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THE CRIMEAN SOLAR MAXIMUM YEAR WORKSHOP

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National Aeronautics and Space Administration
Grant NGL 05-020-272

National Science Foundation
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SUIPR Report No. 841
May 1980

INSTITUTE FOR PLASMA RESEARCH
STANFORD UNIVERSITY, STANFORD, CALIFORNIA

THE CRIMEAN SOLAR MAXIMUM YEAR WORKSHOP

Selected Reports
from the Working Groups
of the Solar Maximum Year Workshop
Held at the
Crimean Astrophysical Observatory
Nauchny, Crimea, USSR

24 - 27 March 1981

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PREFACE

We were recently privileged to take part in the Solar Maximum Year Workshop held at the Crimean Astrophysical Observatory, Nauchny, Crimea, USSR, from 24-27 March, 1981. Approximately 150 scientists attended this workshop, with naturally, a strong delegation from Soviet institutions which afforded a rare opportunity for us to discuss problems "head-to-head" with these scientists, rather than through the infinitely slower process of scientific publication and response. The participants were divided into several groups, some dealing with theoretical aspects of the flare phenomenon and its consequences for interplanetary space, and some with detailed observations of particular events occurring in pre-selected "action intervals". This report is a summary of the proceedings of three of these working groups. These three were the largest, and also provided a focal point for observers to discuss their data with the theoreticians which, after all, is what science is all about. We thus feel that, although not comprehensive, this report provides an adequate summary of the workshop proceedings for anyone interested in finding out what was discussed there.

Because of the fact that each of us spent a great deal of time organizing, contributing to, and summarizing the discussions of, our own respective groups, and in deference to the strong desire of all of us to produce a finished article within a reasonable time span, we have made no attempt to synthesize what follows into a single coherent report. We crave the reader's indulgence in this matter, and trust that, despite this presentation, he does not come away with the impression that there were in fact three separate "submeetings" at the Crimea; this was most definitely not the case.

Surrounding the various group sessions were a number of plenary sessions in which papers of general interest were presented, both invited and contributed. The programs of these plenary sessions are attached as Appendix A. A list of participants is affixed as Appendix B, and a list of the various papers and posters presented within the working groups forms Appendix C.

We would like to thank all the meeting participants for providing the material presented in this report and the staff of the Crimean Astrophysical observatory and the members of the USSR Academy of Sciences for making the meeting as profitable as it turned out to be. In addition, A.G.E. would like to acknowledge support from grant NASA NGL 05-020-272 and S.T.W. from NSF grant ATM-77-22482.

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I. SERF Theory Group

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The main purpose of this group was to consider problems associated with the transport of energy, and acceleration of charged particles, in solar flares, and to critically compare existing theories with observation with a view to either discriminating between rival theories (such as whether hard X-rays are emitted by thermal or non-thermal bremsstrahlung), constraining existing theories (such as deduction of the number of non-thermal electrons present from spectroscopic diagnostics in the soft X-ray part of the spectrum), or suggesting new theories (such as attempting to explain the observed spatial structure of microwave emission relative to Hα).

The discussion in the group was generally very lively, and it is largely for this reason (and also because of my meager understanding of languages other than English with a Scottish-American accent) that it is impossible to adequately credit individuals for their contributions from the floor; I hope that I can nevertheless sum up the 'flavor' of the group sessions in what follows, and I apologize to any individual whose contribution I either minimize or misinterpret in the process.

The group sessions divided naturally into a number of separate topics, summarized in Table 1.1. Also shown in this table is the name of the "moderator" of the discussion under each topic; these "moderators" opened each discussion with a short (5-10 minute) presentation, the object of which was not so much to provide a concise review of the subject but to pose questions to be considered in the informal discussion to follow. In the remainder of this report, I will consider each of the topics of Table 1.1 in turn.

Table 1.1

Topics Discussed by SERF Theory Group

Topic	"Moderator"
Primary Energy Release and Acceleration of Particles	Dr. B. V. Somov (Lebedev Physical Institute)
Stark Broadening Diagnostics	Dr. V. M. Tomozov (SibIZMIR, Irkutsk)
Mechanisms of Chromospheric Heating and Gasdynamics of Flare Chromospheres	Dr. B. V. Somov (Lebedev Physical Institute)
Temperature Minimum Structure and Heating During Flares	Dr. E. E. Dubov (Soviet Geophysical Committee)
High Spatial Resolution Radio Observations and Their Implications	Dr. M. R. Kundu (University of Maryland)
Hard X-Ray Burst Emission	Dr. A. G. Emslie (Stanford University)
Soft X-Ray Diagnostics	Dr. A. M. Urnov (Lebedev Physical Institute)

1.a Primary Energy Release and Acceleration of Particles

Dr. Somov presented a review of current theory of neutral sheet formation and energy release (see Appendix D). A point he strongly emphasized is that, due to the formation, through radiative instability, of cold dense filaments in the sheet, a full three-dimensional treatment of the reconnection process is necessary. He also showed that strong electric fields, which can effectively accelerate particles to the tens of keV necessary for hard X-ray emission, are readily produced inside such a neutral sheet configuration.

Various papers were then presented by Russian authors on mechanisms for acceleration of particles. I feel, however, that I cannot do these papers justice in the present volume. Hopefully, this embarrassing gap will be filled by the meeting proceedings to be published later this year by the USSR Academy of Sciences.

1.b Stark Broadening Diagnostics

Much work has been and is being carried out in Soviet institutions relating to the Stark broadening of spectral lines due to turbulent electric fields substantially greater than the Holtzmark field. Dr. Oks presented observational results of broadening in Balmer lines (Figure 1.1), which he claims is due to the presence of low-frequency plasma turbulence at a level of E = 5 statvolt cm^{-1}. The interesting part of this observation is the densities at which this level of turbulence is inferred, viz. ≈ 10^{13} cm^{-3}.

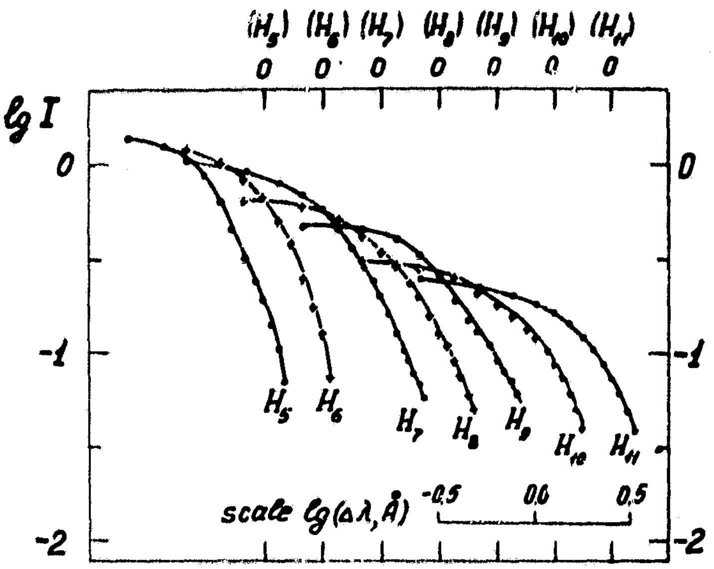

Figure 1.1. Profiles of Balmer series lines observed during a flare. The variation of line width with upper level principal quantum number allows estimation of the magnitude of any turbulent electric field present. (Figure courtesy of Dr. E. A. Oks.)

If this is indeed, as Dr. Oks suggests, in the flare chromosphere, then this is surely evidence for the presence of electron beams. However, such high densities are not incompatible with coronal densities during flares, especially when one considers the possible formation of cold dense filaments during the reconnection process (cf. Section 1.a). Future observations of Stark broadening in lines are thus strongly encouraged; for example, it was suggested that simultaneous measurements of line profiles in both Q and U polarizations would be useful. Candidate lines for measurement are Hδ, if possible simultaneous with $H\beta$. Also, an extension of existing spectrosopic Stark broadening diagnostics to cover lines formed at coronal temperatures was urged.

1.c Solar Flare Chromospheres - Heating and Gasdynamics

The structure of the chromosphere is a very detailed diagnostic of energy transport processes in solar flares. In order to fully understand this structure and its spectroscopic signature, we must first identify the various processes which contribute to chromospheric heating at various levels. Figure 1.2 shows these mechanisms in schematic form, ranging from non-thermal electron bombardment, which heats most of the upper chromosphere (e.g. Brown 1973), through soft X-ray radiation which heats the lower chromosphere (e.g. Somov 1975), to strong lines in the EUV, which heat the deep chromosphere around the temperature minimum region (cf. Emslie and Machado 1979).

To a certain extent, some of these mechanisms may be considered "primary" and some "secondary." For example, enhancements in both soft X-ray and thermal conduction fluxes into the chromosphere are caused by the formation of a very hot corona, energized either by the primary energy release itself or by the passage of a non-thermal electron beam (and its associated reverse current) through it (Emslie 1980). It is thus important, in modeling the solar chromosphere during flares, not to isolate it from its surroundings: a global modeling of the entire atmosphere is necessary in order that the various particle and radiation fields shown in Figure 1.2 be properly related to each other. (For more details, the reader is referred to the paper by Emslie, Brown, and Machado 1981, which considers in some detail the model discrepancies produced by considering the radiation field only locally, and not in the more correct global framework.) The construction of this composite particle-plus-radiation field is clearly only possible from combining many obervations at different wavelengths, such as were carried out during the Solar Maximum Year observing program.

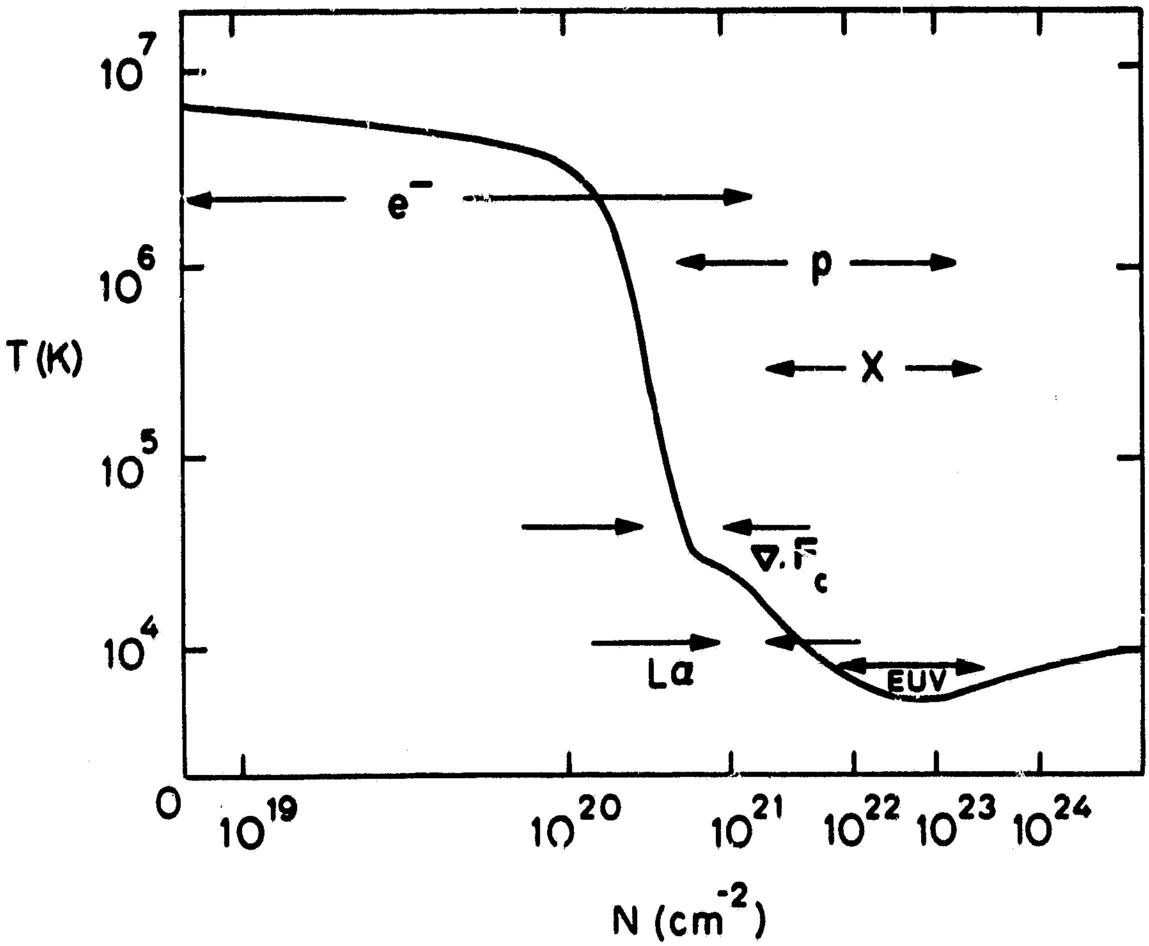

Figure 1.2. Schematic flare model atmosphere showing the ranges over which different heating mechanisms are principally effective. (e^- = non-thermal electron bombardment, p = proton bombardment, X = soft X-ray irradiation, $\tilde{\nabla}\cdot\tilde{F}_c$ = conductive heating, Lα = Lα backwarming, EUV = heating by EUV lines and continua).

An interesting effect caused by the variety of chromospheric heating mechanisms is shown in Figure 1.3, after a presentation by Dr. Somov (Appendix D). Here it is clearly shown that electrons, which move only along magnetic field lines, have their heating power concentrated in the area at the footpoints of the flaring loop, while soft X-ray photons, which of course can propagate in any direction relative to the field lines, spread their heating power over a much larger "halo" surrounding the electron-heated flare kernel. The resulting lateral variation of chromosheric heating rate gives rise

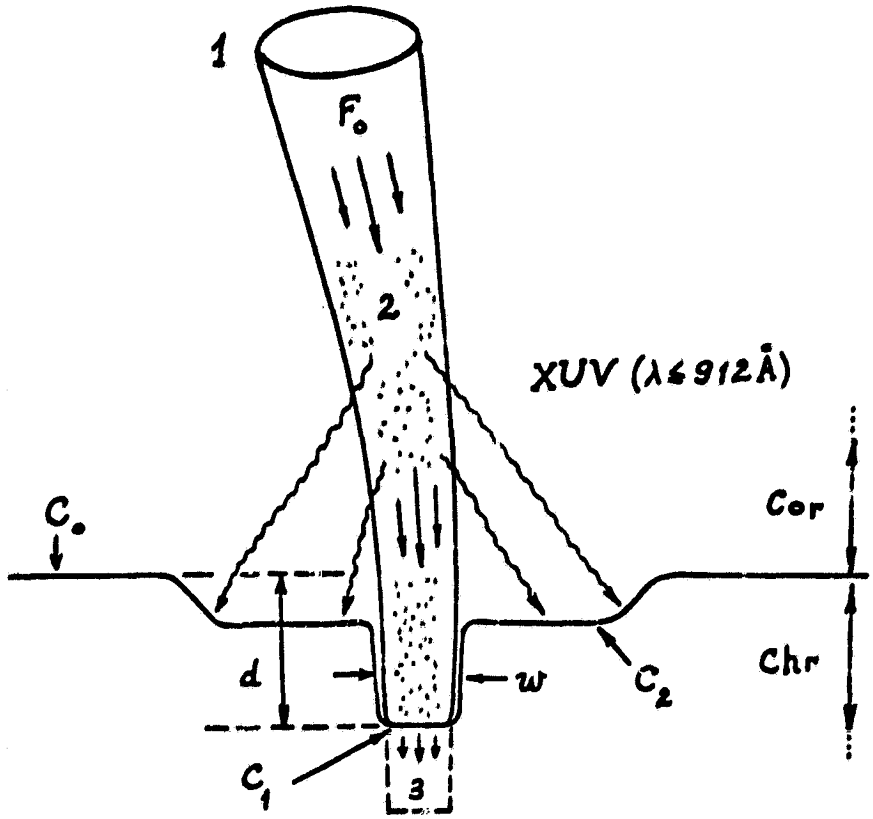

Figure 1.3. Illustration of lateral variation of transition zone depth with position relative to the flare loop. C_1 is caused by strong heating due to non-thermal electron bombardment, while C_2 results from much weaker heating by XUV irradiation. Note that the ratio of depth (d) to width (w) of the chromospheric EUV source may help determine the relative effectiveness of different chromospheric heating mechanisms; values of the ratio d/w may be inferred from EUV measurements (Donnelly and Kane 1978). (Figure courtesy of Dr. B. V. Somov; see also Figure 5 of Appendix D.)

to a transition zone structure which deviates from a plane-parallel structure, as shown; detailed spatially resolved measurements of EUV lines from this transition zone material may thus help to ascertain the relative importance of electron and soft X-ray heating in the chromospheric energy balance.

There was also a great deal of discussion relating to the gasdynamics of solar flare material. Following on from the original work by Kostyuk and Pikel'ner (1975), there have been many detailed calculations made by Russian authors of the hydrodynamic response on the solar atmosphere to an energy input in the form of a beam of non-thermal electrons. Somov, Syrovatskii, and Spektor (1981) have carried out calculations on the hydrodynamics of the high temperature component of the flare plasma, while Livshits (1981, unpublished) presented results on the dynamic response of the cooler, chromospheric material (Figure 1.4).

An extremely interesting feature of these theoretical treatments, from the observational point of view, is the ubiquitous strong downward motion of both high and low temperature material, which is initiated by the onset of impulsive heating and apparently persists for some seconds thereafter. Such a downward velocity field should evidence itself in fairly large redshifts of spectral lines emitted by the downflowing material; while redshifts in Hα are well established (see, e.g., Svestka 1976), spectral shifts in soft X-ray lines, formed at temperatures around 10^7 K, are not always towards the red (Korneev et al. 1980). Presumably this implies that the downward motion of material persists for only a few seconds, after which the free expansion of the heated material and the process of chromospheric "evaporation" (Antiochos and Sturrock 1978) starts to dominate, producing line blueshifts. It is therefore important to observe doppler shifts of soft X-ray lines with as high a time resolution as possible near the impulsive phase of the flare with a view to testing the theoretical gasdynamic calculations.

An interesting result of the gasdynamic calculations is that the time-scales for temperature rise (due to heating) and density fall (due to hydrodynamic expansion of the heated material) are very different, the former being much smaller, in general, than the latter. It is thus easily shown (Emslie 1981) that the gas pressure in the flaring region becomes very large, and may even reach a value for which the assumpton of an infinitely strong confining magnetic field (enabling one-dimensional calculations to be carried out--see Somov, Syrovatskii, and Spektor 1981) is no longer valid. In such a situation the hitherto isolated magnetic loops, which form the complex of loops frequently oberved in active regions, become free to interact via expansion driven by this large gas pressure (Figure 1.5).

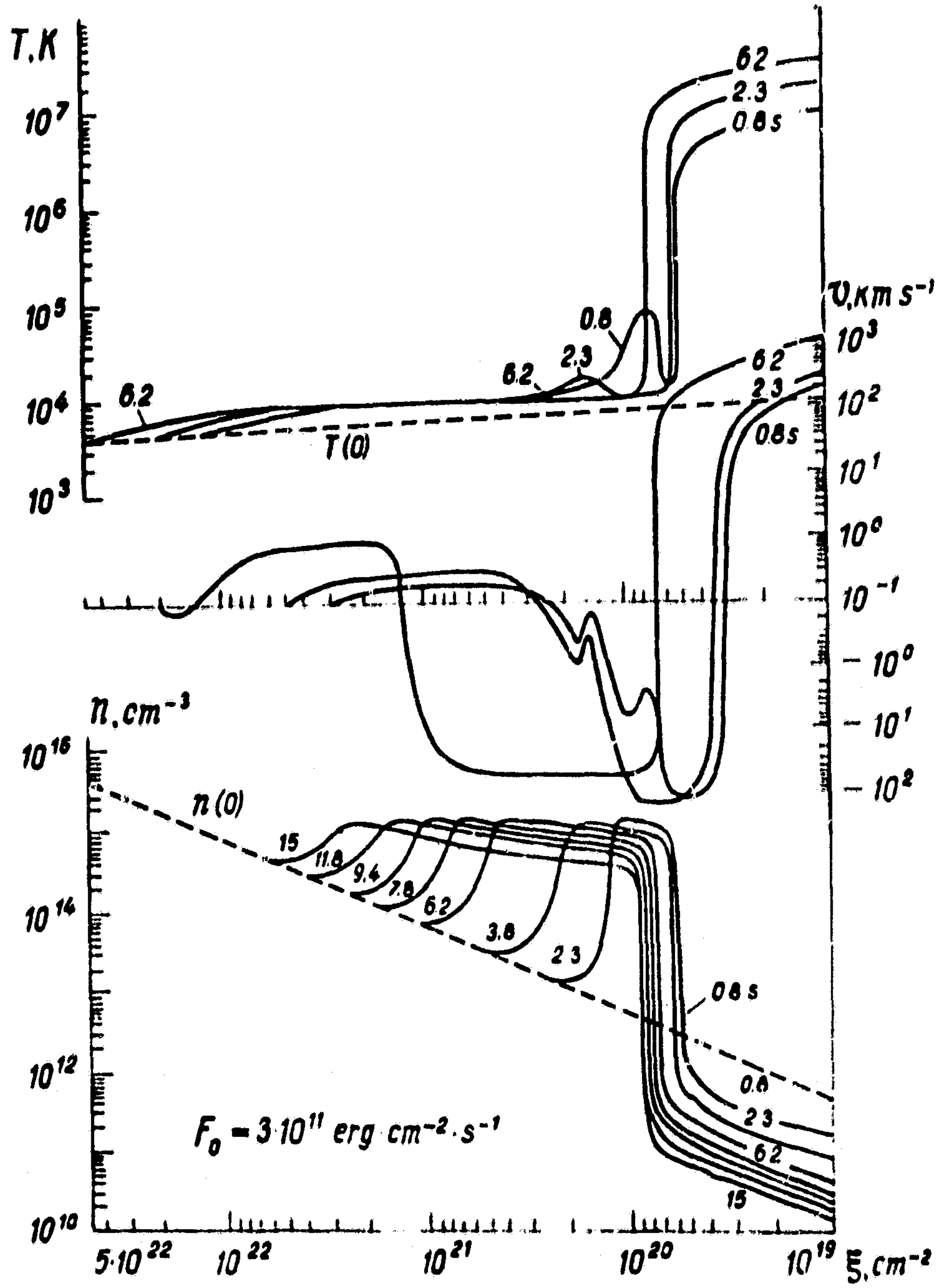

Figure 1.4. Results of flare gasdynamic calculations by M. A. Livshits. The electron temperature, velocity (positive = downward), and density structures of the atmosphere are shown for the times (in seconds after the initiation of electron heating with flux shown) as indicated on the curves.

