally falls between 10^{15} and 10^{16} g and the total energy associated with these events is typically of the order of 10^{31} erg. For flare-associated coronal transients the amount of energy represented by the transient is comparable to or greater than that released by the flare in other forms (e.g., radiation and energetic particles).

In spite of the great progress made in the past decade, much remains unknown about the physics of coronal transients. As for other phenomena observed in the corona beyond heights where measurements by traditional spectroscopic instruments are very limited, there is insufficient empirical information about critical plasma parameters to determine, for example, the spatial and temporal variations of the temperature of the plasma in the transient and in the ambient medium. P/OF does not have these limitations. Because of its capability for acquiring much more detailed plasma diagnostic information and detecting signatures of energetic electrons and nonthermal energy releases, P/OF will provide a quantum leap in capability for addressing a wide variety of questions concerning the physics of coronal transients. With P/OF it will be possible to obtain spectroscopic signatures of shocks associated with transients (measuring, for example, temperature, density, and velocity jumps across a shock front) while simultaneously probing for energetic electrons accelerated in conjunction with the shocks. (Existing observations indicate that coronal transients are often associated with acceleration of energetic particles.) Through use of Doppler-dimming techniques it will be possible to distinguish between brightenings caused by waves and those caused by flows. It will also be possible (1) to determine the fate of cool, low-ionization state matter from eruptive prominences associated with transients, (2) to determine when and where plasma heating occurs, and (3) to obtain insights as to whether the transient is magnetically or thermally driven (see Figure 9).

There are a variety of radio transient phenomena produced by energetic electrons accelerated in or passing through the corona (see review by Pick, 1985). Through simultaneous observations with the P/OF coronal and X-ray instruments and ground-based radio telescopes, it should be possible to learn much about the acceleration of energetic electrons in the corona and their interaction with the coronal plasma. As indicated in Section II, the P/OF coronal instruments can observe the spatial and temporal variations of the coronal structure, density, and temperature of thermal electrons, and provide constraints on ion temperatures, magnetic fields, and turbulent velocities at the coronal sites of electron acceleration and along the paths where the electrons propagate. The P/OF hard X-ray instruments and ground-based radio telescopes can provide simultaneous information of the location of the acceleration site and the number, energy spectrum, and trajectory of the accelerated electrons. With such observations one can investigate, for example, the acceleration of energetic electrons in shocks associated with coronal transients and the physics of Type III bursts. Clearly, such observations offer great promise for improving our knowledge about physical processes governing the production, transport, and energy-dissipation of nonthermal electrons in low-density astrophysical plasmas.

VI. SUMMARY

The Pinhole/Occulter Facility is a powerful tool for studying the physics of the extended corona and origins of the solar wind. It offers unique, unprecedented capabilities for probing the source region of the solar wind, coronal transients, and the acceleration of energetic particles. Spectroscopic data acquired by the P/OF coronal instruments can greatly expand empirically derived information about the temperatures, densities, flow velocities, magnetic fields, and chemical abundances in the extended corona, the region where the solar wind is generated. Empirically derived knowledge of the physical conditions throughout most of this region has been limited and, hence, the processes for energy and momentum transport (other than radiation and thermal conduction) and for energy and momentum deposition have not been identified. Identification of these mechanisms in the Sun will help make possible development of realistic physical models for stellar wind acceleration in late type stars.

Improved knowledge of the physical conditions in the extended corona are required to determine the role of coronal streamers in the generation of the solar wind. Observations made with high spatial resolution are required to establish the role, if any, of the dynamical phenomena such as spicules, macrospicules, coronal "bullets," and fine-scale structures, such as polar plumes, in the generation of the solar wind. Although we have numerous white light photographs of coronal transients and mass ejections, we have little information about the physical conditions in these dynamic phenomena other than densities and velocities. The P/OF coronal instruments can greatly expand the amount and quality of the available information and thereby significantly advance our understanding of these spectacular phenomena which account for a substantial fraction, typically greater than 50%, of the energy released in energetic transient phenomena such as solar flares.

A fundamental problem in astrophysics is the development of knowledge of the processes by which energetic particles are accelerated in nature. Simultaneous solar observations of the signatures of accelerated energetic electrons and of the physical conditions and the structures of coronal sites where acceleration occurs offer exciting prospects for studying particle acceleration in an astrophysical plasma.

In short, coronal observations by the Pinhole/Occulter Facility can lead to major advances in our understanding of the physics of the only stellar corona and source of stellar wind which can be probed in detail to provide tight empirical constraints on critical physical processes involved in (1) the transport and dissipation of energy and momentum, (2) the heating and acceleration of plasma, and (3) the acceleration of energetic particles.

