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L. Acton, chair	H. Hudson, secretary
D. Bohlin, NASA	R. Lin
C. Brueckner	D. Neidig
G. Dulk	R. Ramaty
J. Harvey	R. Rosner
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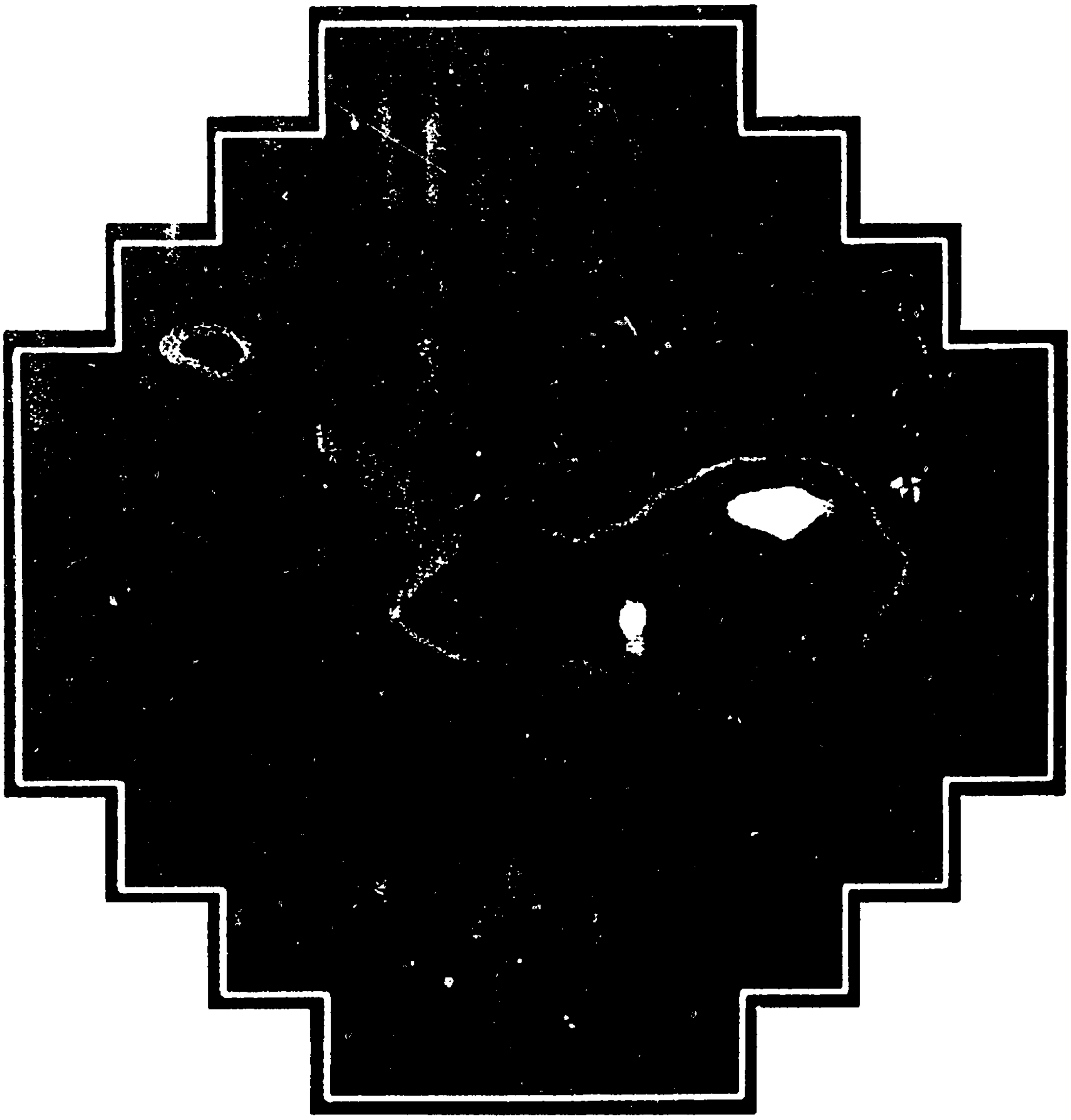
MAX '91: THE ACTIVE SUN

A PLAN FOR PURSUING THE STUDY OF THE ACTIVE SUN AT THE TIME OF THE NEXT MAXIMUM IN SOLAR ACTIVITY

JANUARY, 1985



Commissioned by the Solar Physics Division of the American Astronomical Society and the National Aeronautics and Space Administration

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MAX '91: THE ACTIVE SUN

PREFACE: This report gives the results of the discussions of a working group for the definition of a program for the forthcoming "crest" of solar activity, 1990 - 1993. The working group has the sponsorship of the Solar Physics Division of the American Astronomical Society and the National Aeronautics and Space Administration. It met on April 26-27, 1984, and again on September 27, 1984. Advice was also solicited from the U.S. and international solar-physics communities through a questionnaire circulated by the SPD and at the Solar Maximum Mission Solar Flare Workshop in February, 1984. We list below the membership of the working group:

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Cover Illustration: Observations from the Solar Maximum Mission of a major solar flare on November 5, 1980. The image shows the "foot-point brightening" seen in 16-30 keV hard X-rays (white), together with the structure of the 3.5 - 8 keV soft X-ray sources (colored contours), using data from the Hard X-ray Imaging Spectrometer. Such observations strongly suggest that flares derive their energy from the coronal magnetic structures connecting the foot-points (courtesy B. Dennis and the HXIS experiment team).