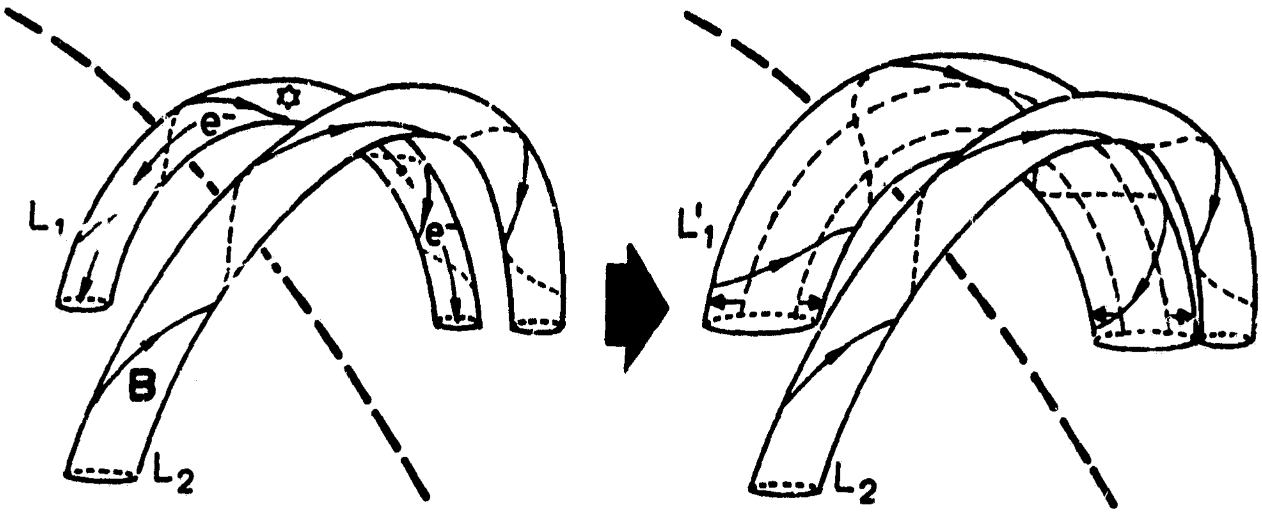

Figure 1.5. Due to the large increase in pressure at chromospheric levels as a result of the strong impulsive flare heating (see Figure 1.4; Somov et al. 1981), the magnetic field lines of flaring loop L_1 may be driven sideways and may interact with field lines in quiescent loop L_2. This "domino" process may be responsible for the "Elementary Flare Burst" structure observed in many hard X-ray events.

This model, if applied to hard X-ray burst emission (Emslie 1981) can apparently satisfactorily account for the detailed time-structure of hard X-ray bursts, i.e. for the phenomenon of Elementary Flare Bursts (EFB's), and also satisfactorily explains the different properties of different EFB's in the same event (de Jager and de Jonge 1978; Karpen, Crannell, and Frost 1979), since each burst originates in a different loop in the flare region.

A possible diagnostic for chromospheric heating by either soft X-ray irradiation or electron bombardment was presented by Dr. Hénoux. He explained that collisional excitation of the Hα line results in a finite linear polarization in this line. Further, since the exciting electrons are almost parallel to the field lines in the case of direct electron heating, while the (photo)electrons are almost perpendicular to the field in the case of soft X-ray heating, determination of the plane in which the Hα polarization vector lies can in principle distinguish between the two mechanisms.

1.d <u>Structure and Heating of the Temperature Minimum in Flares</u>

There is considerable evidence that the deep chromospheric regions around the temperature minimum are substantially heated during flares (e.g., Machado, Emslie and Brown 1978; Cook and Brueckner 1979). It also appears difficult to account for these strong (≈ 200 K) temperature enhancements on the basis of energy transport by either particles or radiation (Machado, Emslie and Brown 1978; Emslie and Machado 1979). There was some discussion in the working group as to (a) the reality of the inferred temperature enhancements, and (b) possible ways of creating them.

Dr. Dubov suggested that a flux of ionizing (e.g., EUV) radiation impingent on the temperature minimum layers could, through alteration of the ionization balance of the Ca ion, significantly reduce the ability of the temperature minimum levels to radiate energy (the Ca II K-line is a dominant source of radiative energy loss at these levels; see Machado et al. 1980). Thus, if we assume that the energy input to the temperature minimum levels from below is substantially unaffected (or even increased) during the flare, the temperature minimum layers of the flare will undergo a temperature enhancement in order to preserve energy balance. Unfortunately, Dr. Dubov has not carried out a quantitative analysis of his proposed mechanism.

Dr. Hénoux contested Dr. Dubov's results, contending that any reasonable flux of EUV radiation would do little to affect the radiative ability of the temperature minimum layers. He did concede, however, that such a flux of radiation could significantly affect the ionization balance in the Si ion, and so produce anomalous spectroscopic effects in the Si continuum, which might be falsely interpreted as being due to a temperature enhancement in the temperature minimum layers (Hénoux and Machado 1981). Dr. Hénoux recommended that observations be restricted to strong lines, such as Mg II and Ca II, which are not so strongly affected by conditions exterior to the temperature minimum itself.

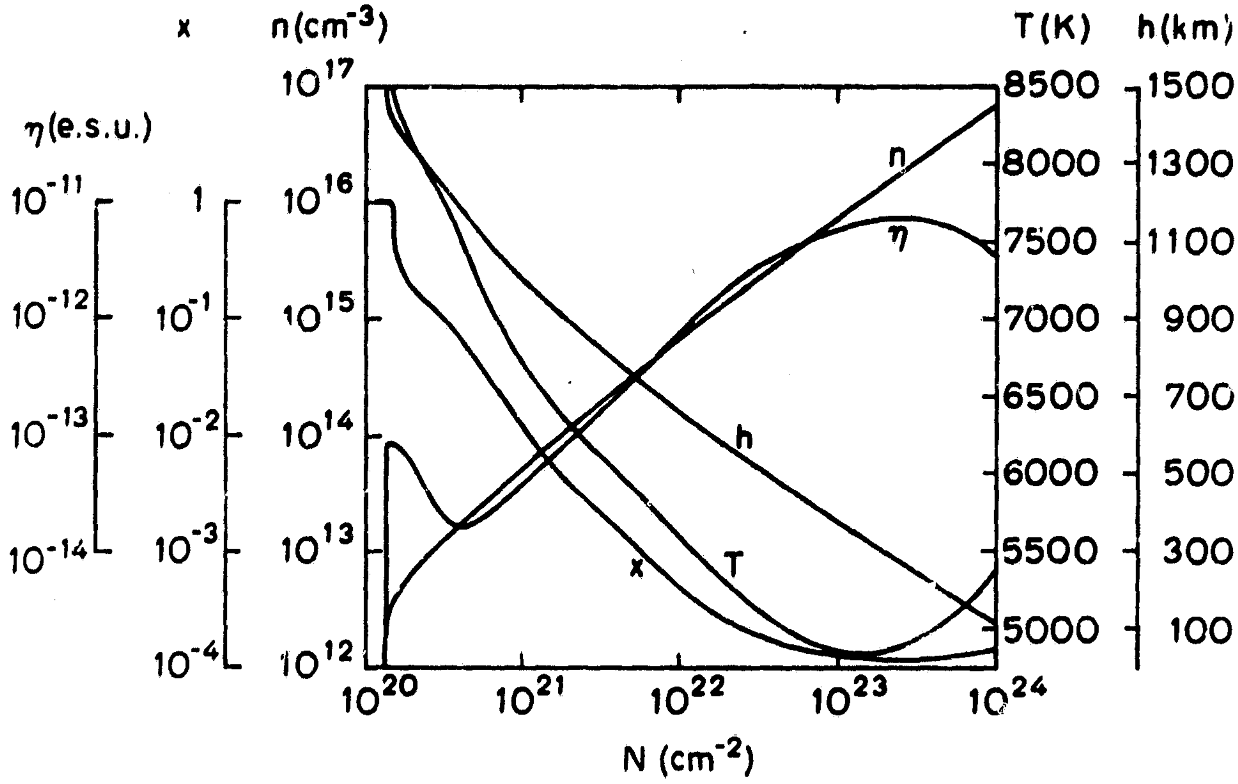

Figure 1.6. Variation of temperature (T), density (n), ionization level (x), height (h) and resistivity (η) with column depth N in the empirical model atmosphere F1 of Machado et al. (1980). Note the large resistivity at depths corresponding to the temperature minimum; this resistivity is principally due to electron-neutral collisions.

Notwithstanding the above discussion, it nevertheless still appears that a source for temperature minimum heating must be found. I presented results showing that magnetohydrodynamic waves, excited by the primary energy release in the corona, could propagate relatively undamped through the corona and much of the chromosphere, but would damp heavily at the temperature minimum layers, due to the enhanced resistivity there (see Figure 1.6). I showed that this mechanism could indeed account for the observations at temperature minimum levels (Emslie and Sturrock 1981).

1.e High Resolution Radio Observations and Their Implications

There has recently been an enormous increase in our knowledge of the characteristics of radio emission from flares, especially through the sub-arc second resolution images at centimeter wavelengths obtained by the Very Large Array (VLA) interferometer. Dr. Kundu presented a summary set of obervations using this instrument; two particular sets of observations merit mention here.

First, Dr. Kundu presented radio polarization maps of an event on May 14, 1980, showing a distinct quadrupole configuration. If one accepts the premise that there is a one-to-one correspondence between radio polarization direction (left or right) and magnetic field direction, then this implies a magnetic field topology which is also a quadrupole. After a few minutes, this quadrupole evolved into a simple dipole pattern, and there was a burst of energy observed near to the center of the original quadrupole pattern. Dr. Kundu interpreted this as being due to the merging and subsequent reconnection of two flux tubes with oppositely directed fields, such as in the flare model of Gold and Hoyle (1960--see Figure 1.7). There was much discussion about the validity and uniqueness of this conclusion, but nevertheless it appears that such radio polarization maps are a powerful tool in following the evolution of magnetic field in a flare region.

Also shown were centimeter-wave maps showing contours of radio intensity. In many cases it is found that the peak radio intensity originates in a region whose projection on the solar disk lies between the Hα footpoints and so presumably lies near the top of the flaring loop. It is possible that this is a directional effect, since synchrotron radiation is emitted preferentially perpendicular to the field lines, so that for a disk flare this implies deficiency in emission at the footpoints (where one is looking essentially along the magnetic field), compared to the top (where one is primarily looking perpendicular to the field lines). However this explanation is not yet confirmed, raising the interesting alternative of how electrons with energies of many hundred keV, which are responsible for the microwave emission, are confined at the top of a coronal loop. This matter was not resolved, but there promises to be a great deal of theoretical work devoted to this problem in the near future.

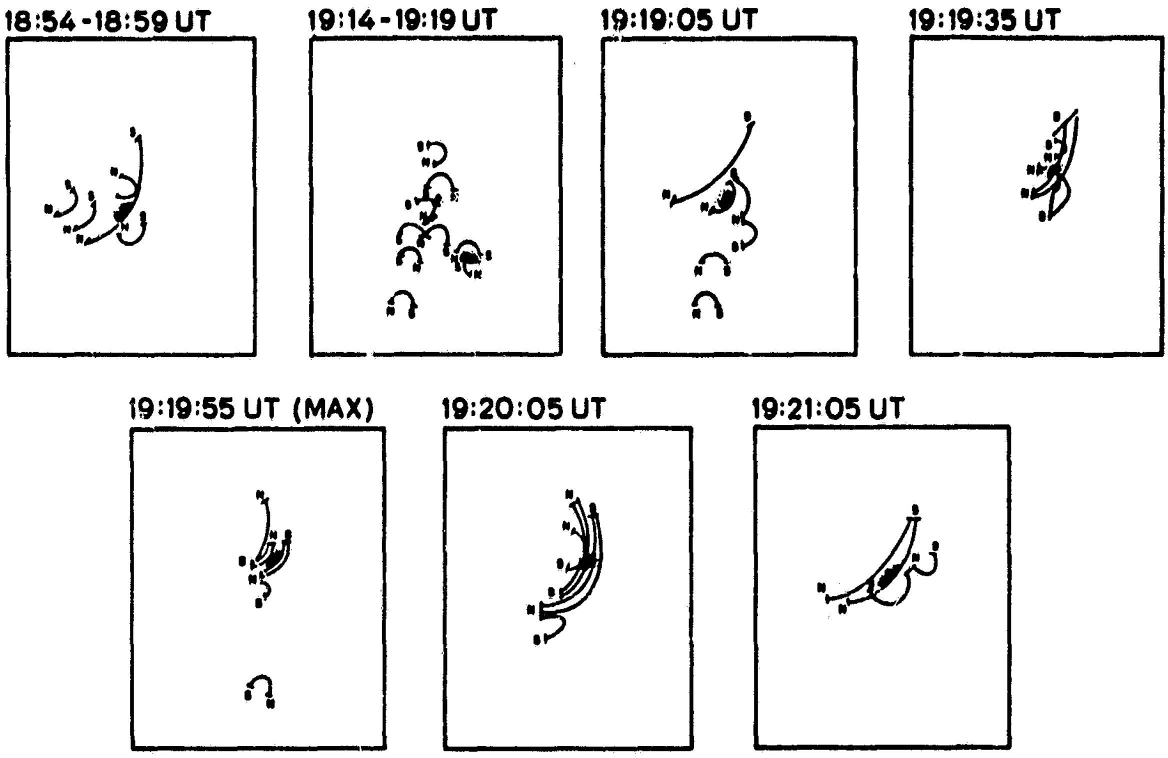

Figure 1.7. Schematic representation of the magnetic field topology of an active region number McMath 16839 on May 14, 1980 at the times shown. Note the quadrupole configuration at 19:20:05 UT, which evolves into a simple dipole 1 minute later with a release of energy at the center of the quadrupole pattern; this behavior is similar to that in the flare model of Gold and Hoyle (1960). This figure was constructed by Dr. M. R. Kundu using the sense of 6 cm radio polarization to infer the magnetic field direction; shaded areas correspond to strong radio emission.

1.f Hard X-Ray Burst Emission in Flares

A current strong controversy is whether hard X-ray emission in solar flares is due to bremsstrahlung from a beam of non-thermal electrons, or due to thermal bremsstrahlung from a confined mass of hot plasma. Appendix E briefly describes the two classes of model, and also suggests possible ways of discriminating between the two models observationally.

Dr. Simnett presented results from the Solar Maximum Mission Hard X-Ray Imaging Spectrometer, showing that in many events the hard X-ray emission in the range 16 keV $\lesssim \varepsilon \lesssim$ 30 keV is concentrated near the Hα footpoints at the impulsive onset of the flare, later spreading to fill the region between these footpoints (see Hoyng et al. 1981). According to the simple pictures outlined in Appendix E, this seems to favor a non-thermal interpretation of the hard X-ray burst, with the subsequent spread in emission being due to an "evaporation" (Antiochos and Sturrock 1978) of material into the corona (cf. Figure 3b of Appendix E). However, it was pointed out that the energy range observed by the Solar Maximum Mission instrument is quite low; further, it is by no means unambiguously resolved that the coronal emission in the events in question is so low as to be inconsistent with a thermal interpretation of the hard X-ray burst.

The existence of simple hard X-ray burst structures with timescales of the order of a few seconds (the so-called "Elementary Flare Bursts") has already been discussed in Section 1.c, where a possible model for their occurrence was outlined. However, hard X-ray bursts also show time structure on much shorter time scales $\gtrsim$ 0.1 s (Orwig, Frost, and Dennis 1981), and there was some discussion as to the origin of these oscillations. It was generally agreed that they must be due to some intrinsic process in a given flaring region, since the coherency time for widely separated regions is much longer than the timescale of the oscillations. Possible plasma modulation processes, such as betatron acceleration, were discussed, but no firm conclusions were reached.

1.g Soft X-Ray Diagnostics

Dr. Urnov presented a talk which covered a wide range of possible ways in which spectroscopic analysis of line emission in the soft X-ray range of the spectrum could be used to diagnose the presence of non-thermal electron beams. For example, analysis of the relative intensities of resonance, satellite, and intercombination lines in the spectra of He-like ions, such as Fe XXV, allows one to determine both electron and ionization temperatures. By using different pairs of lines many such temperatures can be obtained; the degree to which these various inferred temperatures agree or differ can be used to infer the shape of the electron distribution function which is exciting the line. Dr. Urnov quoted results on analysis of such lines in a particular flare event, in which he inferred a non-thermal population of some 1%;

apparently a multi-temperature thermal distribution, with a reasonable emission measure versus temperature dependence, can be ruled out by the data.

Dr. Urnov also pointed out the usefulness of line polarization measurements. For example, the ratio of linear polarizations in the intercombination ('y') and resonance ('w') lines of He-like ions is a sensitive indicator of the low energy cutoff in the non-thermal part of the electron velocity distribution; further, this ratio is insensitive to the spectral index of the non-thermal part of the distribution. The use of a rotating Bragg crystal spectrometer, such as that on the Japanese ASTRO-A satellite, was discussed in this context. Finally, it was noted that line polarization measurements are not confused by the presence of photospheric backscatter (as is the case for continuum polarization measurements); this is because of the wavelength shift of the backscattered line.

The process of $K\alpha$ emission was also discussed. In many events, the peak of the Fe $K\alpha$ intensity coincides well with the peak in the soft X-ray emission measure, indicating a fluorescence mechanism. However, in at least one event observed by the Solar Maximum Mission (Culhane et al. 1981), and in several events observed by Professor Mandel'stam's group, the $K\alpha$ emission peaks simultaneously with the hard X-ray emission, and well before the soft X-ray intensity in other lines, such as Ca XIX, peaks. This apparently rules out a fluorescence mechanism, and is strongly suggestive of direct excitation by electron beams (Culhane et al. 1981). The importance of such observations as a diagnostic was stressed; also it was noted that $K\beta$ diagnostics are in many ways more reliable, since the components of the line (due to various ionization stages of Fe) are wider spaced and so more easily resolve spectroscopically into high and low temperature components.

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II. FBS Working Groups

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The Crimean SMY Workshop followed within 5 weeks the FBS Workshop held at NASA's Goddard Space Flight Center. Both occasions provided observers with unique opportunities to compare sets of data, to find where and how data could be acquired to close critical time gaps, and to plan collaborative analyses. The FBS-related discussions at the Crimean meeting differed in style and substance from those at Goddard. There was a greater emphasis on ground-based observations and on particular periods. More theoreticians attended the meeting. Many preliminary reports were ready for presentation because the Soviet astronomers had made more headway in the analysis of their data. In order to accomodate this situation, some working groups functioned at times in the style of traditional meetings with contributed papers. The FBS portion of the Crimean program was organized according to the topics in the following table.

Table 2.1

FBS Topic	Chairman
Theory	G.V. Kuklin (SibIZMIR, Irkutsk)
Action Interval 2, 22-29 May 1980 (Hale Regions 16862,-3,-4; SESC Regions 2466,-69,-70 resp.)	V. Gaizauskas (HIA, Ottawa)
Action Interval 4, 10-12 June 1980 (Hale 16884; SESC 2490)	F. Chiuderi-Drago (Arcetri)
Action Interval 7, 24-30 June 1980 (Hale 16923; SESC 2522,-30)	C.J. Wolfson (Lockheed, Palo Alto)
20-26 October 1980 (Hale 17212; SESC 2744)	L. Deszö (Debrecen)

Action Interval 2 was the most prolific SMY period for solar ground-based stations in the USSR. The lengthy discussions of these results, always conducted with interpreters at hand, left few opportunities for joint discussions among the FBS working groups. Apologies are therefore offered to the other chairmen for the apparent but wholly unintentional neglect of their deliberations in this summary, and to any participants who may find their presentations misinterpreted.

2.a Pre-Flare Phenomena

Impressive new evidence of pre-flare changes in polarization at centimetric wavelengths, discovered with the VLA by Kundu and his colleagues, was presented at both workshops. In one instance the polarization at 6 cm , and presumably the magnetic field as well, of fine-scale features was observed to reverse sense within a few minutes at the onset of a flare (see Section 1.e).

Also at both workshops de Jager described observations of the pre-flare state in hard X-rays made with the HXIS instrument on the SMM satellite. In a couple of events towards the limb, bright kernels of X-ray emission formed at flare sites 30 or more minutes before the flares did. Tongues of emission then formed above the kernels (within 6 seconds in one case), still some tens of minutes before the flares themselves. In the case of the large two-ribbon flare of 21 May/2054, simultaneous brightening of hard X-rays began in widely-spaced points. These initial results suggest that beams of high energy particles produce hard X-rays near the foot-points of loops prior to the main flare.