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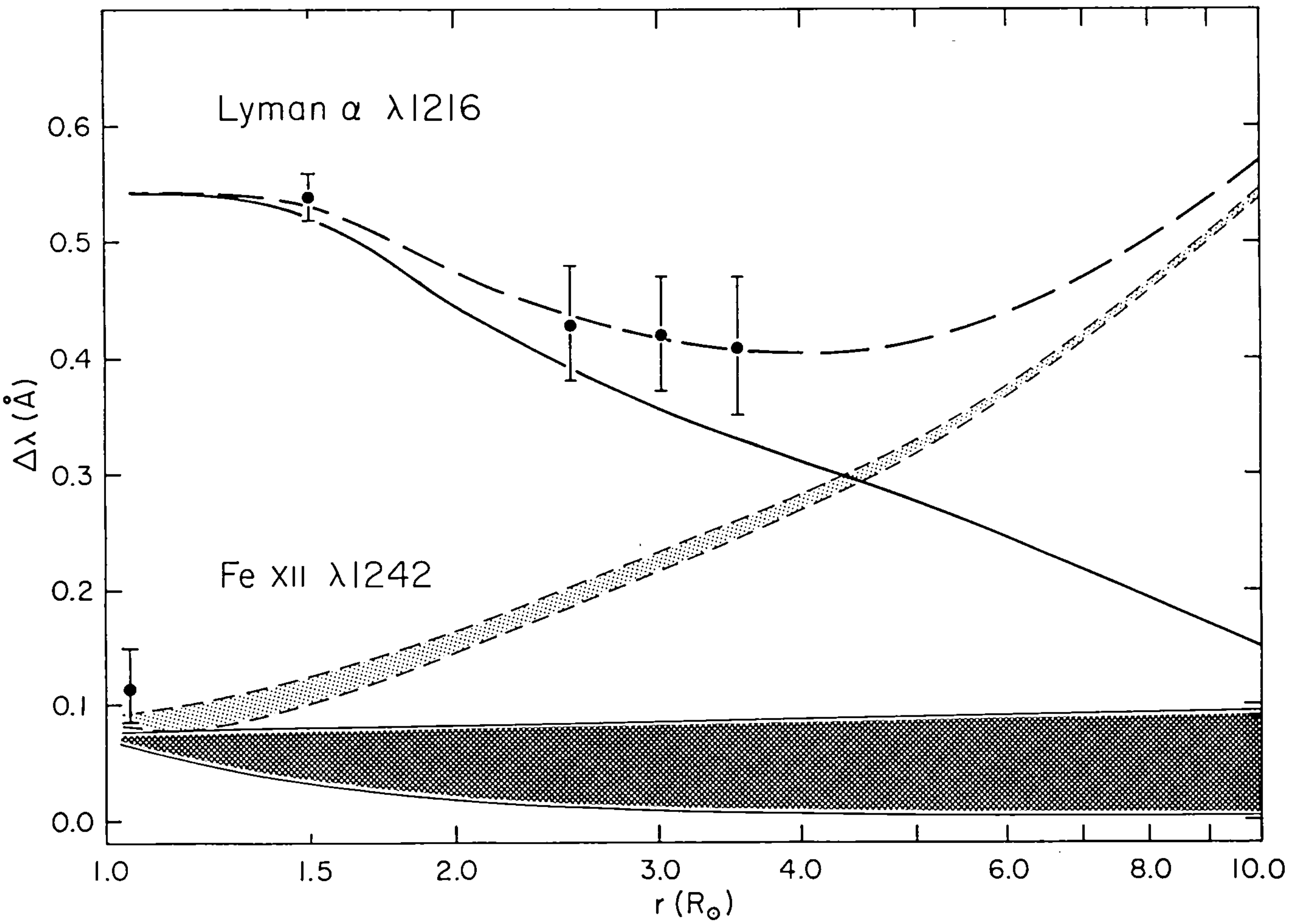

Figure 1. Spectral line widths plotted as a function of distance from Sun-center. The solid curve is for Lyman alpha widths calculated for a simple two-fluid model without any Alfvén wave flux; the dashed line is for a model with an Alfvén wave flux added to account more satisfactorily for the empirical Lyman alpha widths measured (points) in a polar region where a coronal hole was located (see Esser et al., 1985; Withbroe et al., 1985). From the results of the two-fluid model calculations one can estimate the behavior of a line from a heavy ion (e.g., Fe XII λ 1242). The figure shows how the width of this line would vary in a model with Alfvén waves present (narrow cross-hatched region) and without Alfvén waves (nearly horizontal cross-hatched area). (Because of uncertainties of the amount of electron/Fe XII and proton/Fe XII coupling, we can only calculate limits in the Fe XII widths without carrying out a detailed, multi-fluid model calculation.) The empirical Fe XII width (point) near $r = 1\ R_\odot$ is typical of measurements made in quiet coronal regions (cf., Cheng et al., 1981).