Following traditional veins, a study at SibIZMIR reported by Kasinskii (Workshop Ref. 59) claimed that the onset and rate of flare production in the subflare-rich regions of Action Interval 2 (Figure 2.1) could be related to changes in sunspot area, to both growth and decay. Substantial changes were observed to proceed roughly in phase for both magnetic polarities: 25-50% in less than a day for the following and about 20% within hours for the leading polarities. Day-to-day changes are clearly evident for the trailing members of these same groups in Plate 2.2 . The greatest changes occ-

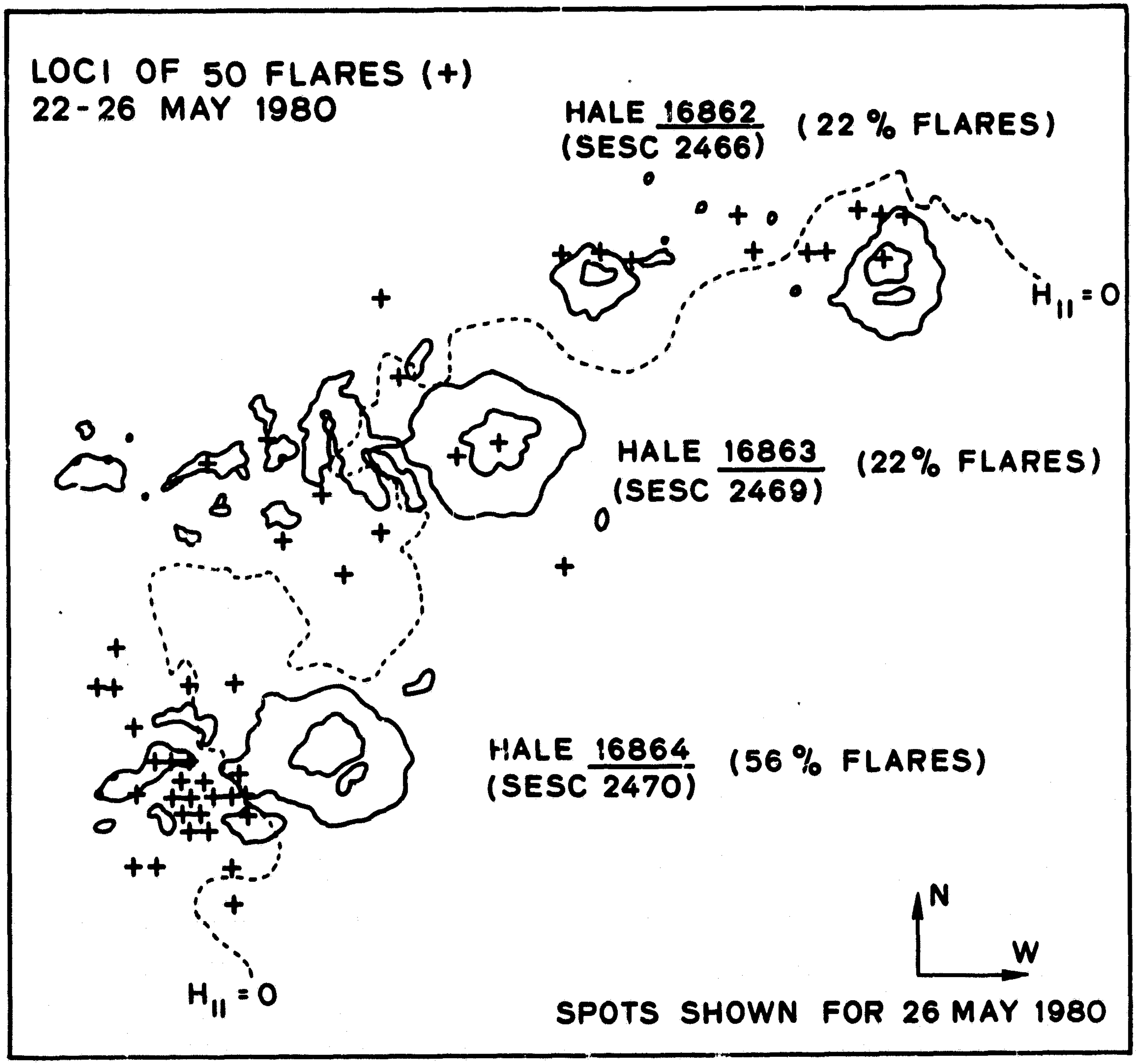

Figure 2.1 (After Golovko, Kasinskii, and Klochek [59])

ured in Hale 16863. This fact at once arouses skepticism about the alleged relationship because the more rapidly growing and decaying region produced fewer than half as many flares in the same period as did region 16864 (Figure 2.1).

The discrepancy in flare productivity of these two large regions had already been examined at the Goddard Workshop. In vector magnetograms from Marshall Space Flight Center, it was clear that the shear in the magnetic field had been very different in the vicinity of the neutral lines located immediately behind each of the leading spots in 16863 and 16864. The transverse field was almost exactly orthogonal to the neutral line trailing 16863 on most days; only two or three flares appeared near the weak δ configuration at this location in the sample of 50 events (Figure 2.1). The SE corner of the leading spot of 16864 had an intrusion of reverse magnetic polarity which did not correspond with any of the umbral fragments. At this intrusion and along the neutral line extending back through the pores trailing the main spot, the transverse field was aligned almost parallel to the neutral line. The preference of subflares for these sheared locations was noted at Goddard (see 23,25,and 26 May in Plates 2.1 and 2.2) and is confirmed in Figure 2.1 .

There was more than just flux emergence responsible for the high incidence of flares on 28 May in the new compact region immediately preceding Hale 16864 (Plate 2.3). The birth of this new feature can be traced back to the emergence of reverse-polarity flux near the NW corner of the leading spot in Hale 16864 sometime between 26 May/0226 (magnetogram from Irkutsk) and 26 May /0654 (filtergram from Debrecen). Early on 27 May there were still only a couple of pores and a well-developed AFS at this location (Plates 2.1 and 2.2). Movies projected at both workshops from Big Bear and Ottawa River Solar Observatories showed that during the second half of 27 May the leading edge of the penumbra of the large spot bulged outwards toward the pores of reverse polarity and within hours broke away entirely from the parent spot to form a compact δ configuration. This feature evolved a highly complex fine structure in Hα and in less than a day after the rapid motions occured it produced a train of energetic homologous flares (cf. 2.b). These examples reinforce the long-established view that the emergence or decay of flux are by themselves insufficient to create flares. The complexity of the field and motions at the photospheric foot-points are also key factors.

Action Interval 2 provides an ideal case study of large regions which are highly productive only in small flares and subflares. On a coarse scale, the magnetic configurations were rather stable and not greatly confused for days in succession before the formation of the compact δ region preceding Hale 16864. In order to extend their analysis of this interval, the Soviet groups are anxious to obtain highly-resolved magnetograms as contour maps or digital plots which could be used to calculate force-free approximations of the fields on each day. Proper motions of spots in these large clusters were pronounced; Deszö has determined some of them (Workshop Ref. 64) and has agreed to extend this work to the rapidly-formed δ configuration preceeding Hale 16864.

In his summary remarks, Kuklin acknowledged that many interesting pre-flare situations and precursors had been described during the workshop. However, the observed situations differed so greatly from one flare to the next that it is not yet possible to agree upon a standard set of necessary and sufficient conditions for a flare. Great flares which might have cleared away some confusion by signalling crucial pre-flare events did not occur during the FBS. He suggested homologous events as a possible alternative source for specifying the critical parameters.

2.b <u>Homologous Flares</u>

Homologous flares were so abundant during several FBS intervals that a special working group was convened on this topic by B.E. Woodgate at the Goddard Workshop. At least 11 flaring regions were identified as homology-prone. A major task already undertaken by that group is to assemble joint descriptions of each homologous set based on structural similarities in $H\alpha$, UV, soft X-rays, and on burst signatures in X-rays and microwaves. It is anticipated that pre-flare situations will recur among the members of the same homologous set but will likely differ between sets in accordance with the large-scale magnetic character of the associated active regions. Specific evolutionary trends will be sought: magnetic reorganization in active regions, emerging flux, spot movements, formation of δ configurations, and filament activations.

Homologous flares received further attention at the Crimean Workshop. Two trains of such events, discussed in detail by the working group for Action Interval 2, differed widely. One sequence of 5 highly localized flares, two of which were classed as 2B events, erupted in less than 24 hours beginning on 28 May in the compact δ configuration preceding Hale 16864 (Plate 2.3). First identified at the Goddard Workshop, this set gained an additional member at 29 May/0540 which was found in observations from Alma Ata (Workshop Ref. 16). The other homologous train was spread much more widely in space (involving all three regions 16862,-3,-4) as well as in time (25-29 May, although two events occured within 6 hours on 25 May). Many observations of these flares were made in the USSR with filtergrams, magnetograms, and spectra obtained at Alma Ata(GAISh), Crimean A.O., Irkutsk (Sib-IZMIR), IZMIRAN, Shemakha, and Tashkent. The common features of most interest in this second train of flares were:(a) the small flaring segments located inside the large umbra of Hale 16863; (b) the tendency for flaring segments to brighten in near synchronism at locations along the line: tail 16862 - main umbra 16863 - tail 16864. For some events the patches were spread as much as 2×10^5 km apart. A likely addition to this train of events is illustrated in Plates 2.1 and 2.2 for 25 May.

The recurrence of umbral flares, a rare species, in the leader of Hale 16863 excited considerable interest among the Soviet astronomers (Workshop Ref. 17, 18,19). One of their suggestions was that this recurrence might be connected with the formation of this large umbra from the gradual coalescence of as many as 7 fragments of like polarity. Weak chromospheric brightening persisted over this umbra even in the absence of flares (e.g. 24 May in Plate 2.1).

The discord in the energetics and time delays between flares in the two homologous trains described above attracted Kuklin's attention. The flares in the δ configuration were more productive of optical, X-ray and radio emissions than the subflares involving all three adjacent regions. The stronger events however succeeded each other by just a couple of hours while many hours and even more than a day elapsed between the weaker events. Yet earlier indications are that large homologous proton flares are spaced days apart (e.g., 4, 7, 11 August 1972). It is premature to decide whether present observations contradict prevailing views of energy storage in flares. Kuklin advised observers to determine the time delays between flares in as many certifiable homologous sets as possible. How are the time delays related to the energy outputs and to the magnetic characters of the erupting regions?

2.c <u>Synchronous Flares</u>

Several observers reported instances of synchronous eruptions among the adjacent active complexes during Action Intervals 2 and 7. As noted above (cf. 2.b) one train of 5 homologous events during Action Interval 2 consisted of nearly synchronous eruptions along the same 'line' running from Hale 16862 south-eastwards to the tail of 16864. The 'synchronicity' varied from 0 to 12 minutes. The most striking synchronous event in this set was reported at the Goddard Workshop by A. Kattenberg who observed it with the Westerbork array at a wavelength of 6 cm . A subflare beginning just before 0800 on 27 May had microwave and X-ray emissions (HXIS) roughly following the Hα events in the sequence typical of this homologous set. At the flash phase (0821) however the microwave sources in Hale 16863 and 16864 jumped up together to peak brightness, to within 1 second.

The target regions for Action Interval 2 returned on the next rotation, dispersed and displaced to higher latitudes, as the targets for Action Interval 7. Mogilevskii (Workshop Ref. 18) and Kasinskii (Workshop Ref. 59) claimed that the orientation and chronology of the synchronous events were preserved after one rotation, i.e. disturbances were initiated preferentially in the leading NW corner and skipped towards the trailing SE corner of the large active complex. The orientation was better preserved than the chronology. Mogilevskii has used these events to develop a hypothesis for sub-photospheric excitation by MHD solitons of flares.

An analysis presented by Ogir (Workshop Ref. 14) of subflares during Action Interval 2 found that subflares erupted in chains in individual active regions and with a higher frequency at the beginning of each chain. Furthermore, the onset of a chain in one region was soon followed by a chain erupting in another and again in another remote complex, as though the sympathetic interaction extended over the whole visible hemisphere. Although highly suggestive, it is not entirely clear that these coincidences are statistically significant.

Obviously many aspects of activity in Intervals 2 and 7 need to be considered together. An essential first step has barely begun: the compilation of a definitive chronology of flares and subflares which identifies their membership in homologous and/or synchronous groups during these intervals.

2.d Evolution of Active Regions

The huge size of the active complexes of May and June 1980 and their sustained high level of flaring activity have motivated a search for possible associations between the formation of these regions and large-scale evolution in magnetic and velocity patterns on a global scale. P.A. McIntosh (SESC, Boulder) sent his initial results of such a study based on Hα synoptic charts to the Goddard Workshop. He pointed out that the global sector structure changed late in 1979 from 2 to 4 major sectors. This development was preceded by a sudden change in the rate of rotation of the -/+ sector boundary from 28½ to 26½ days, a change which coincided with the formation east of the sector boundary of the most active group (McMath 16239) of the 1979-80 period. Several rotations later, Hale 16863,-4 formed in the center of a new sector of -ve polarity. Of additional interest to the FBS is McIntosh's claim that stronger active regions are usually located where an enhanced and complex shear is created by the relative motions between long-lived, large-scale magnetic patterns in adjacent latitudinal zones.

PLATE CAPTIONS

Plate 2.1:

Filtergrams taken in the core of Hα of Hale Regions 16862,-3,-4 from 22 to 27 May 1980. The lower left corner of each frame is marked with the wavelength offset from line center in Å; the lower right corner displays UT. The frames are oriented the same way as Fig.2.1 .Subflares are in progress in the frames for 23, 25, 26, and 27 May.

Plate 2.2:

Filtergrams taken in the shoulder of Hα of the same regions as in Plate 2.1 and in the closest possible time coincidence. The wavelengths, times and orientation are displayed as in Plate 2.1 .

Plate 2.3:

Three spatially homologous flares of progressively increasing strength in Hale Region 16864 on 28 May 1980 with maxima at: 1555(SB), 1718(1B/M3), 1951(2B/X1). The frames are labelled and aligned as in Plate 2.1 .

OTTAWA RIVER SOLAR OBSERVATORY

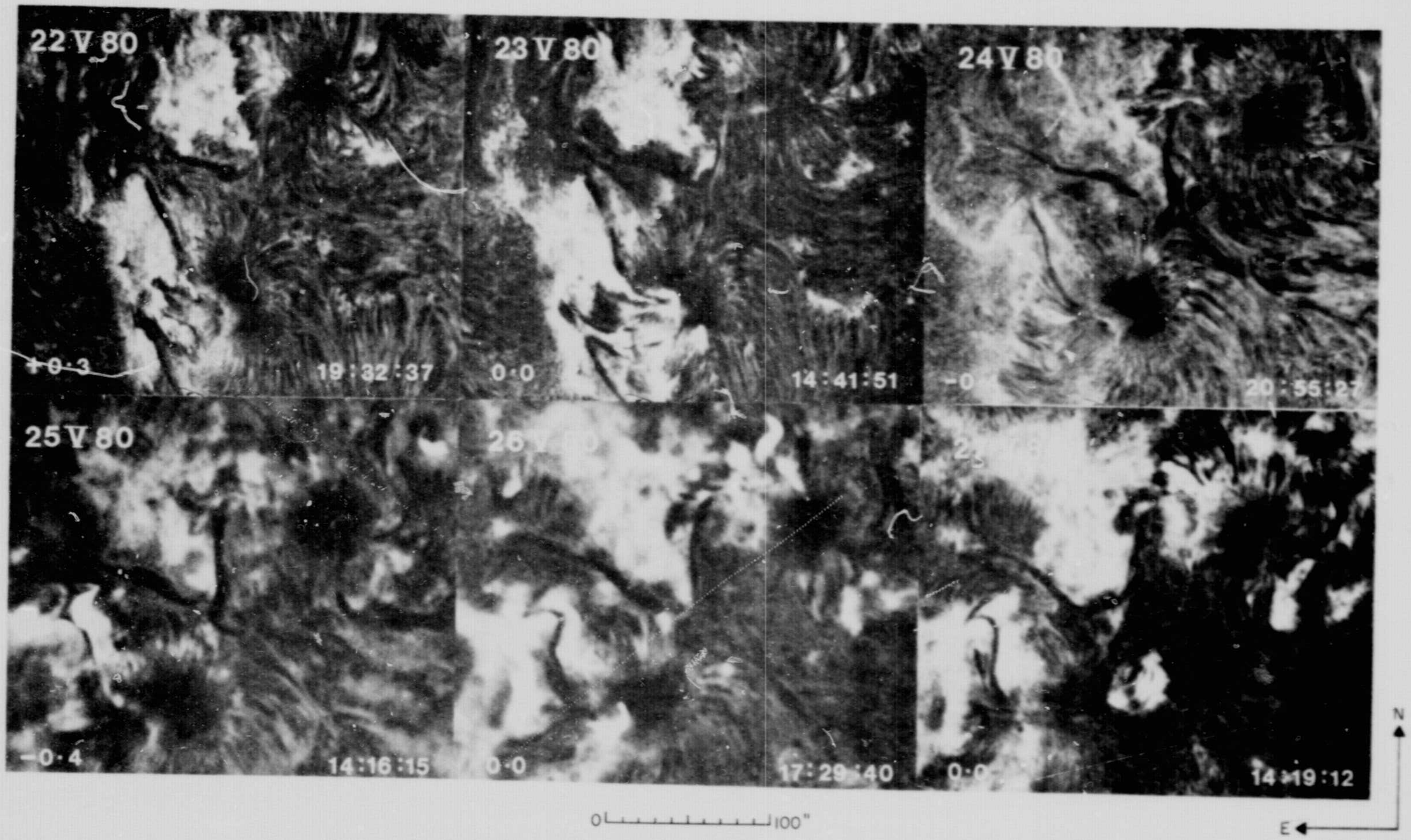

Plate 2.1

OTTAWA RIVER SOLAR OBSERVATORY

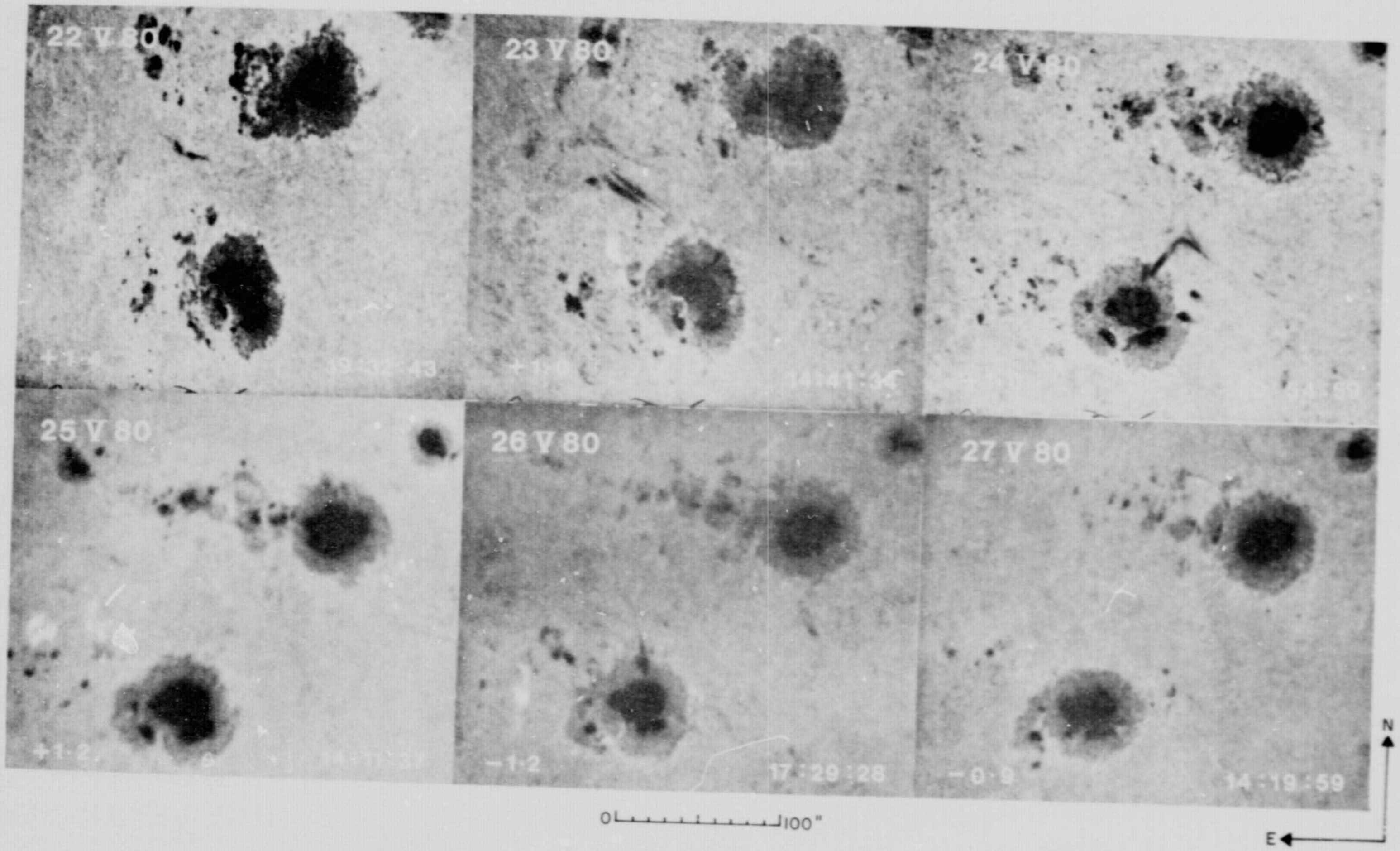

Plate 2.2

OTTAWA RIVER SOLAR OBSERVATORY

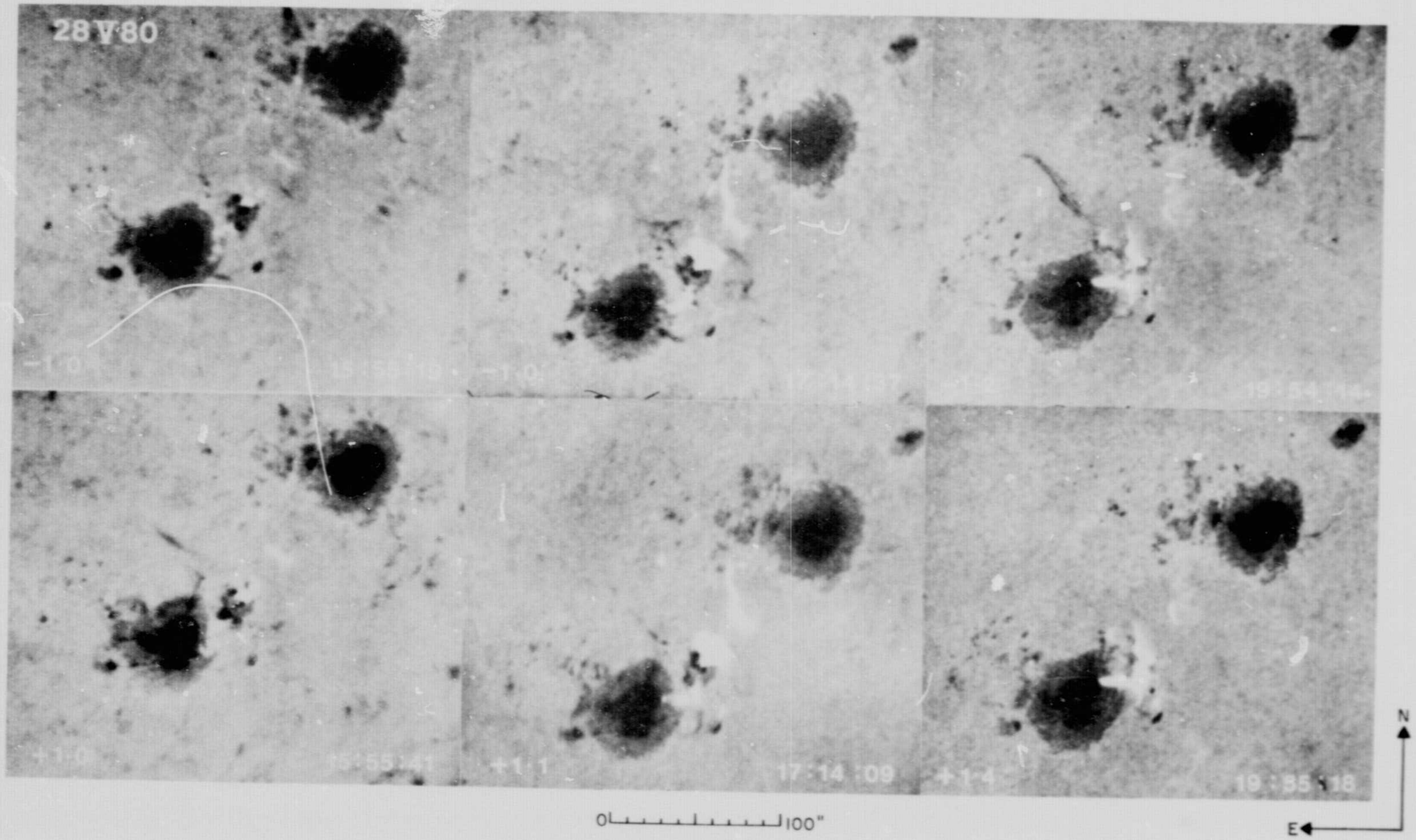

Plate 2.3

III. SMY - STIP

S. T. Wu

The University of Alabama in Huntsville

In this section, the activities of Study of Traveling Interplanetary Phenomena (STIP) during the period of Solar Maximum Year (SMY) (i.e., August 1979 - February 1980) will be discussed. In particular, we will summarize those activities which occurred during the Crimean SMY Workshop. In addition, some interesting scientific problems concerning solar/interplanetary dynamics will also be mentioned as a core of STIP projects during the SMY.

III.a. Introduction

Study of Traveling Interplanetary Phenomena (STIP) is one of the three programs that constitute the activities of Solar Maximum Year (SMY). The main objective of STIP is to understand the physics of space plasma phenomena between the Sun and Earth and other planets. In the period of SMY, we shall utilize the coordinated observations at both the Sun and the interplanetary medium to further our understanding of the dynamical phenomena of the transient solar wind magnetic field, energetic particles, and other effects in interplanetary space due to various forms of solar activity period. In order to achieve these goals, the programs devised for STIP can be stated as follows:

- synoptic observation coordinated with theory.
- two-month intervals declared in advance; a list of the STIP intervals is included in Table I
- "self-declared" retrospective intervals; for example, the STIP interval for the August 1972 flare study was declared after the events.

These are the operational methods for STIP. The interesting physical problems of STIP are as follows:

1. physics of interplanetary space; the "transmission line"

2. solar wind physics.

These two subjects are discussed as follows:

1. Transmission Line

It has been recognized that various traveling interplanetary phenomena were caused by the solar activities. Therefore, it is obvious that in order to understand the physics of these phenomena, one must start at the Sun and follow the "transmission line" though interplanetary space. To trace these signals through the transmission line, we need to utilize all possible available observational data. These observational data can be classified into three parts:

(i) Solar Observations

In this category, essential observational data necessary to trace the traveling phenomena may be the H_α, X-ray, UV transient (imaging), white-light ttansients and radio bursts (Types II, III and IV). A schematic representation of these phenomena associated with a large-scale mass ejection is depicted in Figure III-1 (Emslie and Rust, 1979). In this representation, the origin of the solar radius-time axes represents the flare onset. After flare onset, H_α-emitting ejecta are seen to be about two solar radii ($R_\odot$). Coronal transients have been traced from about 1.5 $R_\odot$, but, as the question marks indicate, extra-polarization of coronal transients trajectories back to time zero is uncertain in some cases. Metric type III bursts are recorded before time zero, but the starting time and height of coronal transients and their forerunners are uncertain. Energetic particles revealed by metric type II and type IV emissions may be accelerated in or near the shocks ahead of fast-moving transients.

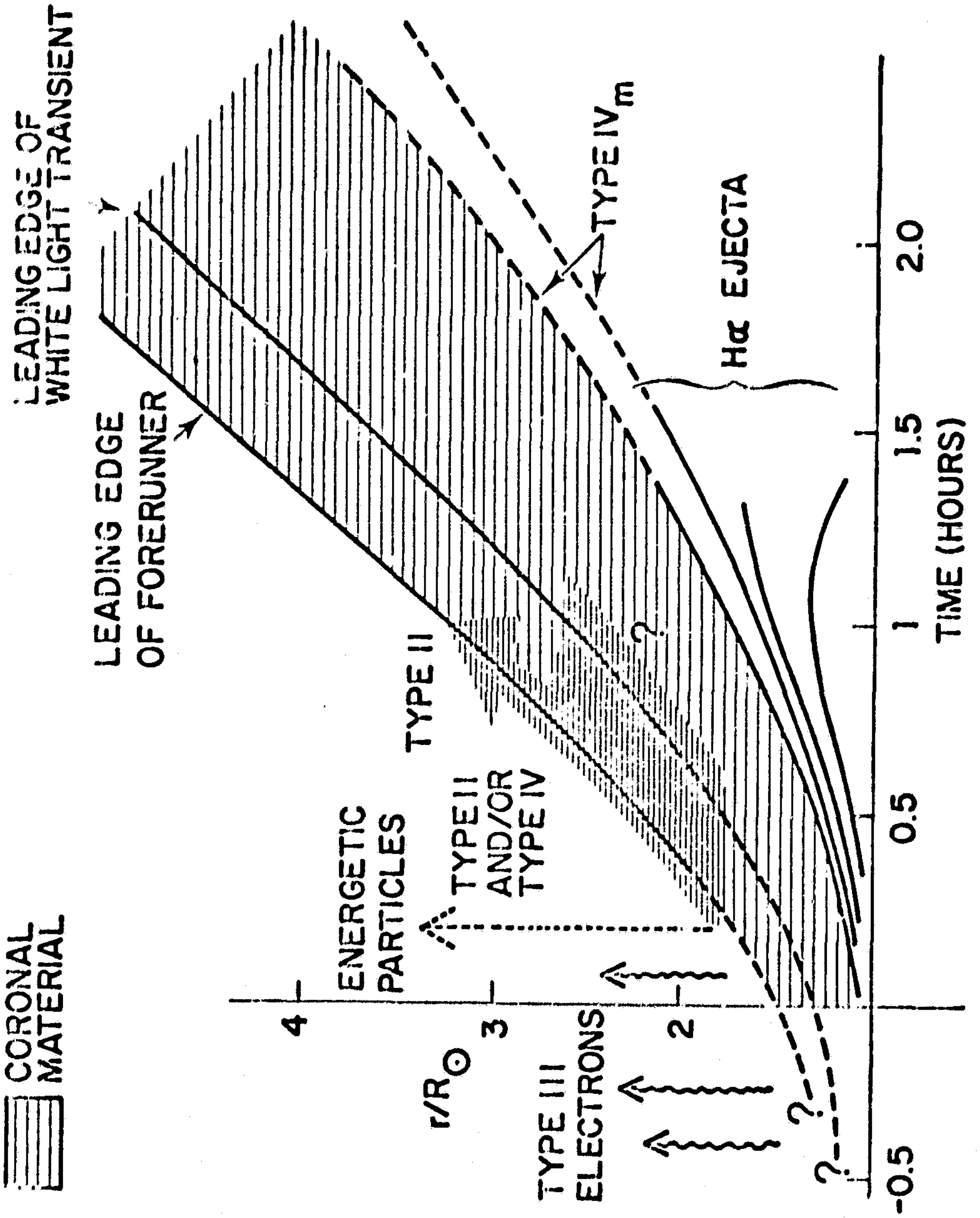
CORONAL MATERIAL
LEADING EDGE OF WHITE LIGHT TRANSIENT
LEADING EDGE OF FORERUNNER
TYPE II
TYPE IV_m
Hα EJECTA
ENERGETIC PARTICLES
TYPE II AND/OR TYPE IV
TYPE III ELECTRONS
$r/R_\odot$
4
3
2
?
-0.5
0.5
1
1.5
2.0
TIME (HOURS)

Figure III-1

Certainly, this is just a typical example. Other observational data such as X-ray, UV, magnetic transients, etc. can be added to make the trajectory more accurate. The task of STIP is to use these interdisciplinary observations as the starting point and to trace their consequences outwardly through interplanetary space.

(ii) Remote Tracking of Distrubances through Interplanetary Medium

To trace these disturbances further, remote tracking can be an extremely useful and complementary tool. Typical observational data can be obtained through Interplanetary Scintillations (IPS) measurements and up-link/down-link spacecraft telemetry signals that may be spectrally-boradened and/or phase-shifted.

(iii) In Situ Measurements

To further understand the physical structures of traveling phenomena, it is necessary to have in situ measurements of all plasma, magnetic, and electric field parameters together with energetic particle detectors. This can be achieved by using the space probes that have been launched during the past decade as well as for future planned space missions. Indeed, the Comet Halley apparition in 1985-86 can prove to be a valauble probe, especially when examined by the international program of the USSR/France, Japan, ESA, and USA "comet watch" that will include existing spacecraft such as Pioneer-Venus, ISEE-3, etc.

With all these three major efforts it is possible to improve our present physical picture of the interplanetary "transmission line".

2. Solar Wind Physics

The above-mentioned investigations can, at best, give us a physical description of traveling interplanetary features. In order to understand their detailed physical structures, solar wind physics must be studied in conjunction with the morphological description. The representative scientific problems in the understand of solar wind distrubances may be summarized as follows:

(a) magnetic field topology near the Sun

(b) coronal holes

(c) hydromagnetic waves (low frequency)

- mode coupling
- energy and momentum transfer to solar wind
- steepening into shocks

(d) large scale structures

- mass ejections from flares
- corotating interaction regions; such as the interaction regions of fast/slow shocks and turbulent contact surfaces
- transport properties

(e) particle energization and modulation

- modulation of solar/galactic cosmic ray
- energization at shock
- three-dimensional effects

All of these subjects should be approached from both experimental (observational) and theoretical points of view. An outline of current theoretical modeling efforts has been summarized by Wu (1980). A schematic representation of the present scope of solar wind observations and theoretical study is shown in Figure III-2. An example of the current state-of-the-art for the direct confrontation between observation and theoretical modeling in the study of traveling interplanetary phenomena is depicted in Figure III-3. This figure shows the comparison of an MHD model (Dryer et al, 1978) with Pioneer 10 observations at 4.9 AU. The phasing and

SOLAR WIND - PRESENT SCOPE

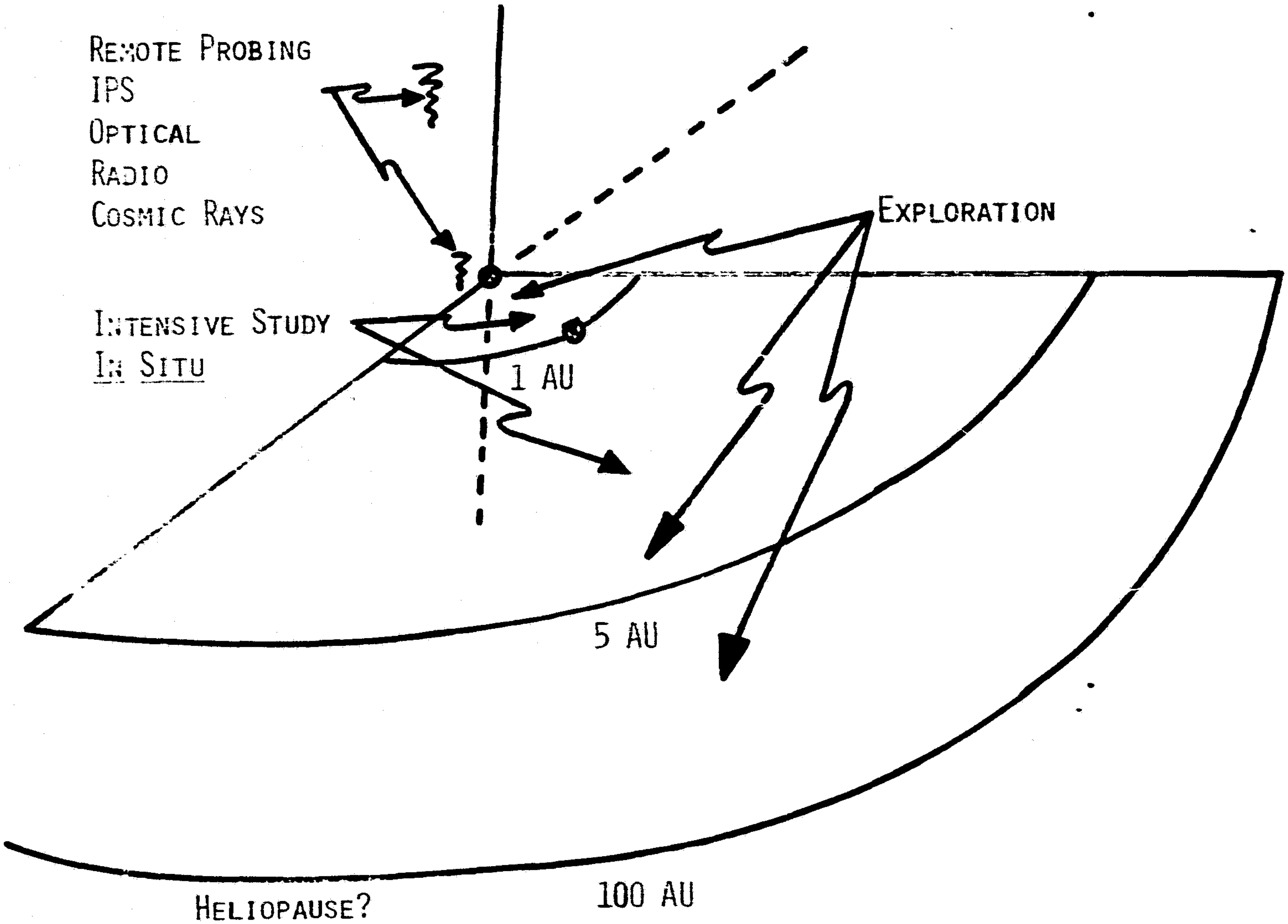

Figure III-2

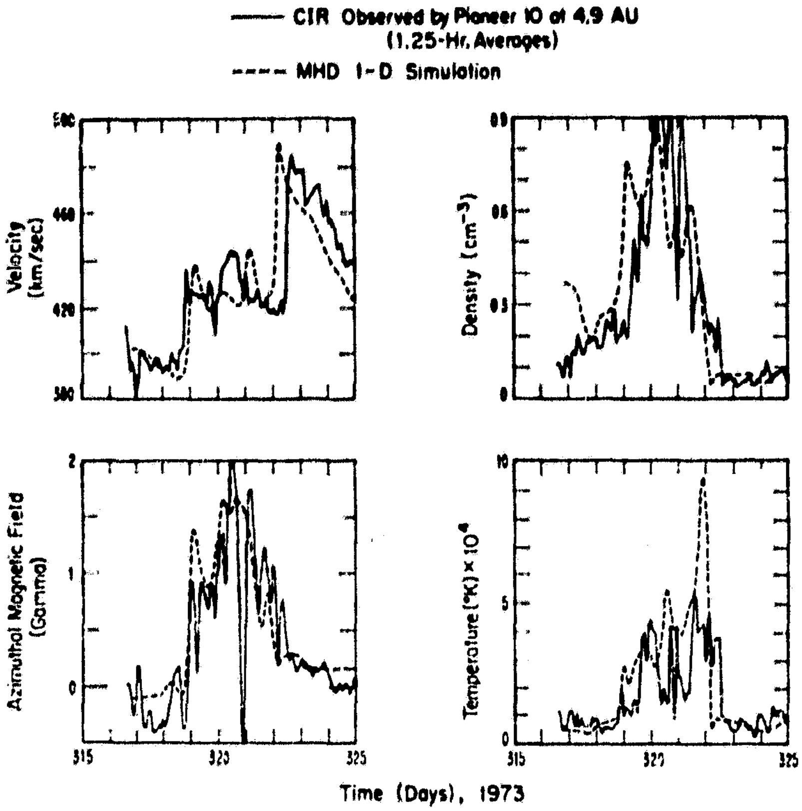

Figure III-3 Direct comparison at 4.9 AU of a single observed and predicted corotating interaction region with the use of higher temporal (1.25-hour averages) resolution. This region developed from the region observed earlier (days 308-317) by Pioneer 11 at 2.8 AU (Dryer et al. 1978).

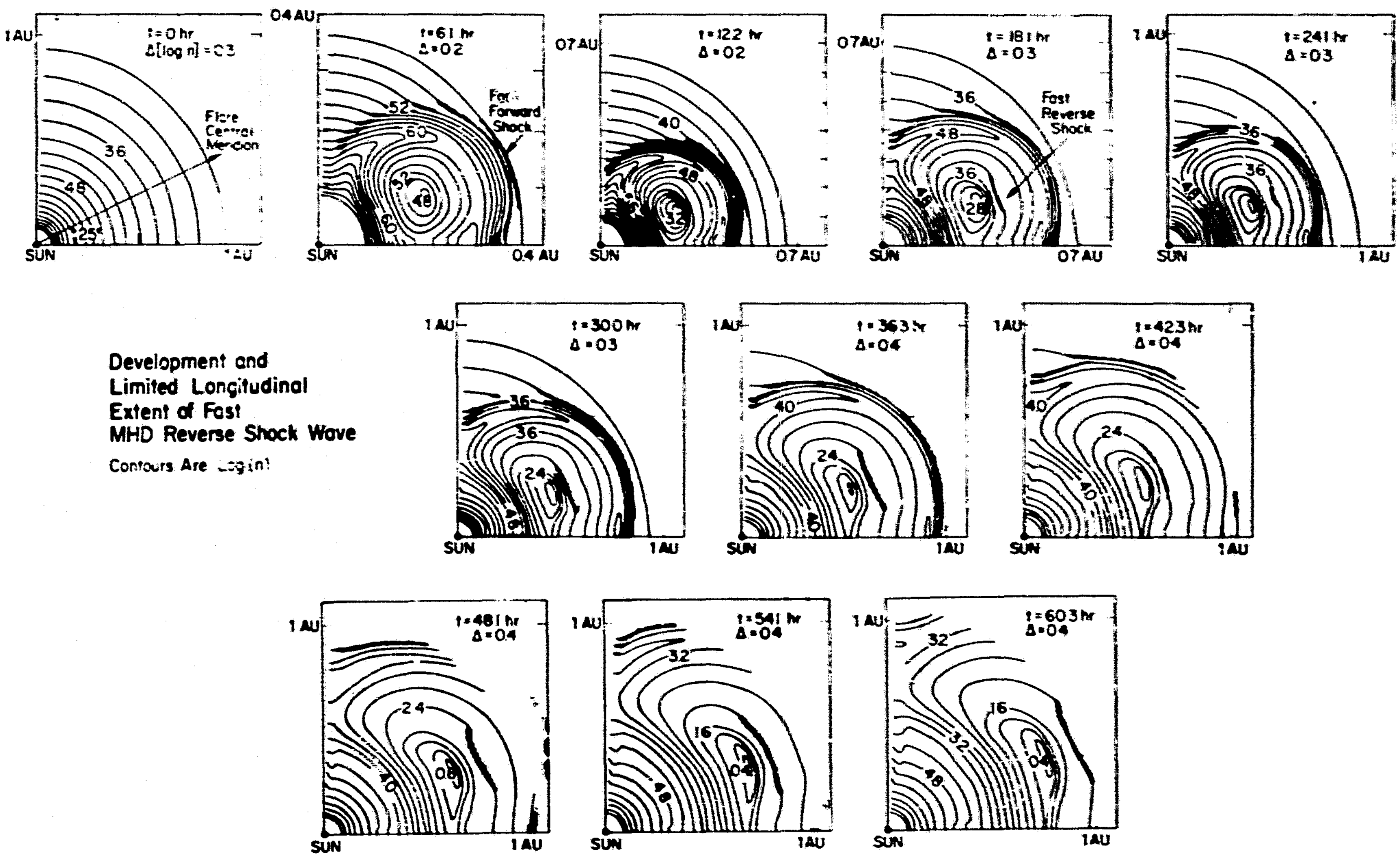

Figure III-4 Contour maps of log (n) showing the development and the extension of the shock fronts. Compressions and rarefactions can be determined at t ≠ 0 by reference to the predisturbance level (t = 0) (D'Uston et al. 1981) magnitude of the fully-developed forward shock (F) were predicted extremely well by the model. The reverse shock (R) was predicted somewhat earlier than the actual one. In addition, the model prediction of the evolution of the position of the forward and reverse shocks in the interplanetary space generated due to a flare disturbance is shown in Figure III-4 (D'Uston et al., 1981). In this model simulation results, it is noted that the shock front is definitely nonspherical, although its shape, relative to the flare's central meridian, lacks any discernible asymmetry. A longitudinally-restricted reverse MHD shock appears some 18 hours after the source perturbation (i.e., flare) is terminated. These two figures represent the current state of MHD time-dependent modeling capability.

III.b. Study of Traveling Interplanetary Phenomena During the SMY

We discussed the general description of the STIP program in the previous section. We will now attempt to describe the specific programs upon which STIP has embarked during the period of SMY. In Table I, the STIP Intervals for the SMY are given. In addition, the "SMY/STIP Events" for the period of SMY are listed as follows:

SMY/STIP Event #1 August 14-18, 1979 (Dr. S. Kane, Space Sciences Laboratory, Univ. of California, Berkeley, Calif. 94720, U.S.A.)

- ● ISEE-3 X-rays correlated with microwave burst (UC, Berkeley)
- ● P78-1 coronal transient (NRL)
- ● Radio (telemetry) transient (spectral broadening: JPL, Stanford)
- ● IPS solar wind velocity enhancement (Toyokawa)
- x Type II (Harvard)
- x Radio (telemetry) spectral broadening transient (JPL)
- x P78-1 Coronal Transient (NRL)
- x ISEE-3 Type II shock observed, ~10 $R_\odot$ to Spacecraft (Goddard)

x ISEE-3 in situ shock observed (JPL, LASL)

x IMP-8 solar wind enhancement at Earth (MIT)

x IPS solar wind velocity enhancement (Toyokawa)

(FLARES: ●~1243 UT, S22°E73°; x~1420 UT, N09°E90°)

SMY/STIP Event #2. April 4+, 1980 (Dr. M. Pesses, Dept. of Physics and Astronomy, Univ. of Maryland, College Park, Maryland 20742, U.S.A.)