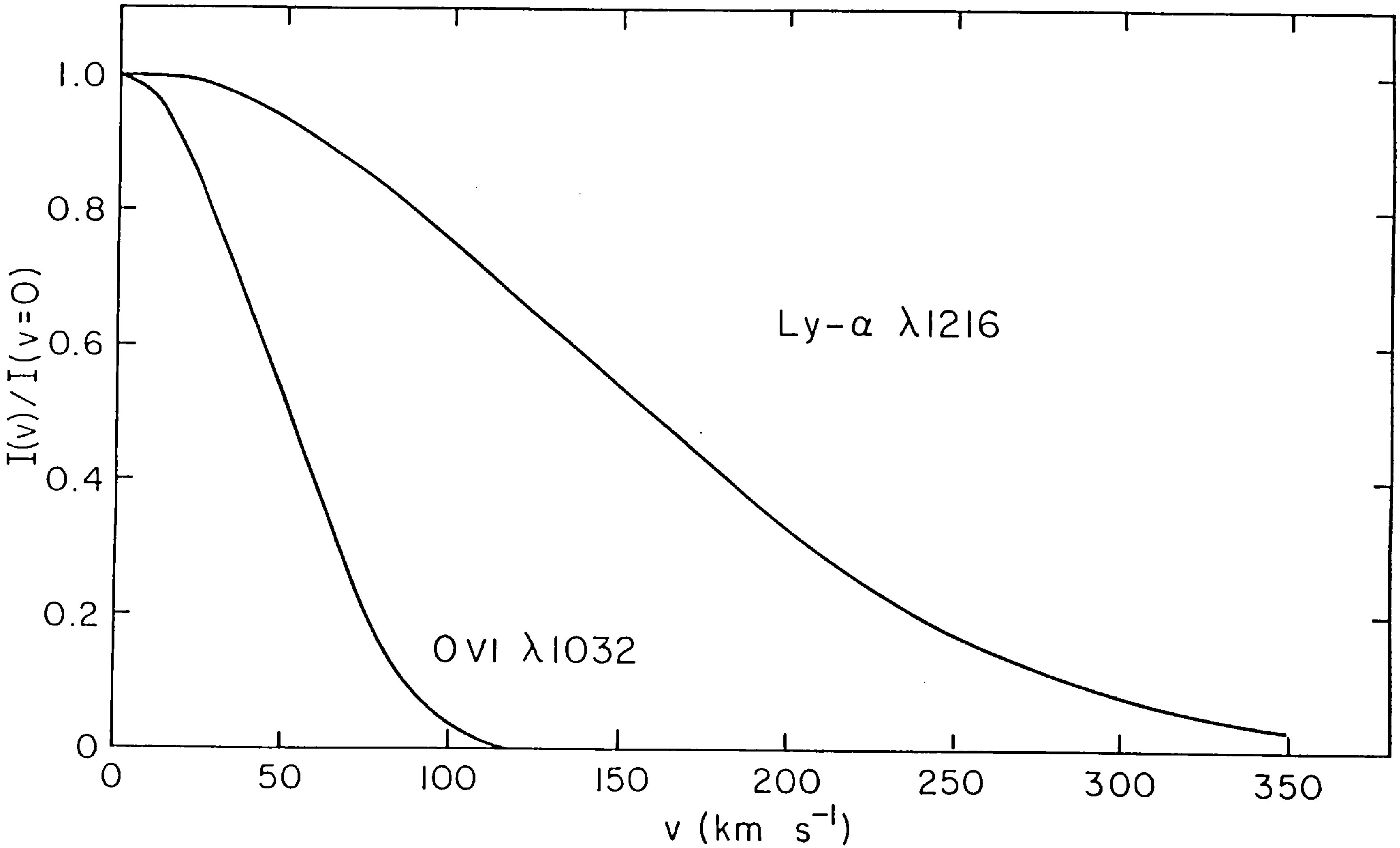

Figure 2. Doppler-dimming calculated for an isothermal corona with T = 1.5 x 10^6 K.