● Type II, IV (Harvard, Weissenau)

● ISEE-3 Type II shock, ~10 $R_\odot$ to spacecraft (Goddard)

● ISEE-3 energetic particles (Univ. of Maryland)

● SMM Coronal Transient (HAO) - East Limb

● P78-1 Coronal Transient (NRL) - East Limb

(4+ means plus additional events after this one: ●1502 UT)

SMY/STIP #3. April 12, 1980 (Dr. C. Sawyer, NCAR/HAO, Boulder, Colorado 80307, U.S.A.)

● SMM Coronal Transient (HAO) - West Limb

x Hα flare, surge, spray (Big Bear)

x SMM instruments (XRP: both FCS and BCS, slow event)

x Type II, III (Culgoora, Harvard, Palehua, Clark Lake)

x SMM Coronal Transient (HAO) - Northwest

x P78-1 Coronal Transient, gradual streamer changes (NRL)

(Flares: ● prior to 1400 UT; x~2053 UT)

SMY/STIP Event #4. April 27-, 1980 (Dr. R. Stewart, Div. of Radio Epping, N.S.W., Australia)

● Type II, IV m (Culgoora, Palehua, Learmonth)

● SMM Coronal Transient (HAO) - East Limb

x Hα eruptive prominence (Udaipur)

x SMM Coronal Transient (HAO) - East Limb

(27- means plus additional events before this one: ●~0231 UT, x~0517 UT)

SMY/STIP Event #5. June 29, 1980 (Dr. S. McKenna-Lawlor, Dept. of Experimental Physics, St. Patrick's College, Maynooth, Co. Kildare, Ireland)

- ● SMM - all (?) instruments observed flare
- ● Type II, IV (Culgoora)
- ● SMM Coronal Transient (HAO) - West Limb
- \+ Hα flare spray (Big Bear)
- \+ Type II (Harvard)
- \+ SMM Coronal Transient (HAO) - West Limb

(●~0233 UT, +~1822 UT)

STIP plans to extend this list of events when additional interdisciplinary observations and coordinators can be identified. These observations are undoubtedly incomplete. Other observers are invited to send their summaries to the STIP SECRETARY and COORDINATORS as listed above.

The above list of events and coordinators is up-to-date (as of April 15, 1981), and the number of events has, thus far, been confined to a manageable size of five. Others may be added, depending upon the consensus of various observers and consultation with our sister Projects, FBS and SERF, via the SMY Steering Committee.* This list of events was chosen because of the closely-related number of interdisciplinary observations associated with one of more solar flares corresponding to one of the major scientific objectives during SMY. This enables understanding of the flare process itself and its ambiguous, conocmitant consequences in interplanetary space and even in near-space of the planetary magnetospheres, ionospheres, and atmospheres.

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*Since the original preparation of this paper, the Sun "declared" its own SMY/STIP Interval #6, April 10-24+, 1981. The STIP Coordinator is Dr. Thomas Gerley, Radio Astronomy Program, Univ. of Maryland 20742, U.S.A.

Table I. List of STIP Intervals During the Period of SMY

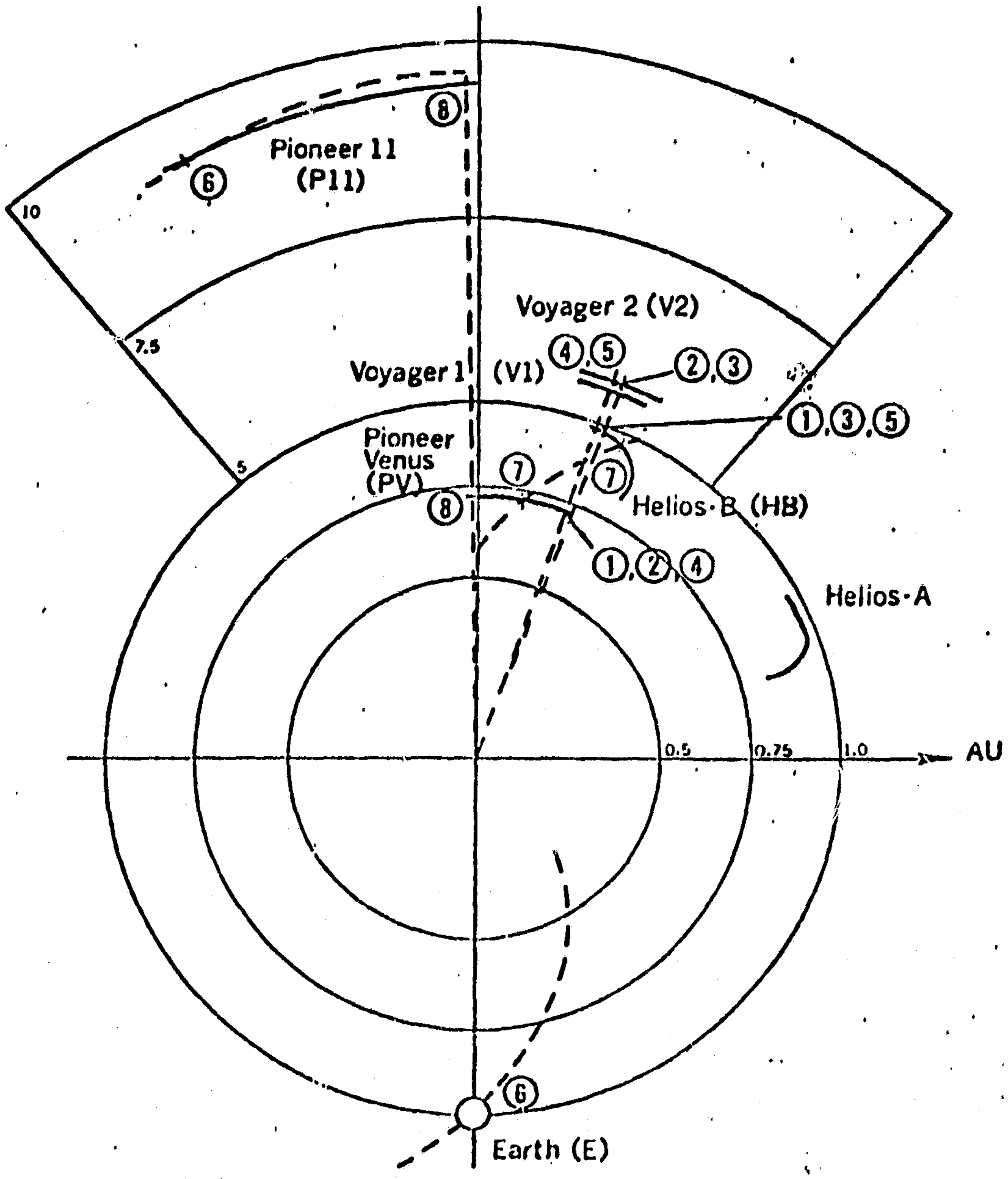
STIP Interval No. VII.	August - September 1979
STIP Interval No. VIII.	15 October - 15 December 1979
STIP Interval No. IX.	15 February - 16 March 1980
STIP Interval No. X.	26 April - 27 June 1980
STIP Interval No. XI.	October - November 1980
STIP Interval No. XII.	24 April - 21 June 1981 (post SMY)

Figures III-5 and III-6 show the spacecraft "constellations" (prepared by Dr. James Vette's group at NASA/GSFC). These spacecraft "constellations" exhibit the positions in a fixed Sun-Earth coordinate system of Helios - 1, Helios - 2, Pioneer-Venus, Voyager - 1, Voyager - 2, and Pioneer - 11 during the first two months, August-September 1979, of the SMY (Figure 4), and successive STIP Intervals IX through XII (Figure 5 during SMY period).

In the Crimea Workshop, the June 29, 1980 event was discussed in detail by Dr. S. McKenna-Lawlor, SMY/STIP Event #5 Coordinator, and the future Chairperson of the Working Group for this Event. The highlights of this event constitute, to our knowledge, the most complete coverage of the whole series of observations for that period. In addition, the following papers were presented in this Working Group session.

- June 29, 1980 event observation from X-ray polychromator on-board SMM, by C. J. Wolfson.
- Coronal transients observed by C/P experiment on-board SMM, by L. L. House and W. Wagner.
- The interactions and the evolution of strong discontinuities in the solar wind plasma, by S. A. Grib
- The speed of the shock wave generated by a solar flare and H-alpha line with measurements, by A. D. Chertkov and S. K. Rybachuk
- Model of a solar flare with subphotospheric energy source, by A. D. Chertkov, A. A. Polyakov, and Yu I. Dokuchaev
- Solar wind observations during STIP intervals and SMY, by O. L. Vaisberg and G. Zastenker
- MHD modeling of solar-interplanetary events, by S. T. Wu

STIP INTERVAL VII
(Start of Solar Maximum Year)
1 AUGUST - 30 SEPTEMBER 1979



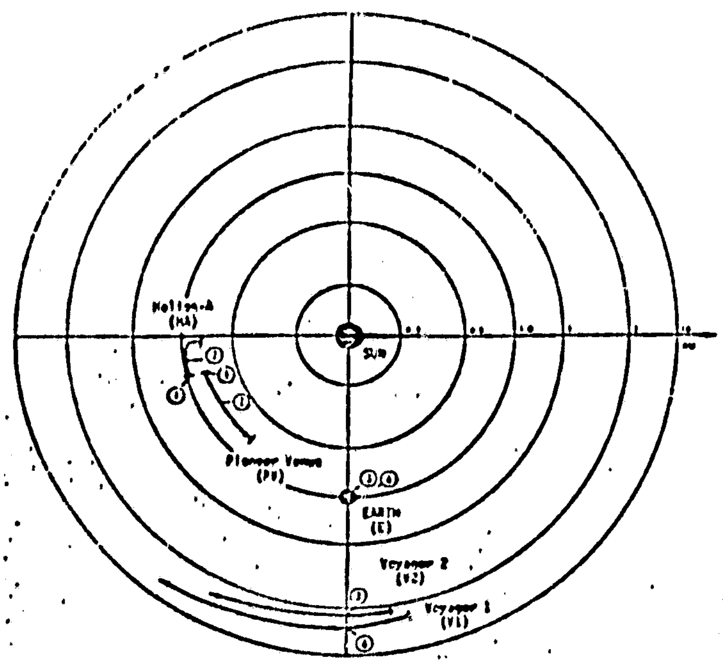
Special Conjunctions

1	PV & HB;	RA	8/06	2.0h	5	HB & V2;	RA	8/08	3.5h	
2	PV & V1;	RA	8/06	3.0h	6	E & P11;	IMF	8/13	18.0h	τ = 0.0d
3	HB & V1;	RA	8/06	4.0h	7	PV & HB;	IMF	8/22	15.0h	τ = 11.5d
4	PV & V2;	RA	8/07	0.0h	8	PV & P11;	RA	9/09	14.0h	

Figure III-5

STIP INTERVAL IX

15 FEBRUARY - 16 MARCH 1980

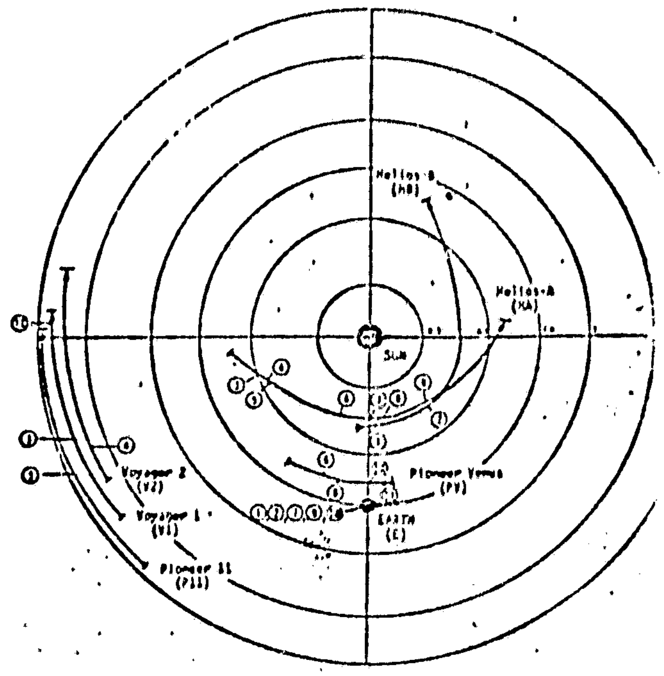


Special Conjunctions

1	HA/PV;	RA	2/15	1700m
2	HA/PV;	IMF	3/04	150m, τ = -6.18d
3	E/V2;	RA	3/15	600m
4	E/V1;	RA	3/18	900m

STIP INTERVAL X

26 APRIL - 27 JUNE 1980

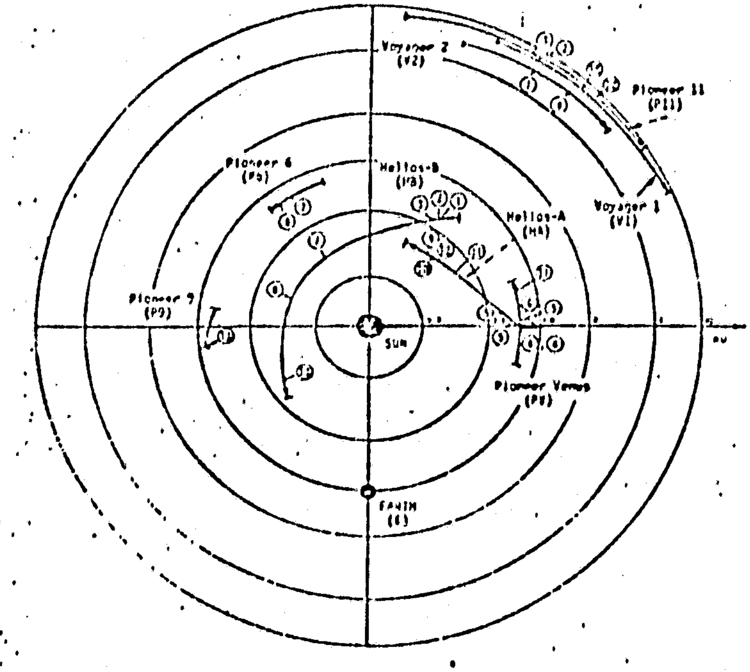


Special Conjunctions

1	E/HB;	RA	5/01	150m
2	HB/E;	IMF	5/?	100m, τ = 0.0d
3	HA/V1;	RA	5/11	850m
4	HA/V2;	RA	5/12	1700m
5	HA/P11;	RA	5/14	2150m
6	HA/PV;	RA	5/26	2300m
7	HA/E;	RA	5/27	1200m
8	HA/PV;	IMF	5/29	1100m, τ = -2.01d
9	HA/E;	IMF	6/03	1200m, τ = 0.0d
10	E/PV;	RA	6/13	1300m
11	PV/V1;	IMF	6/27	800m, τ = -0.47d

STIP INTERVAL XI

1 OCTOBER - 30 NOVEMBER 1980

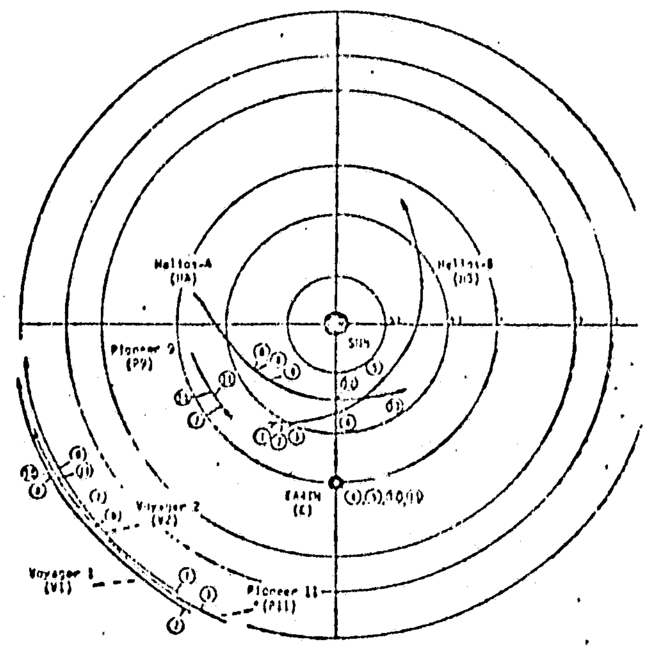


Special Conjunctions

1	HB/V2;	RA	10/18	1400m
2	HB/V1;	RA	10/20	1100m
3	HB/P11;	RA	10/21	200m
4	HA/PV;	IMF	10/25	2300m, τ = 5.69d
5	HA/PV;	RA	10/27	0m
6	HA/PV;	RA	11/07	1300m
7	HB/PA;	RA	11/09	2200m
8	HB/P6;	IMF	11/15	700m, τ = -11.70d
9	HA/V2;	RA	11/20	2200m
10	HA/V1;	RA	11/21	1300m
11	HA/PV;	IMF	11/23	1500m, τ = 6.98d
12	HA/P11;	RA	11/23	1300m
13	HB/P9;	IMF	11/29	2000m, τ = -6.23d

STIP INTERVAL XII

24 APRIL - 21 JUNE 1981



Special Conjunctions

	SAT/SAT	TYPE	MM/DD	MM	DAYS
1	HB/V2;	RA	04/26	20m	
2	HB/V1;	RA	04/28	6m	
3	HB/P11;	RA	05/01	21m	
4	HB/E;	RA	05/09	7m	
5	HB/E;	IMF	05/17	17m,	τ = 0.0d
6	HA/V2;	RA	05/31	5m	
7	P9/V2;	RA	06/01	13m	
8	HA/V1;	RA	06/02	5m	
9	HB/P11;	RA	06/06	4m	
10	P9/V1;	RA	06/08	20m	
11	P9/P11;	RA	05/10	9m	
12	HA/E;	RA	06/13	21m	
13	HA/E;	IMF	06/26	10m,	τ = 0.0d

Figure III-6

A detailed account of these discussions will be prepared by Dr. S. McKenna-Lawlor, chairperson of the working group.

Up-to-date, there are quite a number of observations being collected from the Sun and throughout heliospheric space. For example, sample plasma parameters obtained by Pioneer XII have been deposited with the NOAA WDC-A from January 1979 through December 1980. Figure III-7 shows the proton (3.7-12.6 MeV) intensities recorded by Helios-1 (contributed by Dr. G. Wibberenz, Univ. of Kiel) during STIP Interval X and the FBS-interval. The occurrence of Events 1-4 is illustrated. Event-1 indicates that a white light coronal transient was observed by SOLWIND at the south-east limb. Event-2 indicates that both SOLWIND and C/P experiments have recorded transient events at the northwest and west and southwest, respectively. Event-3 indicates that SOLWIND recorded an event on the west limb and finally Event-4 indicates the C/P observed an event at the east limb.

Figure III-8 shows radio burst data provied by Drs. R. Stone and H. Cane, NASA/GSFC, from ISEE-3 spacecraft during STIP Interval VII, the beginning of SMY. In this data the occurrence of Type III is shown at ~ 1430 UT on August 18, 1979. A few hours later, Type II slow drift appeared at 0120 UT, August 19, 1979. Another Type III appeared with a small flare and was also recorded. These are the data which are being received. Our next task is to utilize the richness of observations in order to understand the physics of traveling phenomena in interplanetary space.