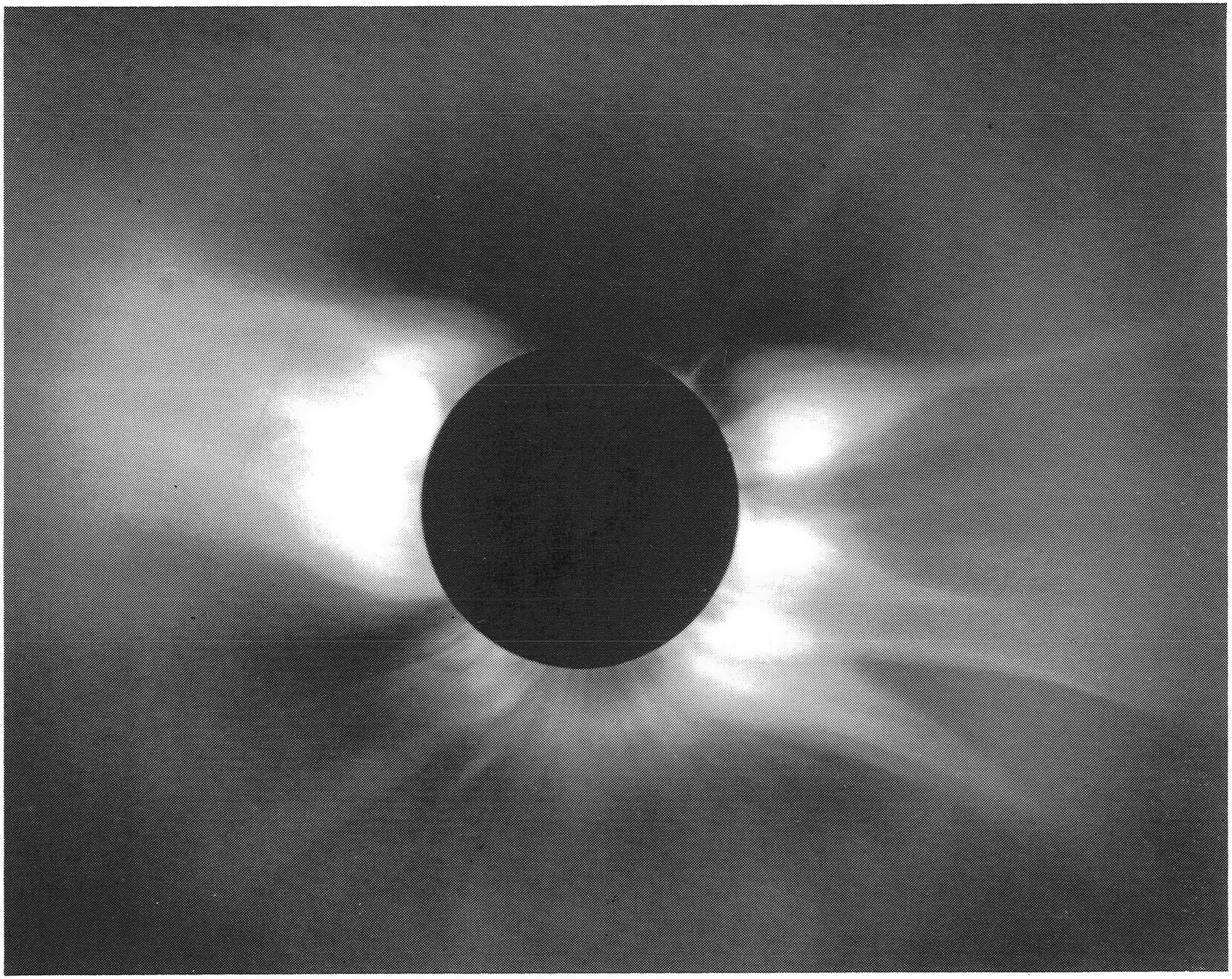

Figure 3. White-light eclipse photograph of the corona obtained at a total eclipse in 1973 (courtesy of High Altitude Observatory). A large polar coronal hole is located at the north (upper) pole.

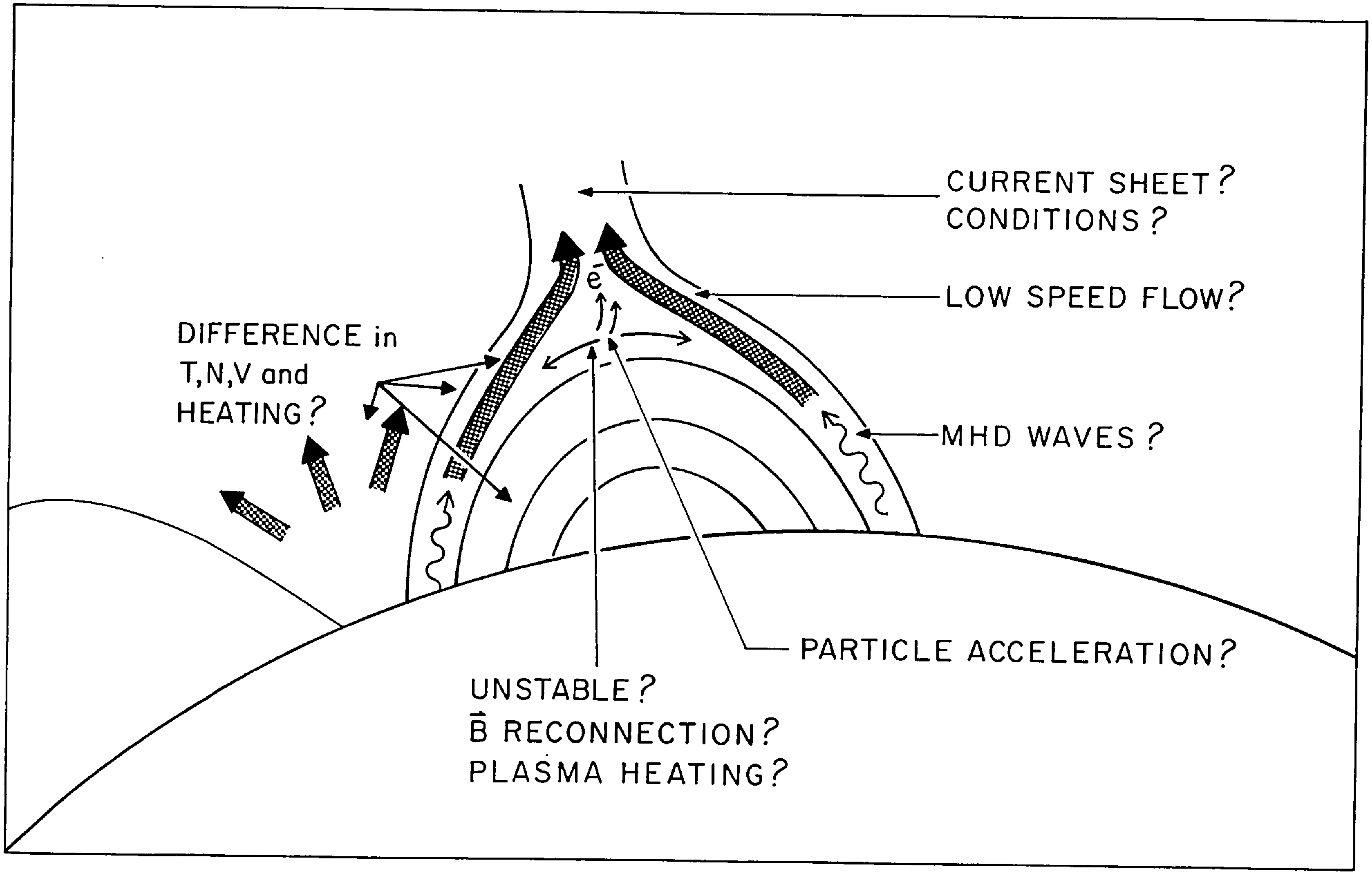

Figure 4. Schematic summarizing some questions concerning the structure and physics of streamers.

Figure 5. X-ray photograph of the solar corona acquired during Skylab (courtesy American Science and Engineering and Harvard College Observatory). Coronal holes are visible as dark areas at the north (upper) pole and near the east (left) limb.