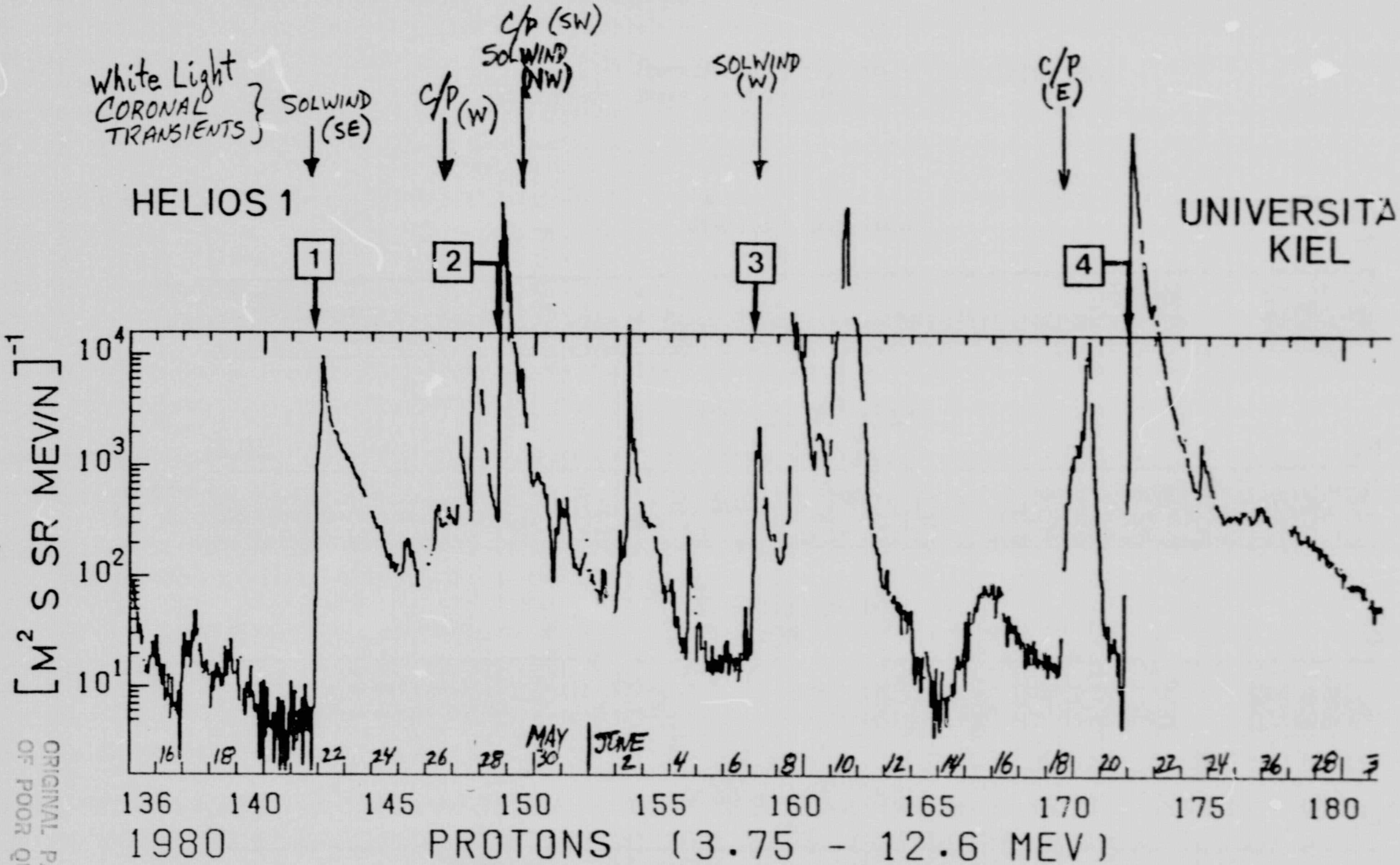
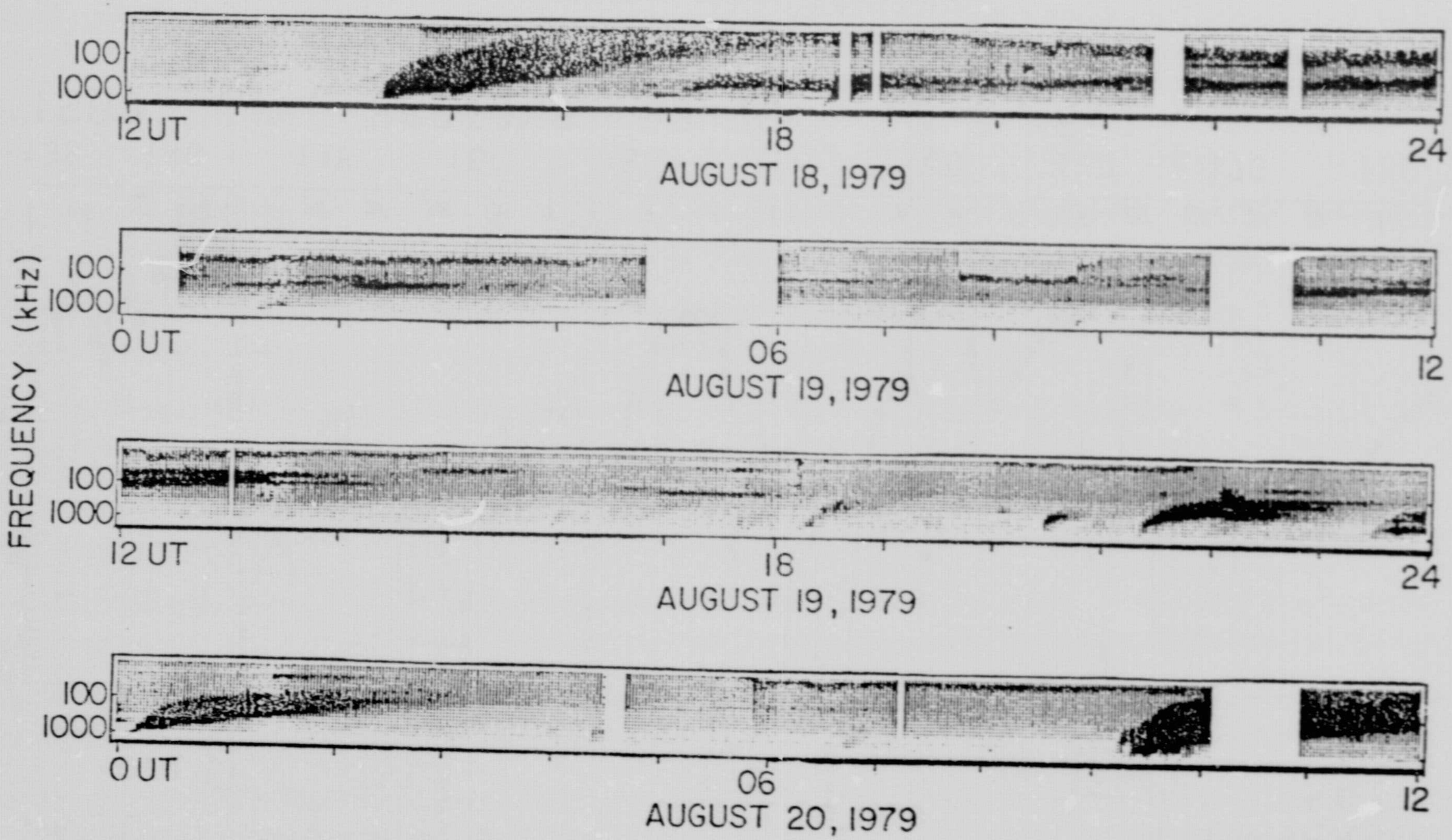


Figure III-7. Intensities of protons (3.7-12.6 MeV) During STIP Interval X and the First FBS-Interval.



Type III-8. Radio Bursts Recorded by ISEE-3
(Courtesy of Dr. R. Stone, GSFC/NASA, 1981)

REFERENCES

Dryer, M., Smith, Z.K., Smith, E.J., Mihalov, J.D., Wolfe, J.H., Steinolfson, R.S., and Wu, S.T. 1978, J. Geophys. Res., 83, 4347.

D'Uston, C., Dryer, M., Han, S.M., and Wu, S.T. 1981, J. Geophys. Res., 86, 525.

Emslie, A.G., and Rust, D.M. 1979, Solar Phys., 65, 271.

McKenna-Lawlor, S. 1981, St. Patrick's College Report, Department of Experimental Physics.

Wu, S.T. 1980, IAU Symp., 91, 443.

APPENDIX A

PROGRAM

PLENARY SESSIONS

TUESDAY

MORNING SESSION

10.00 Introductory presentation: C. de Jager.

10.15 V. N. Obridko: A talk in commemoration of N. V. Pushkov.

10.25 V. Gaizauskas: FBS Review.

10.45 A. G. Emslie: SERF Review.

11.05 S. T. Wu: STIP Review.

11.30 C o f f e e   b r e a k

12.00 V. E. Stepanov, V. V. Kasinsky, G. V. Kuklin: Implementation of the SMY program in the USSR.

12.20 G. E. Kocharov et al: Why are flares so rich in ^{3}He?

12.40 M. Kundu: V L A.

13.00 G. B. Gelfreikh et al.: RATAN-600.

13.30-14.00 L U N C H

AFTERNOON SESSION

15.00 L. House: SMM presentation.

15.20 W. Wagner: C/P Experiment.

15.40 C. de Jager: HXIS Experiment.

16.00 E. Antonnucci: XRP Experiment.

16.20 C o f f e e   b r e a k

16.50 P. Landecker: P 78-I Experiment.

17.20 V. A. Kotov, A. B. Severny, T. T. Tsap: Global oscillations of the Sun.

17.40 R. E. Gershberg: Activities of the Sun and of red dwarfs.

18.00 E N D   O F   S E S S I O N

WEDNESDAY

10.00 S. McKenna-Lawlor: a) STIP Meeting in Ireland.
b) The flares of June 29, 1980.

10.10 A. G. Emslie: Observational signatures of thermal and non-thermal models of hard X-ray emission in solar flares (see Appendix D).

10.20 G. Simnett: Time and spatial variations of hard X-rays in the very compact flare of July 5, 1980.

10.30 W. Wagner: UVSP - Observations.

10.40 H. Zirin: Big Bear movie.

11.00 Nikolskii: Some pictures.

FRIDAY

10.00 E. Hiei: The Astro-A project.

10.10 C. Slottje: Radio Observations at Westerbork and Dwingeloo.

10.20 K. Lang: VLA - Observations of Solar active regions.

10.30 V. M. Bogod: Measurement of radio-granulation parameters with RATAN-600.

10.40 J.-C. Hénoux: Impact polarization in Hα flares.

10.50 G. F. Sitnik: The $^{3}He/\ ^{4}He$ Ratio.

10.55 S. T. Wu: Modelling of flare build-up.

APPENDIX B

List of SMY Workshop Participants at Simferopol

(Addresses follow)

A. Soviet

Mogilevsky E.I. - IZMIRAN

Nikolsky G.M. - IZMIRAN

Obridko V.N. - IZMIRAN

Shilova N.S. - IZMIRAN

Nikolskaya K.I. - IZMIRAN

Utrobin V.T. - IZMIRAN

Ishkov V.N. - IZMIRAN

Ivanov E.V. - IZMIRAN

Ivanov K.G. - IZMIRAN

Livshits M.A. - IZMIRAN

Prutesnkaya E.I. - IZMIRAN

Kim I.S. - IZMIRAN

Shmeleva O.P. - IZMIRAN

Zhugzhda Yu.D. - IZMIRAN

Ioshpa B.A. - IZMIRAN

Starkova L.I. - IZMIRAN

Chertok I.M. - IZMIRAN

Konstantinova L. Yu. - IZMIRAN

Shelting B.D. - IZMIRAN

Akinyan S.T. - IZMIRAN

Badalyan O.G. - IZMIRAN

Chernov G.P. - IZMIRAN

Grib S.A. - Leningrad Branch of IZMIRAN

Dubov E.E. - Soviet Geophysical Committee (WDC)

Borovik - Pulkovo Astronomic Observatory

Ge. freikh G.B. - Pulkovo Astronomic Observatory

Akhmedov Sh.B. - Kislovodsk Astronomic Station

Gnevyshev M.N. - Kislovodsk Astronomic Station

Ermoshenko V.L. - Kislovodsk Astronomic Station

Altukhov A.M. - Institute for Nuclear Physics, Moscow University

Lyubimov -Institute for Nuclear Physics, Moscow University

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Logachev Yu.I. - Institute for Nuclear Physics, Moscow University

Kuzhevsky B.M. - Institute for Nuclear Physics, Moscow University

Charakhchyan - Institute for Nuclear Physics, Moscow University

Veselovsky N.S. - Institute for Nuclear Physics, Moscow University

Ganzha S.I. - Main Astronomic Observatory of Ukranian Academy

Kondrasheva - Astronomic Observatory of Kiev University

Redyuk - Astronomic Observatory of Kiev University

Pogodin N.E. - Physical Research Institute of Leningrad University

Grebinsky A.S. - Physical Research Institute of Leningrad University

Ponyavin D.I. - Leningrad University

Chertkov A.D. - Leningrad University

Laba I.S. - Astronomic Observatory of L'vov University

Bazilevskaya G.A. - Levedev Institute

Svirzhevskaya A.K. - Lebedev Institute

Frank A.G. - Lebedev Institute

Dogel V.A. - Lebedev Institute

Somov B.V. - Lebedev Institute

Zhitnik I.A. - Lebedev Institute

Urnov A.M. - Lebedev Institute

Kazachevskaya T. - Institute of Applied Geophysics

Ivanov-Kholodny G.S. - Institute of Applied Geophysics

Korobova Z.B. - Astronomic Institute, Tashkent

Sitnik G.F. - Shternberg Institute

Kiryukhina A. - Shernberg Institute

Prokudina V.S. - Shternberg Institute

Porfiryeva G.A. Shternberg Institute

Yakunina G.V. - Shternberg Institute

Makarova E.A. - Shternberg Institute

Efimov Yu. Crimean Observatory

Nesterova - Crimean Observatory

Tsvetkov - Crimean Observatory

Gopasyuk S.I. - Crimean Observatory

Orlova N.E. - Crimean Observatory

Steshenko N.V. - Crimean Observatory

Kotov V.A. - Crimean Observatory

Stepanyan N.N. - Crimean Observatory

Babin A.N. - Crimean Observatory

Koval - Crimean Observatory

Vaisberg O.L. - Space Research Institute

Zastenker G.I. - Space Research Institute

Locans V.A. - Radioastrophysical Observatory, Riga

Kuznetsov V.D. - MFTI

Aimanov A.A. - Alma-Ata

Mandelshtam S.L. - Institute of Spectroscopy

Romanov V.A. - Krasnoyarsk University

Kocharov M.G. - LPI

Stepanov V.E. - SibIZMIR

Kasinsky V.V. - SibIZMIR

Kuklin G.V. - SibIZMIR

Golovko A.A. - SibIZMIR

Tomozov V.M. - SibIZMIR

Mikhalkovsky G.V. - SibIZMIR

Klochek N.V. - SibIZMIR

Ermakova L.V. - SibIZMIR

Palama-chuk L.E. - SibIZMIR

Firstova N.M. - SibIZMIR

Maksimov V.P. - SibIZMIR

Mamedov S.G. - Shemakha, Astrophysical Observatory

Oridzhev E.Sh. - Shemakha, Astrophysical Observatory

Bogod B.M. - Shemakha, Astrophysical Observatory

Korzhavin - Shemakha, Astrophysical Observatory

Seidov A.G. - Shemakha, Astrophysical Observatory

Dyatel N.P. - Astronomic Observatory of Kharkov University

Orishenko A.V. - LFTI

Charikov Yu.E. - LFTI

Kulidzhanishvili V.I. - Abastumani

Oks E.Ya - V.N.I.I.F.T.R.I.

Zheleznyakov V.V. - Institute of Applied Physics, Gorky

Korshunov A.I. - NIRFI

Kozhevatov I.E. - NIRFI

Non-Soviets

Wu S.T. - University of Alabama (U.S.A.)

Wolfson C.J. - SMM XRP Experiment - Lockheed Missiles & Space Co. Inc. (U.S.A.)

Antonucci E. - SMM XRP Experiment - Rutherford & Appleton Laboratories (U.K.)

Wagner W. - SMM C/P Experiment - High Altitude Observatory (U.S.A.)

House L. - SMM C/P Experiment - High Altitude Observatory (U.S.A.)

Simnett G. - SMM HXIS Experiment - University of Birmingham (U.K.)

Jain R. - Vedshala Udaipur Solar Observatory (India)

Prokakis Th. - National Observatory of Athens (Greece)

McKenna-Lawlor S. - St. Patrick's College (Ireland)

Garcia de la Rosa J.I. - Instituto de Astrofisica de Canarias (Spain)

Hiei E. - Tokyo Astronomical Observatory (Japan)

Emslie G. - Stanford University (U.S.A.)

Urpo S. - Metsahovi Radio Research Station (Finland)

Simon P. - Meudon Observatory (France)

Henoux J.C. - Meudon Observatory (France)

de Jager C. - Space Research Laboratory (The Netherlands)

Slottje C. - Dwingeloo Radio Observatory (The Netherlands)

Landecker P. - Aerospace Corporation (U.S.A.)

Gaizauskas V. - Ottawa River Solar Observatory (Canada)

Kundu M. - Clark Lake Radio Observatory, University of Maryland (U.S.A.)

Zirin H. - Hale Observatories, California Institute of Technology (U.S.A.)

Lang K.R. - Tufts University (U.S.A.)

Chiuderi-Drago F. - Osservatorio Astrofisica di Arcetri (Italy)

Jakimiec J. - Astronomical Observatory of the Wroclaw University (Poland)

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APPENDIX C

List of Posters and Reports

1. V. N. Ishkov, V. A. Kovalev, E. I. Mogilevsky, G. P. Chernov, N. S. Shilova, V. M. Plotnikov: The complex analysis of a solar flare on August 20, 1979.
2. K. V. Alikaeva, N. N. Kondrasheva, P. N. Polupan, S. I. Gandzha, I. U. Redyuk: Variations in Fraunhofer lines related to flare activity.
3. G. B. Gelfreikh, V. I. Makarov, V. P. Mikhailutsa, A. N. Korzhavin, G. B. Rybkina: Simulations of optical and radio observations of a coronal condensation off the limb on November 19, 1980.
4. Sh. B. Akhmedov, V. M. Bogod, G. B. Gelfreikh: The results of an SMY program study of a local radio source in solar active region McMath 15974 using RATAN-600.
5. R. Jain: 28 March Hα flare in AR 2363.
6. G. S. Ivanov Kholodny, T. V. Kazachevskaya: Variations of EUV integral flux in the period of the solar activity maximum from Prognoz-7 measurements.
7. B. N. Vasilyev, I. A. Zhitnik, V. I. Karev, B. V. Korneev, V. V. Krutov, V. M. Lomkova, S. L. Mandelshtam, S. N. Oparin, A. M. Urnov: Preliminary results of investigations of the X-ray spectrum of the Sun by the Vertikal-8 rocket.
8. V. I. Bulavina, A. I. Kiryukhina, V. S. Prokudina, G. V. Yakunina: Prominence observations with an Hα filter in August and September 1980.
9. G. F. Sitnik, V. S. Prokudina, V. I. Bulavina, E. A. Makarova: Observation of the active regions from 1/9 to 5/9, 1980.
10. H. Zirin: Magnetic transients in flares.
11. H. Zirin, G. Hurford, K. Marsh: Small radio sources in flares.
12. V. A. Efanov, I. G. Moiseev, N. S. Nesterov: Radio emission characteristics of McMath 16862-64 sunspot groups at 8 and 13.5 MHz.
13. H. Kunzel: Variations of the maximum magnetic field strength in the main sunspots of the group N 11°, L = 298°, Rotation #1699 on September 2 to 4, 1980.
14. M. B. Ogir: Intercorrelations between solar active regions according to Hα observations on May 25, 28 and 29, 1980.
15. R. Jain: 22-27 May 1980, Region #s 2456 and 2469.

16. A. N. Babin, A. A. Golovko, A. B. Delone, V. V. Kasinsky, A. N. Koval, A. I. Kiryukhina, E. A. Makarova, N. N. Stepanyan, N. S. Shilova, G. V. Yakunina: Some features of pre-flare situations in the complex ARs 16862, 16863, 16864, May 23-29, 1980.

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APPENDIX D

MAGNETIC RECONNECTION AND ENERGETICS OF A SOLAR FLARE

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In this report we discuss the folowing matters: (1) the two regimes of fast magnetic reconnection and nonsteady processes in the solar atmosphere, (2) thermal instability and the three-dimensional character of magnetic reconnection in a current sheet, and (3) physical processes in the solar atmosphere induced by flare energy release.

(1) Fast Magnetic Reconnection

The idea of a current sheet (Syrovatskii and Somov 1980) is essential for the explanation of fast hydrodynamic flows of solar plasma in the chromosphere and corona during flares and flare-like events (the so-called coronal transients), and for explaining relatively slow motions observed in the photosphere. On the one hand, a comparatively slow energy accumulation may take place in such sheets. This process ends in a sudden explosion when the sheet goes over to a turbulent state. The explosion is accompanied both by direct plasma ejection from the current sheet and by fast motions in the surrounding chromosphere and corona due to field reconnection; an example of such motions is considered by Somov and Syrovatskii (1980a). On the other hand, under certain conditions a turbulent current sheet located above magnetic flux emerging from under the photosphere can penetrate rapidly (at a velocity close to the Alfven velocity) into the upper corona and change the overall field topology by transforming a closed magnetic configuration into an open one (Syrovatskii and Somov 1980; Somov and Syrovatskii 1980b). This process must be accompanied by the appearance of rapid motions (transients) and by a direct transition of magnetic energy into heat and radiation. We should note here that some direct relations between coronal transients and the appearance of open field regions (coronal holes) have been established (Rust 1978; Webb et al. 1978).

Thus, two regimes of fast magnetic reconnection in current sheets are of interest from the viewpoint of the interpretation of nonsteady hydrodynamic phenomena in the corona (Syrovatskii and Somov 1980). The first of them is "rupture" of a laminar quasi-stationary current sheet due to its instability and transition to a turbulent state. In this regime the utmost power of energy release is observed, which corresponds to the flash phase of a solar flare in Syrovatskii's model. The second regime is a fast magnetic reconnection in a quasi-stationary turbulent sheet which may be compared with such coronal phenomena as fast rising of loops and transients (Syrovatskii 1981). The latter processes are frequently observed to be associated with particle acceleration in the corona.

We now consider the determination of current sheet parameters in the regime of fast magnetic reconnection with anomalous resistance and high plasma temperature inside the sheet.

Low-temperature ($T \lesssim 10^5$K) equilibrium states of a current sheet were investigated by Syrovatskii (1976). He showed that in a certain range of temperatures and external parameters (density of the surrounding plasma n_o, strength of the external electric field E_o, and magnetic field gradient scale h_o in the vicinity of its zero line) a quasi-stationary equilibrium of the current sheet is determined by Joule heating (under conditions of Coulomb conductivity) in balance with radiative cooling. Under certain conditions this regime breaks down and there begins an essentially unsteady stage of the current sheet development as a result of which it is likely to come to a new equilibrium state with a high temperature ($T \gtrsim 10^6 - 10^7$K) and low turbulent conductivity. Such a sheet will be referred to as a high-temperature turbulent sheet (HTTS).

An essential role in the energy balance of a HTTS is played by thermal fluxes from the sheet (Somov 1981a). To investigate this question we write the continuity equation, Ohm's law, and momentum and energy conservation laws in the form of the following simple relations applicable under the conditions of a strong magnetic field (cf. Syrovatskii 1976):

$$a n_s v_x = b n_o v_d, \quad B_s^2/8\pi = n_s kT = m_i n_s v_x^2/2, \qquad (1)$$
$$c B_s/4\pi a = \sigma_a E_o,$$
$$H_{ja} = L(T) + C_{\perp e} + C_{\perp i} + C_{||e} + C_{||a}.$$

Here a and b are the half-thickness and half-width of the sheet (Figure 1). We do not consider here slow MHD shocks which can be joined to the edges of a current sheet. n_o and n_s are the plasma densities near and inside the sheet, L(T) is the Cox and Tucker function, which characterizes radiative losses of energy, H_{ja} characterizes current heating of the sheet in the presence of anomalous resistance, $C_{\perp e}$ and $C_{\perp i}$ correspond to sheet cooling due to the electron and ion heat conductivity across the magnetic field, and $C_{||e}$ and $C_{||a}$ characterize sheet cooling due to the classical and anomalous heat conductivity (one or the other applicable depending on the level of plasma turbulence and on the degree of thermal flux saturation).