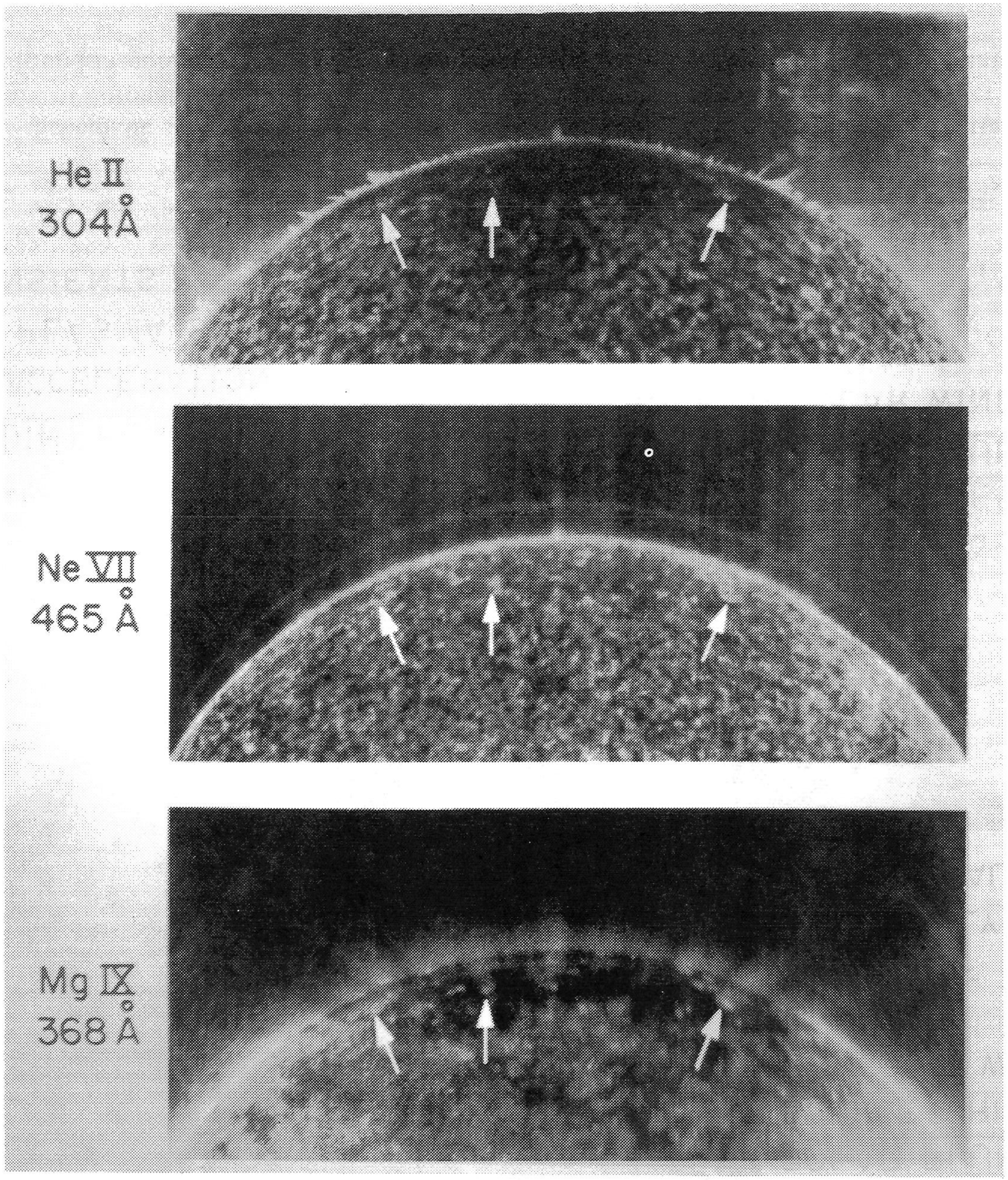

Figure 6. Spectroheliograms obtained by the NRL experiment on Skylab showing coronal bright points and overlying polar plumes (arrows) and macrospicules at the limb in a polar coronal hole.

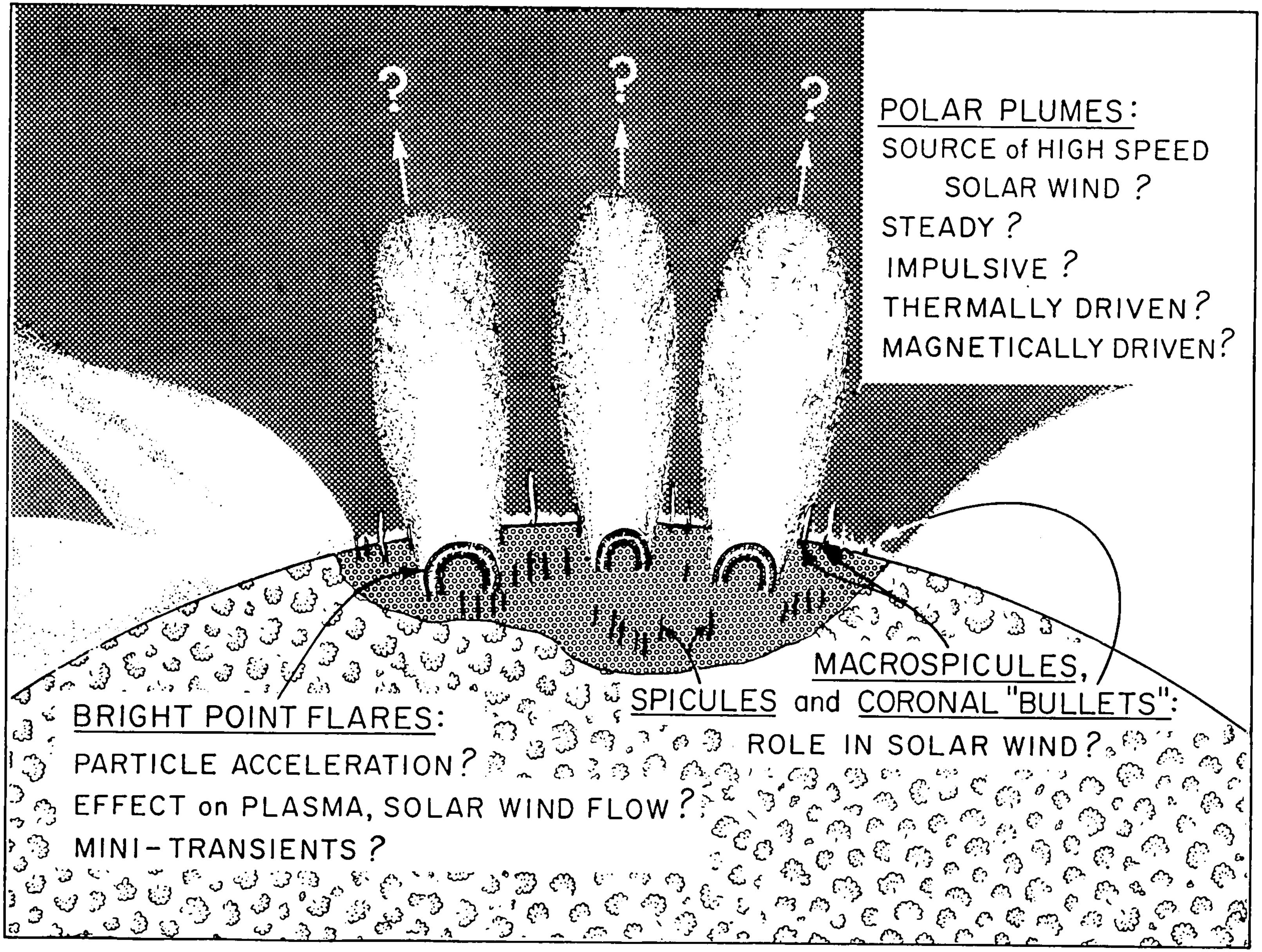

Figure 7. Schematic summarizing some questions concerning the role of small-scale structures in the physics of coronal holes. (In this illustration the plumes are drawn several times wider than usually found in nature in order to show the loop structure of the underlying bright points – compare with plumes visible in Figures 3 and 6.)