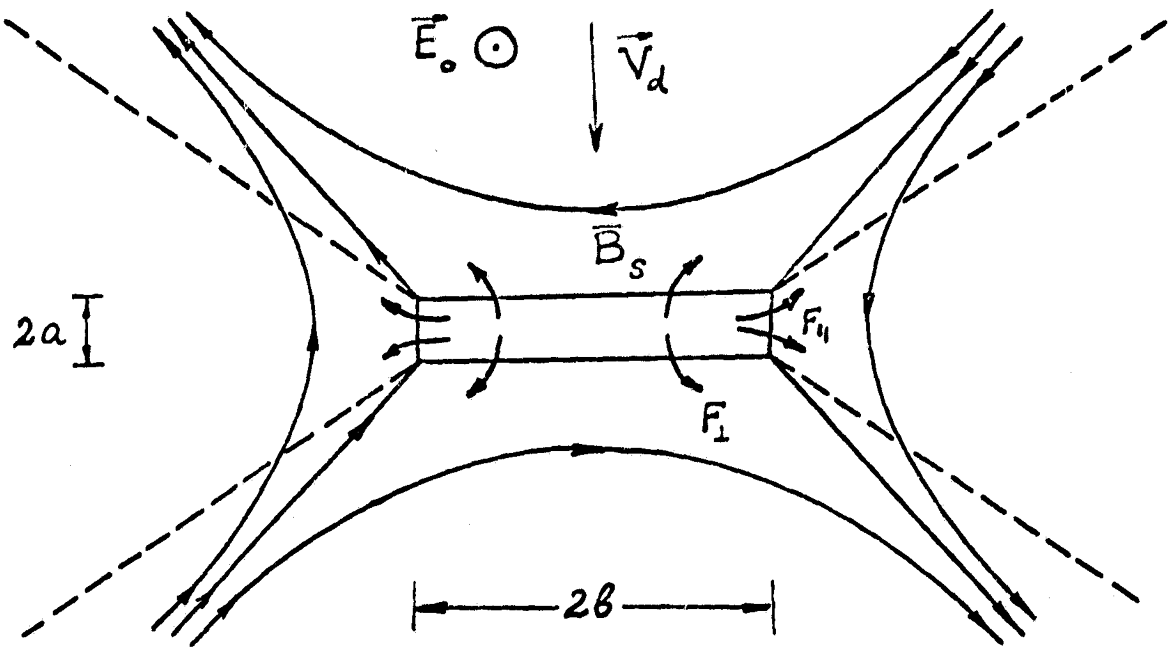

Figure 1: Steady-state model for the magnetic reconnection region. $F_{\perp}$ and $F_{||}$ are heat fluxes across and along the magnetic field. The dotted lines show four possible slow MHD shocks.

Preliminary analysis of the above-mentioned conservation laws for a HTTS in the solar corona makes it possible to determine current sheet parameters and to draw the following conclusions:

(a). There exist high-temperature turbulent equilibrium states of a current sheet. For such HTTS in the solar corona the electron and even ion heat conductivities across the magnetic field do not play any role compared to the thermal fluxes along the field. The role of radiative cooling in an HTTS is also comparatively small. It should be noted, however, that under chromospheric conditions both thermal fluxes across the field and radiative cooling may prove to be important.

(b). The thickness 2a of a HTTS increases with temperature T (at fixed n_o, E_o and h_o) and in general considerably exceeds the thickness of a low-temperature current sheet with Coulomb conductivity. The width 2b of a HTTS depends weakly on the temperature but changes within a wide range of values depending on the values of the external parameters. The plasma density in the sheet decreases as its temperature increases and lies within a wide range of values. The HTTS is characterized by comparatively small magnetic fields, which is convenient for the phenomena occurring high in the corona.

(c). Depending on the size of the electric field E_o, the velocity v_d of plasma influx to the sheet (or the velocity of the HTTS rising in the corona) may be very low, which corresponds to long-lived X-ray loops, or very high, as in the case of coronal transients. At velocities $v_d \approx 10^3$ km s^{-1}, corresponding to the characteristic values of the local Alfvén velocity in the corona, the electric field inside the HTTS may reach enormous values ($\approx$ 10 V cm^{-1}) and may effectively accelerate particles. This conclusion agrees qualitatively with observations of secondary effects induced by accelerated electrons during transients in the absence of solar flares (Webb and Kundu 1978).

Thus, the HTTS model, which provides a fast "break" of the rising magnetic flux into the upper corona and a quick opening of the magnetic field, provides a unique insight into three different but interdependent phenomena: coronal transients, transient coronal holes (as well as quick changes of boundaries of coronal holes [Solodyna, Krieger, and Nolte 1977]) and particle acceleration in the corona.

(2) Thermal Instability

There is no doubt at present that the process of magnetic reconnection can provide transformation of magnetic energy into the energy of fast hydrodynamic flows of solar plasma, fluxes of heat, radiation and accelerated particles necessary for a flare (Syrovatskii 1979). At the same time some properties of this primary mechanism of energy release remain either unknown or not fully investigated (for more details see Somov 1981b). Thus, for example, the mechanism of instability leading to a flare has not been established. In particular, Sweet (1969) assumed, in the general plan, and Coppi (1975), in application to the problem of magnetic reconnection, that thermal instability may be a possible mechanism. However it was possible to justify this assumption only after the parameters of the pre-flare current sheet had been found (Syrovatskii 1976). The current sheet turned out to be a thin cold plasma formation in the energy balance of which an important role is played by radiative cooling; the sheet is heated by Joule dissipation of electric currents and cooled by radiation. As soon as the sheet reaches critical values of its parameters, thermal equilibrium of the current sheet becomes impossible: radiative energy losses cannot balance Joule heating, and rapid sheet heating begins. This process may lead to a chain of kinetic phenomena: the rapid increase of electron temperature, the development of ion-acoustic waves or other plasma instability, transition of the current sheet into a turbulent state, and its reconnection or rupture. Thus thermal instability of a current sheet may play the role of the trigger mechanism of a solar flare.

Analogous conclusions were drawn by Heyvaerts and Priest (1976), who showed that as a result of radiative cooling the region of magnetic reconnection has a lower temperature than the surrounding coronal plasma. However, when rising in the solar atmosphere this region reaches some critical height above which low-temperature thermal equilibrium is no longer possible. As distinct from Syrovatskii's (1976) model, critical parameters were found for Petschek-type reconnection in the vicinity of the magnetic neutral line. Neglecting Joule heating compared with that by heat and wave fluxes, Smith and Priest (1977) investigated the energy balance and thermal instability in a uniform current sheet in connection with the problem of prominence formation. With an increase of the sheet width (dimension 2b along the magnetic field) up to some maximum value, the hot current sheet, which is in thermal equilibrium with the corona owing to a high heat conductivity along the magnetic field, gradually reaches a critical state after which it is cooled rapidly by radiation and contracts as a whole. Such a process may result in cold dense formations in the solar corona like quiet prominences (Smith and Priest 1977).

Longitudinal stability of a sheet homogeneous in the direction of the current is considered by Somov and Syrovatskii (1980c). The problem of plane neutral sheet stability to small perturbations with the wave vector parallel to the current (Figure 2) was solved in the magnetohydrodynamic approximation taking into account heat conductivity and radiative losses of energy. It was shown that when account is taken of radiation losses, the current sheet breaks up into a system of filaments with a higher density and a lower temperature. These filaments are parallel to the magnetic field. This process corresponds to the condensation mode of thermal instability (Field 1965). However, even in the given simplified formulation of the problem it evidently differs from the formation of cold dense condensations in a uniform medium when the velocity of matter contraction on large scales is restricted to the sound velocity. In the case of a homogeneous medium the instability increment tends to zero in the long wavelength limit ($k_z \to 0$). On the contrary, as is seen from the linear analysis (Somov and Syrovatskii 1980c), a current sheet may be cooled by radiation and contract as a whole. This contraction proceeds across the current sheet on a scale 2a. For perturbations with a finite wavelength, along with plasma flows across the sheet (v_y), flows along the current sheet (v_z) are also important.

Note that plasma flows along the current sheet cannot be taken into account in two-dimensional magnetic reconnection models.

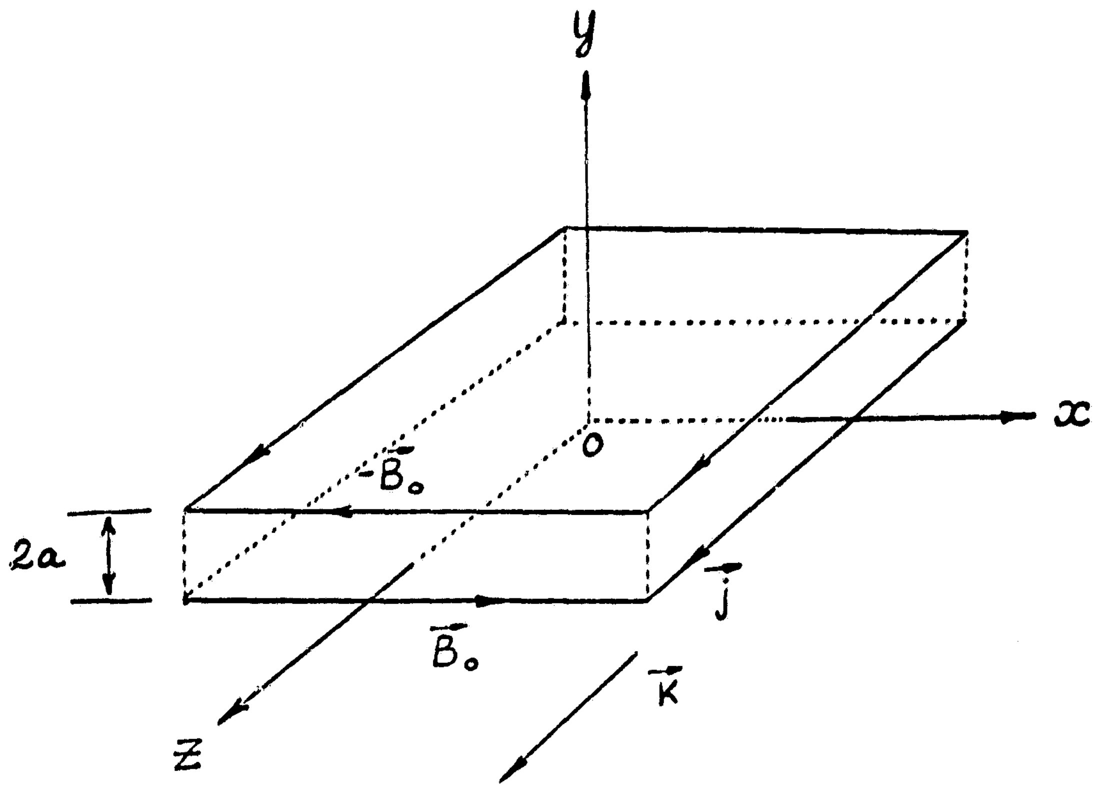

Figure 2. Plane neutral current sheet induced by the jump of a uniform magnetic field parallel to the x-axis from the value B_o at $y < -a$ to the value $-B_o$ at $y > a$. $\underset{\sim}{K}$ is the wave vector of small disturbances propagating parallel to the current $\underset{\sim}{j}$.

At the same time it is not excluded that these flows considerably change the mass and energy balance in a three-dimensional picture (Figure 3) of magnetic reconnection, which should be expected as a result of current sheet thermal instability. At a nonlinear stage of development cold dense filaments radiating in optical and UV-bands may be formed inside the sheet. These filaments are surrounded by high-temperature rarefied plasma which is the source of X-ray radiation, and also the source of thermal fluxes directed along magnetic lines. Coronal plasma flows into the current sheet with drift velocity $v_y \simeq v_d$ and is heated. Then, moving across (v_y) and along (v_z) the sheet, the hot plasma gets inside the filaments, is cooled by radiative losses and contracts. Cold plasma must flow out of the sheet along the filaments at velocities close to the Alfvén velocity ($v_x \approx v_A$), like in the two-dimensional magnetic reconnection model (see Sweet 1969; Syrovatskii 1976).

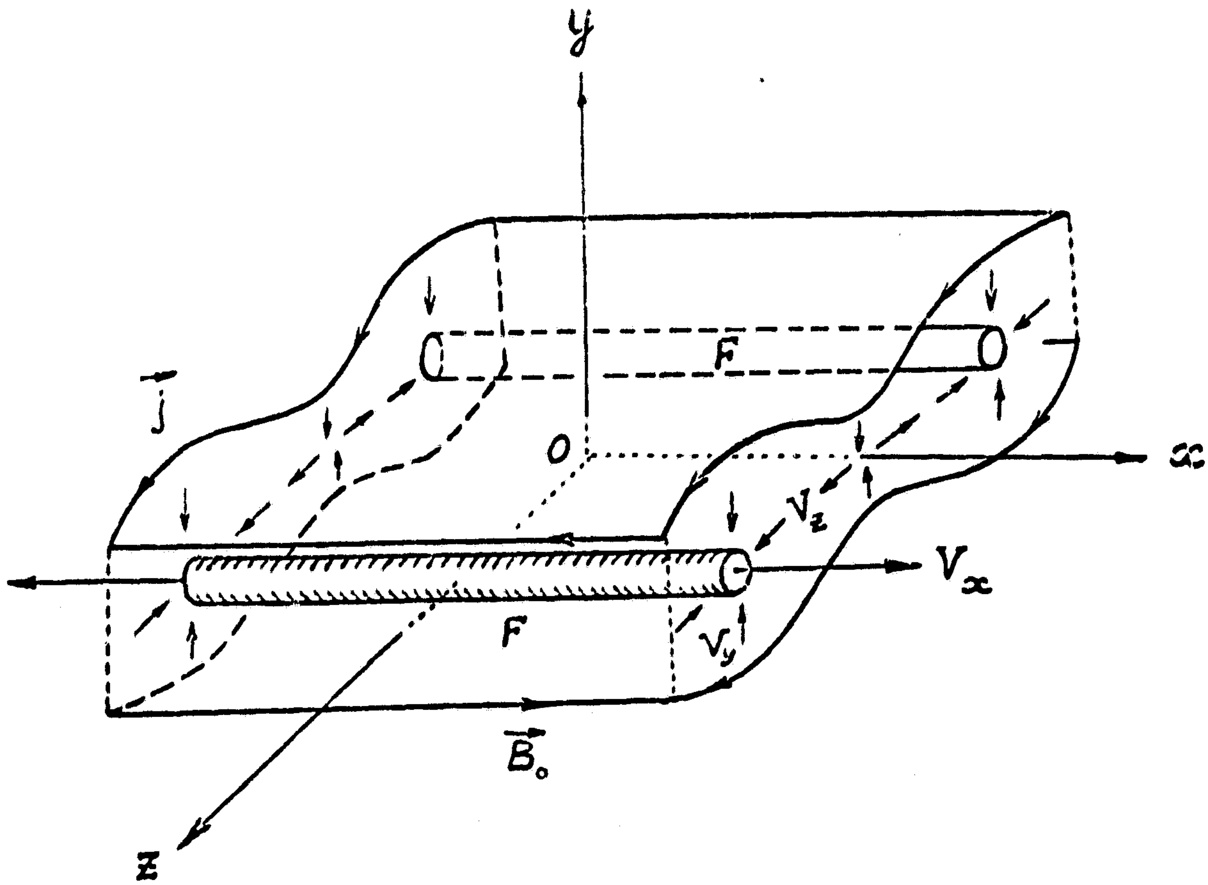

Figure 3. Expected picture of the three-dimensional magnetic reconnection. F shows cold dense filaments produced by the thermal instability; v_z is the velocity of plasma flows along the current sheet.

Thus, plasma motion in the vicinity of and inside a current sheet which has undergone the thermal instability has a complex three-dimensional character.

One may assume (see Somov and Syrovatskii 1980c) that the current sheet thermal instability process considered here is the cause of the appearance of arcades (Figure 4) of hot cool-cored loops observed in the solar corona (Foukal 1975; Levine and Withbroe 1977). In the case when thermal instability serves as a trigger mechanism of a flare, it must evidently result in arcades of flare loops and "elementary bursts" (see de Jager 1979) of hard X-rays. However, for comparison with observations further development of the theory is necessary, namely the study of the nonlinear stage of thermal instability in the framework of a three-dimensional MHD problem of magnetic reconnection.

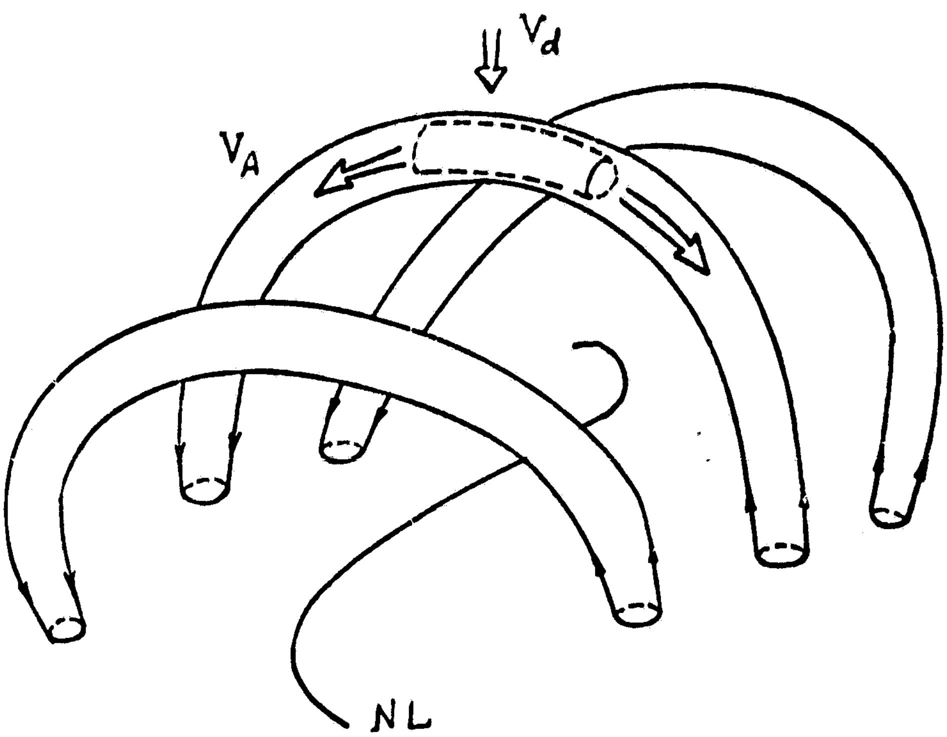

Figure 4. The arcade of hot, cold-cored, loops in the solar corona. NL is a photospheric neutral line.

3. Induced Processes in the Solar Atmosphere

We shall not present here a detailed discussion of all physical processes in the solar atmosphere induced by flare energy release (see the reviews by Somov and Syrovatskii 1976 and by Syrovatskii and Somov 1981). We shall only mention two new results which directly concern the International Solar Maximum Year program.

The first of them is a calculation of the hydrodynamic response of the chromosphere to a impulsive heating by very powerful heat fluxes during an "elementary flare burst" in the framework of a thermal (with an electron temperature $T_e \gtrsim 10^8$K) model of hard X-ray radiation (Somov 1980; Sermulina, Somov, and Spektor 1980). The characteristic feature of the models, with account taken of all essential dissipative processes, of the difference between the electron and the ion temperatures and also of the thermal flux saturation effect, is a dense cold condensation under the flare transition layer. As was discussed by Somov (1980; see also Somov 1979a), at sufficiently large energy fluxes into the chromosphere such a condensation may be a short-lived source of continuous optical radiation (compact impulsive white-light flare [Zirin and Tanaka 1973]). Rapid cooling and contraction of plasma under the flare transition sheet accelerates the formation of the flare transition layer which is a short-lived source of EUV radiation.

EUV burst intensities are known to depend in a complicated way on the heliocentric distance of the flare (Donnelly and Kane 1978). This dependence may evidently be explained within the following model (Somov 1979b).

When propagating along a magnetic flux tube (1 in Figure 5) into the chromosphere, a flux F_0 of energetic electrons (either thermal or nonthermal) creates a high-temperature region and a flare transition layer C_1. The hot plasma and the transition layer are a source of X-ray and EUV-radiation. Radiation with $\lambda < 912$ Å is absorbed in the upper chromosphere, heats it and as a result gives rise to a secondary, shallower, transition layer C_2. The observed dependence of the EUV burst amplitude on the heliocentric angle (Donnelly and Kane 1978) can be brought into agreement with the model under consideration if the ratio of the depths d, at which the transition layers are placed, to their widths w are such that $d/w \approx 2$ for C_1 and $d/w \approx 0.1$ for C_2. It is typical that the same process, namely a rapid heating of the upper chromosphere by a shortwave ($\lambda < 912$ Å) radiation, enhances soft X-ray radiation since it leads to an additional "evaporation" of the upper chromosphere.

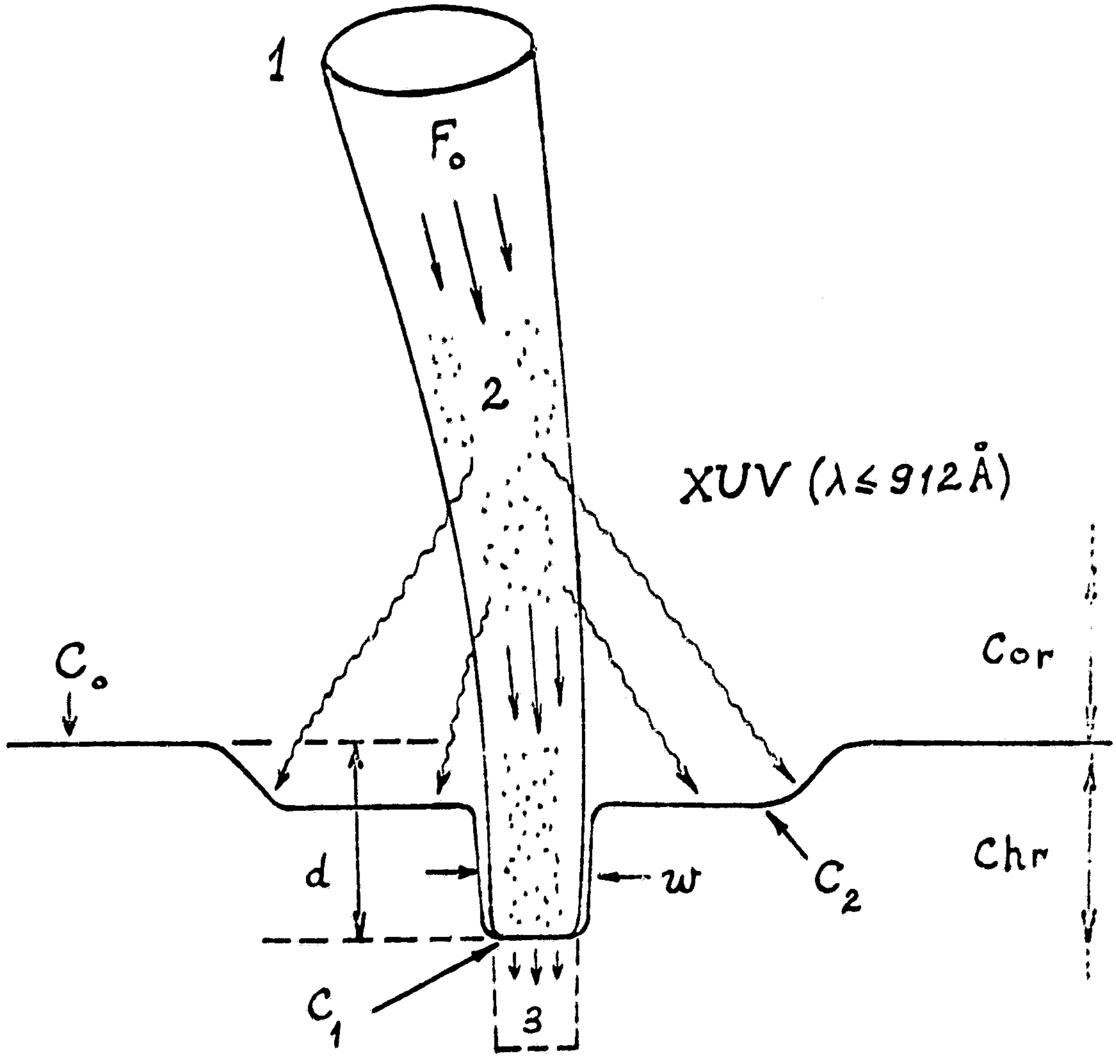

Figure 5. Flare transition layers as the source of EUV radiation: Cor means the corona, Chr is the chromosphere, (1) magnetic flux tube, (2) high-temperature plasma, (3) low-temperature (optical) plasma. C_o shows the transition layer in quiet atmosphere, C_1 is a primary transition layer inside the magnetic tube, C_2 is the secondary transition layer.