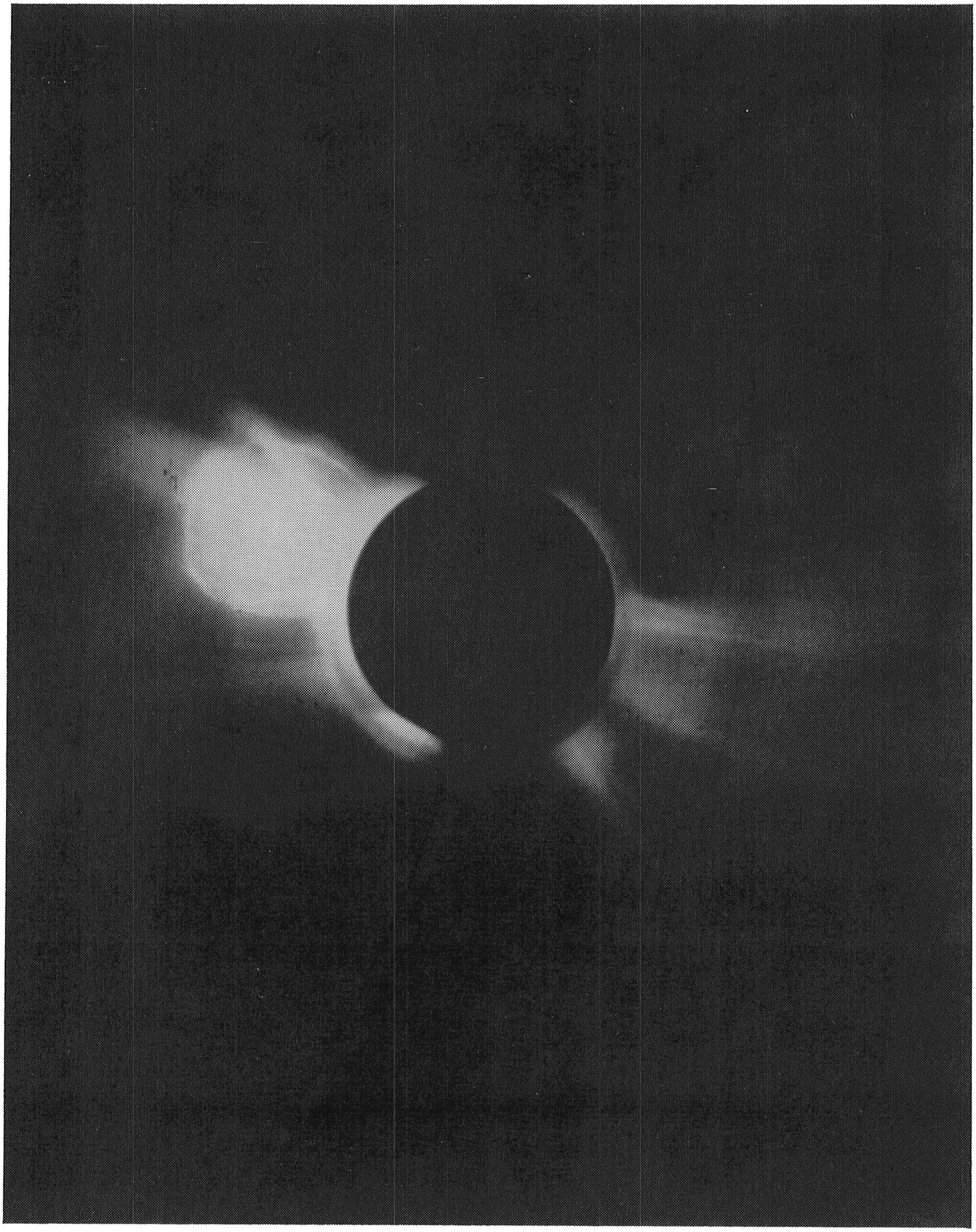

Figure 8. Coronal transient observed by HAO white-light coronagraph on Skylab.

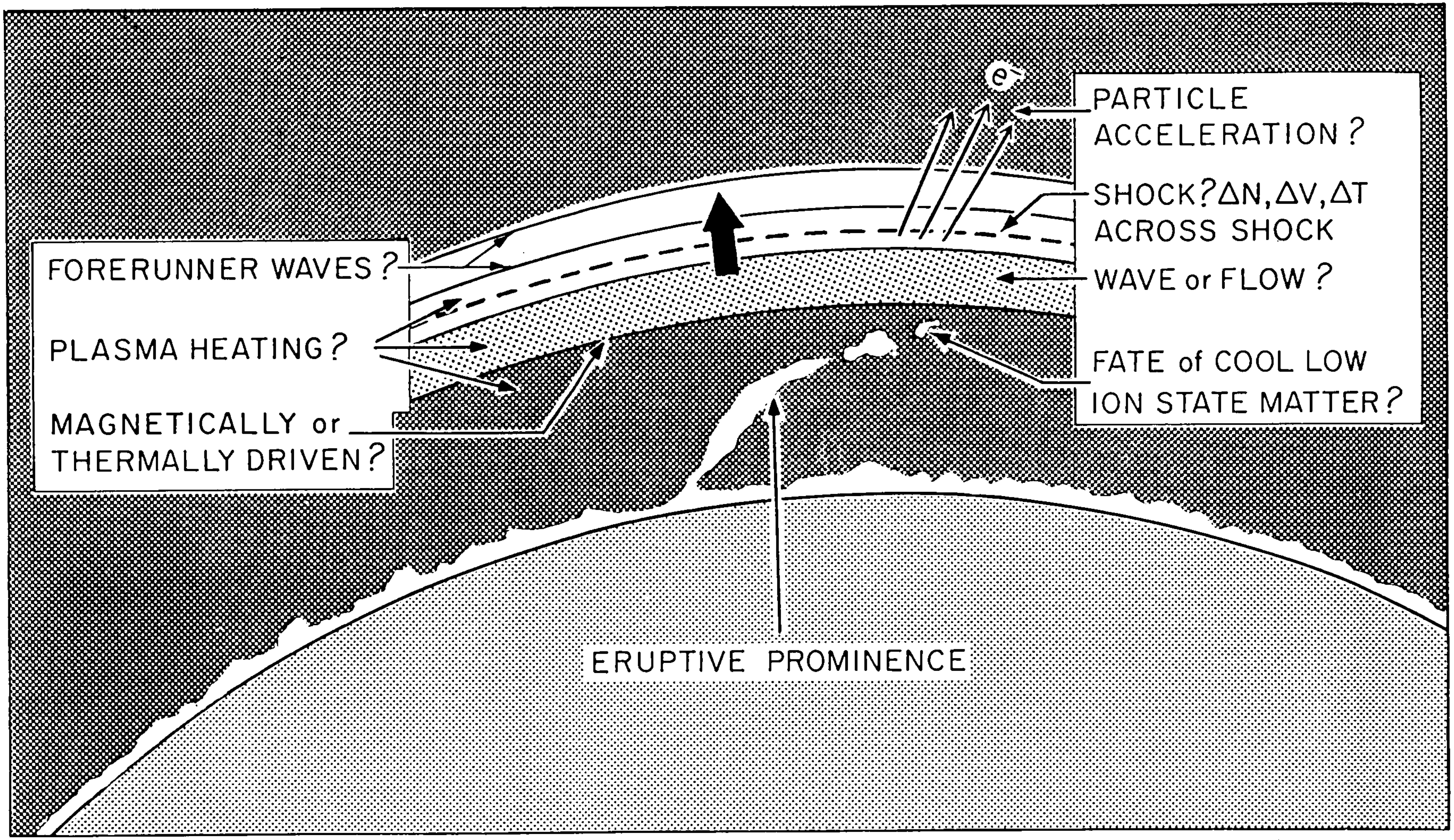

Figure 9. Schematic illustrating some problems concerning the physics of coronal transients and associated phenomena.