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APPENDIX E

Observational Signatures of Thermal and Non-Thermal Models of Hard X-Ray Emission in Solar Flares

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The emission of hard X-ray radiation in solar flares is usually attributed to electron-proton bremsstrahlung from an ensemble of very high energy electrons. However, there is currently much controversy as to whether these electrons form part of a thermally relaxed distribution (i.e, a "thermal" model) or instead a beam of suprathermal electrons (i.e, a "non-thermal" model). Non-thermal models may be further subclassified into beam and trap models. The most efficient of these models is the "thick target" model (Brown 1971). For this reason I shall subsequently compare the thick target model, as a representative of the class of non-thermal models, with the thermal model proposed originally by Brown, Melrose, and Spicer (1979).

The essential physical difference between the two models lies in consideration of the energy losses from the high energy electrons. In the non-thermal thick target model the dominant energy loss is Coulomb collisions with the ambient cold electrons in the target. In the thermal model the dominant energy losses are due to conduction and convection from the hot plasma. Since the collisional lifetime of an electron is a decreasing function of target density, one can easily show that for source densities greater than about 10^{10} cm^{-3}, the thermal model is more efficient (e.g., Smith and Auer 1980). This is the principal reason for the renewed interest in thermal models, since it is easily demonstrated that the energetic requirements of a thick target model (or any other non-thermal model) require that a large fraction of the flare energy be released in the form of accelerated electrons. It is at present unclear how to accomplish this satisfactorily.

As is the case for any radiation field, there are five observational signatures which can perhaps help us distinguish between thermal and non-thermal models of hard X-ray emission in solar flares. These are the intensity, spectrum, directionality, polarization, and spatial location of the hard X-ray emission. We shall next consider each of these in turn.

The intensity and spectrum of hard X-ray emission in solar flares is frequently described by the mathematical fit of a power law to the observed intensity vs. (photon) energy points. This fitting procedure is highly artificial and has little physical basis. It is, however, frequently used as an indication of a non-thermal origin of the hard X-ray emission, since a power law deviates substantially from a Maxwellian over a significant range in energy. However, it is by no means apparent that thermal emission must have a Maxwellian spectrum. In fact, it can be easily shown that, for a distribution of temperatures in a thermal source, a power law spectrum can be easily reproduced. We thus conclude that spectral measurements, by themselves, are incapable of distinguishing between thermal and non-thermal interpretations of hard X-ray emission in flares.

An observation with potentially great promise for discriminating between thermal and non-thermal interpretations is the directionality and polarization of the hard X-ray emission produced. Since a non-thermal model involves beams of electrons, one should expect any X-ray radiation to be highly polarized and furthermore highly anisotropic. In thermal models, however, one expects only a low degree of polarization; any polarization in fact present is due to the presence of a thermal conductive flux, which skews the electron distribution from a Maxwellian. However, one must bear in mind that in the thermal model currently in vogue, there is a substantial non-thermal component at high energies (greater than about 100 keV). These electrons have such high energy that they are not effectively confined by the plasma turbulence which confines the lower energy electrons, and they therefore form a beam much as in the thick target model. One thus expects, in the thermal model, the directionality and polarization of the hard X-ray emission to vary from being quite low at low energies to being substantially higher at high energies (Emslie and Vlahos 1980). The effects of photospheric backscatter somewhat complicate this picture.

We now turn to observations of the directionality and polarization of hard X-ray emission in flares. There are few stereoscopic measurements of a solar flare in hard X-rays. The few that do exist (Kane et al. 1980) are consistent with essentially isotropic emission from the flare in question. Most results on the directionality of hard X-ray emission in flares are based on statistical center-to-limb studies of both intensity and spectra. Due to the great difficulty in allowing for the variation in brightness of individual flares themselves, the results from this observational program are at present inconclusive. With regard to polarization measurements, carried out principally by Soviet scientists (e.g., Tindo, Shuryghin, and Steffen 1976), one notes that they are carried out at low energies only. Further, they are subject to large uncertainties due to the method of data collection used. However, at present such observations definitely seem to favor the non-thermal interpretation of hard X-ray emission.

Finally we turn to the most recently available diagnostic of hard X-ray emission, namely the spatial location of this emission. In the thick target model, one should expect the greatest hard X-ray brightness to be in the chromosphere, due to the high ambient plasma density there. In the thermal model, we similarly expect a bright component in the chromosphere, due to the escaping high energy tail of electrons; however we also expect a large brightness in the coronal part of the loop due to the emission from the confined thermal plasma. This results in a quite complicated hard X-ray spatial structure, which is also sensitive to the parameters of the model. Predictions of the spatial structure in both models for a range of parameters have been made by Emslie (1981).

Observations of the spatial structure of hard X-ray emission have been carried out by the Hard X-ray Imaging Spectrometer on board the Solar Maximum Mission. This instrument consists of an array of photomultiplier detectors, which are sensitive to emission in six energy channels. We shall here be concerned with the high energy channels, namely channel 5, which ranges from 16 to 22 keV, and channel 6, which ranges from 22 to 30 keV. Observations with this instrument (Hoyng *et al.* 1981) of a flare on May 21, 1980 (2050 UT) show strong emission at the foot points but very little emission in the corona. These observations therefore seem to favor a non-thermal model.

It is my personal opinion that current observations are by no means conclusive. Future observations which I believe to be of use in the discrimination between the two interpretations are:

1. Stereoscopic pictures of flares in hard X-rays. This could be accomplished by two different satellites separates by a suitable difference in ecliptic longitude (see Kane *et al.* 1980).
2. Hard X-ray imaging at higher energies (> 30 keV).
3. Polarization measurements over a *range* of energies.

Such measurements are suited to a program of international cooperation such as that of the Solar Maximum Year.

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Figure Captions

Figure 1 - (a) Hard X-ray models. (b) A comparison between non-thermal (N-T) and thermal (T) models (see Emslie and Rust 1979, Solar Phys., 65, 271 for details).

Figure 2 - (a) X-ray spectrum from a thermal source (Emslie and Brown 1980, Ap. J., 237, 1015). i and Φ refer to the orientation of the loop on the solar disk. Note that a power law is a better fit. (b) Variation of polarization versus energy (from Emslie and Vlahos 1980).

Figure 3 - (a) Predicted spatial structure of hard X-rays, for a variety of photon energies E (from Emslie 1981). (b) The resulting appearance of hard X-ray loops for three cases.

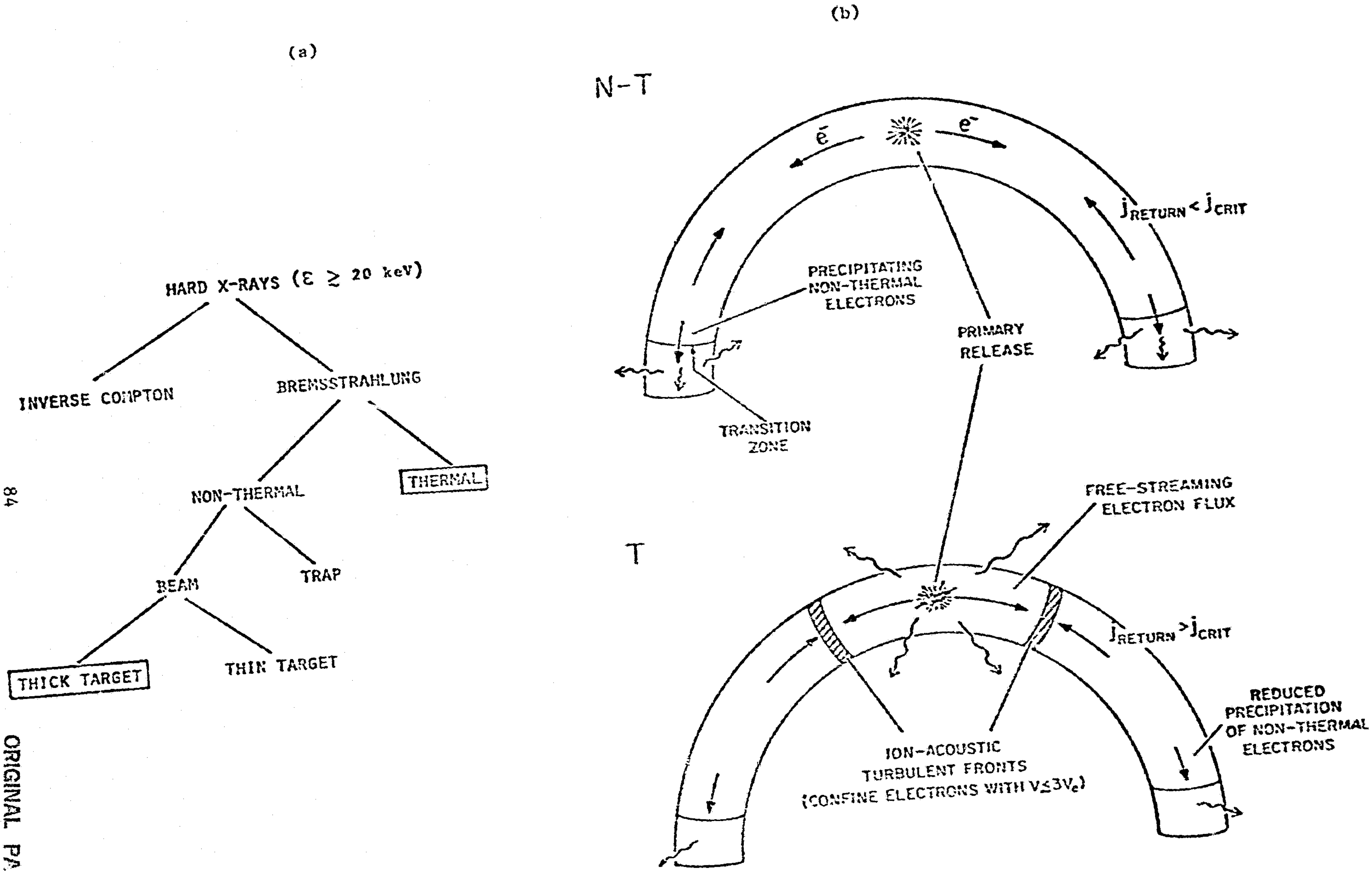
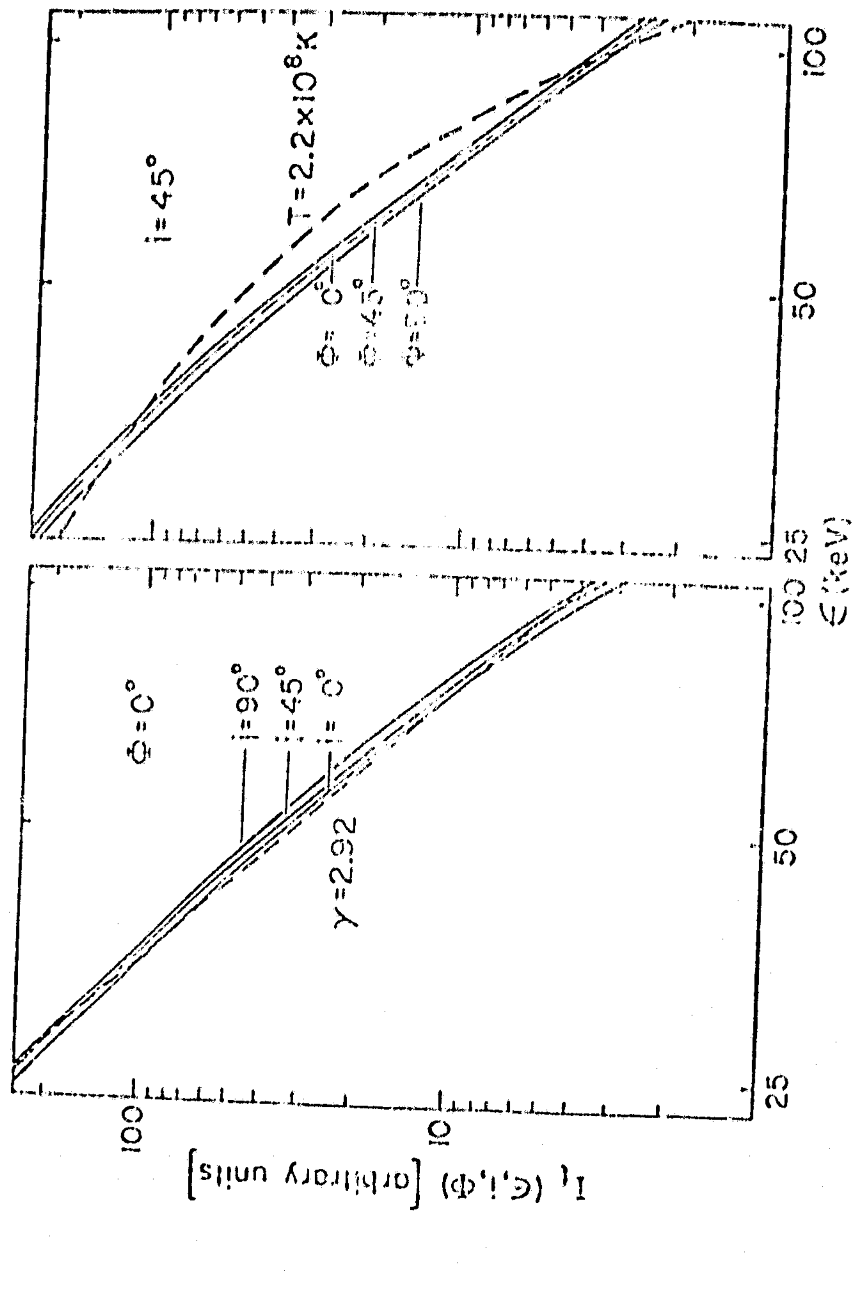
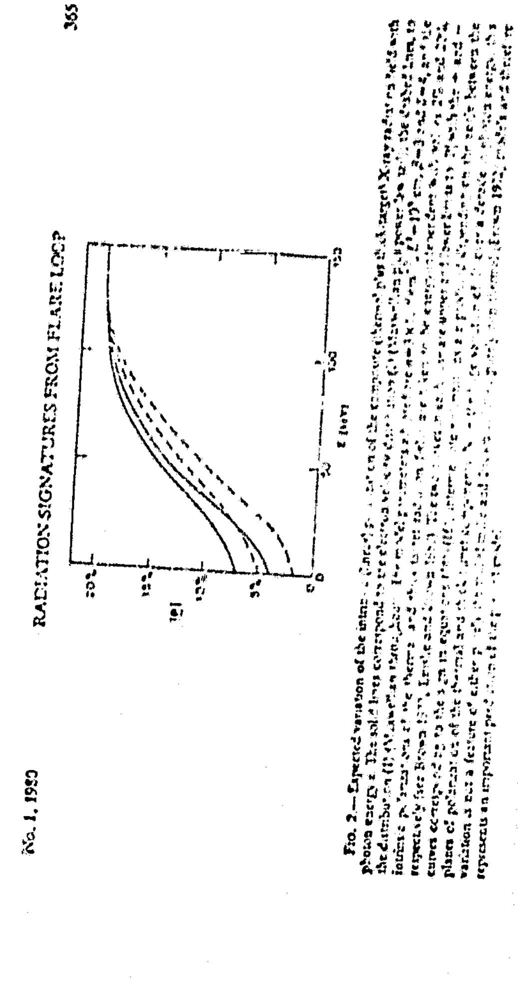

(a)
HARD X-RAYS ($\varepsilon \geq 20$ keV)
INVERSE COMPTON
BREMSSTRAHLUNG
NON-THERMAL
THERMAL
BEAM
TRAP
THICK TARGET
THIN TARGET
(b)
N-T
e^-
e^-
$j_{RETURN} < j_{CRIT}$
PRECIPITATING NON-THERMAL ELECTRONS
PRIMARY RELEASE
TRANSITION ZONE
T
FREE-STREAMING ELECTRON FLUX
$j_{RETURN} > j_{CRIT}$
REDUCED PRECIPITATION OF NON-THERMAL ELECTRONS
ION-ACOUSTIC TURBULENT FRONTS (CONFINE ELECTRONS WITH $V \leq 3V_e$)

Figure 1


Φ=0°
i=90°
i=45°
i=0°
γ=2.92
i=45°
T=2.2×10^8 K
Φ=0°
Φ=45°
Φ=90°
I1 (ε,i,Φ) [arbitrary units]
ε (keV)
25
50
100
10
100

(a)

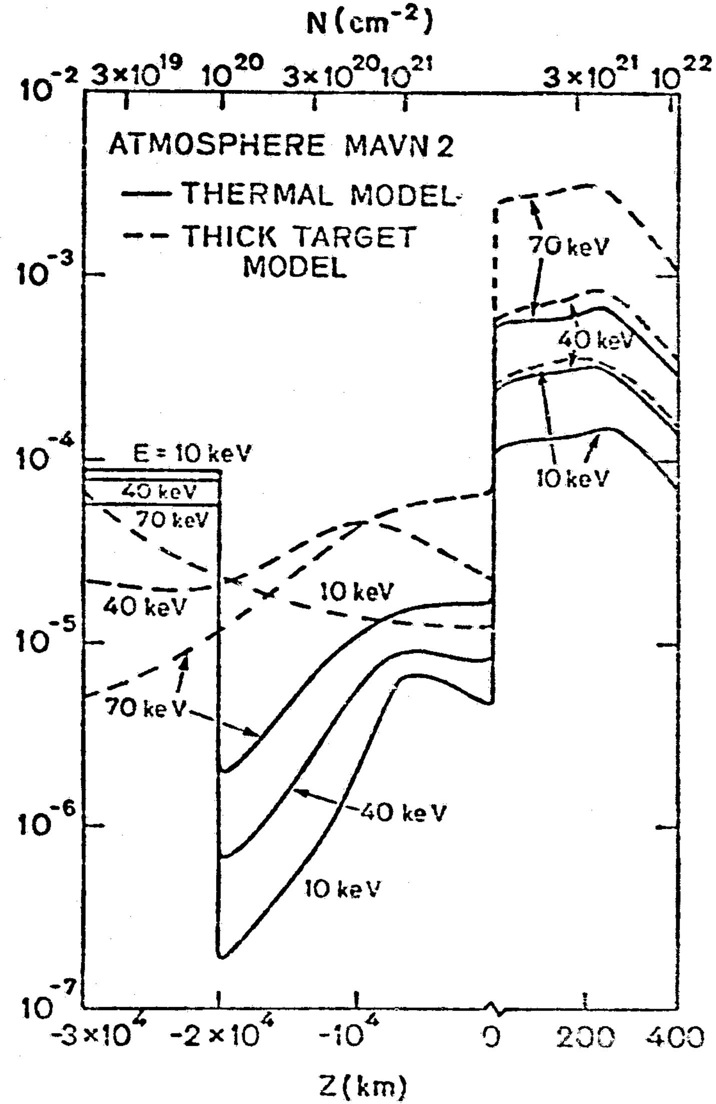

No. 1, 1980
RADIATION SIGNATURES FROM FLARE LOOP
365

(b)

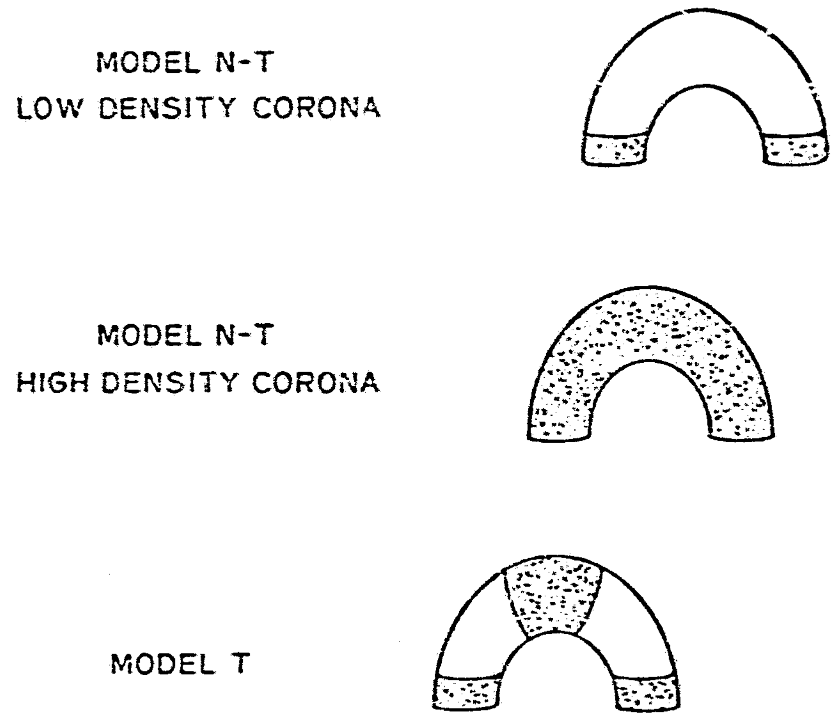
Figure 2

Figure 3

(a)


N (cm⁻²)
3×10^19 10^20 3×10^20 10^21 3×10^21 10^22
ATMOSPHERE MAVN 2
THERMAL MODEL
THICK TARGET MODEL
E = 10 keV
40 keV
70 keV
10 keV
40 keV
70 keV
40 keV
10 keV
70 keV
40 keV
10 keV
φ (km⁻¹)
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
-3×10^4 -2×10^4 -10^4 0 200 400
Z (km)

(b)


MODEL N-T
LOW DENSITY CORONA
MODEL N-T
HIGH DENSITY CORONA
MODEL T