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I. INTRODUCTION AND SUMMARY

The rise and fall of solar activity paces our studies of active-plasma phenomena such as sunspots, solar flares, particle acceleration, and coronal mass ejections. Such displays are due to the evolution of magnetic structures produced in the solar cycle, which controls phenomena occurring on both short and long time scales. Understanding the physics of solar activity is a basic element in understanding the physics of active plasma phenomena in many other places in the Universe beyond the solar system.

The MAX '91 program described here intends to achieve important scientific goals within the context of the natural solar variability. The heart of the MAX '91 program is a series of campaigns oriented towards specific scientific problems, and taking place in the solar maximum period 1990 - 1993. These campaigns will take advantage of the load-carrying capability of the Space Shuttle to fly instruments with observational capabilities very different from those of the Solar Maximum Mission. These instruments presently exist (*e.g.* rocket or balloon), are under development (*e.g.* the SUNLAB instruments and the Solar Optical Telescope), or are planned for development by the time of the next solar maximum (*e.g.* the Pinhole/Occulter Facility). Various combinations of instruments appropriate to the specific scientific problem of a given campaign would be flown on a Shuttle sortie mission. Ground-based, suborbital, or other space observations would participate fully in the campaigns. The experimental and scientific program of each campaign will be defined by a team of experimenters, observers, and theorists to be solicited by an Announcement of Opportunity. Each campaign team will follow its program through to completion, and the continuity of attention to the campaign by the team and by the remainder of the community will allow for the best possible theoretical input at all phases of the program, rather than essentially after the fact as in past programs. We feel that this increased level of communication and information transfer will produce major rewards in the quality and relevance of the scientific results.

The exact nature of campaign themes will be reserved for the responses to an Announcement of Opportunity, but we list several typical ones here:

1. <u>Active-region</u> <u>Energetics</u>. How does an active region distort the energy flow in the solar envelope? Are faculae energetically associated with sunspots? A representative active region should be studied in detail during its disk passage, with optimal capability for diagnostic analysis of magnetic and structural evolution, with precise irradiance measurements to define the radiant energy.

2. Flare Energy Release. Is the energy released in a flare provided by storage in the corona, or is the energy release driven by a photospheric mechanism? The high-energy emissions from solar flares must be observed simultaneously with diagnostic data on structures and physical conditions in the flare energy-release site.

3. Determinations of Conditions for Particle Acceleration. Where and when does particle acceleration occur in any of the sites now known to exist? What are the plasma conditions and the magnetic field geometry?

4. Sources of the Solar Wind at Activity Maximum. Where are the open field lines supporting the solar wind at maximum, when coronal holes may not be available? This is coupled to the basic question of identifying the mechanism for energy and momentum deposition in the corona, which is not understood. Sensitive coronal diagnostic observations would be the cornerstone for investigations of these questions.

5. Search for Drivers of Coronal Transients. What are the instabilities which lead to explosive reconfiguration of coronal structures? Are transients the result of large-scale configurational adjustments of coronal magnetic fields, or are they the cause of such adjustments? What is the division of energy among kinetic, thermal, enthalpy, associated shocks, and convected magnetic fields? What is the relationship - cause and effect - between coronal transients and low-coronal flares?

6. Exploration of the Physics of "Thermal Tail Escape". How are the excitation conditions altered in situations with steep temperature gradients, as in flares or the corona/chromosphere transition zone? How does this "thermal tail escape" (*i.e.*, the escape of the high-energy tail of the Maxwellian distribution of electron velocities) affect the theory of thermal conduction in the solar atmosphere?

7. Exploring and Understanding the Origins of Spatial Intermittency in the Solar Atmosphere. The few available very high (< 1") spatial resolution observations of the Sun suggest that the next generation of high-resolution instruments will find a wealth of fine-scale structures, seen at visible, UV, and X-ray wavelengths. We do not understand the origins of this prevalence of departures from homogeneity, whether in the photosphere or in the corona.

These and other "campaigns" will involve theorists and others (such as non-solar specialists) from their inception. We anticipate that the structure of a campaign will not be rigidly determined at the time of team selection, in order that the team can play a major role in defining the campaign. Each campaign will necessarily have secondary objectives since its success will depend upon solar conditions to a certain extent. A uniform data-base management scheme would be very desirable, both to permit all of the team members to participate in the analysis and also to assure that the analysis aspect of the program is not omitted from the planning and development stages of the campaign. This data base should of course include ground-based as well as space data.

II. SCIENTIFIC PROBLEMS NEAR THE CREST OF SOLAR ACTIVITY

A. Introduction

The solar maximum of 1980 has seen the introduction of remarkable new observational techniques and an unprecedented growth in our knowledge of solar activity. The Solar Maximum Mission and the Japanese Hinotori satellites carried, for example, the first hard X-ray imaging instruments. The new discoveries of this period, as reviewed below, have shown that our earlier concepts of the physics of solar activity were seriously incomplete or wrong in many cases. In order to exploit these basically new developments, we need new observations. The purposes of the MAX '91 studies are to determine what critical new measurements are required, to obtain these measurements, and to use them to expand our knowledge of the physics of solar activity.

In this section we briefly review and comment upon the scientific status of solar-activity research. The following list enumerates major discoveries resulting from observations of solar activity in the recent (1978-1982) solar maximum; we regard this as a good way of illustrating the vigor of the field and as an indication of areas that require further research.

Major Recent Discoveries about Solar Activity

* Non-thermal energy release in flares. In the impulsive phase of a a flare, hard X-ray and EUV flashes occur in the foot-points of the magnetic loops revealed by soft X-ray emission. The electron energy loss in these cool regions at the footpoints represents a substantial transport of energy from the corona to the foot-point regions, sufficient to drive other flare effects.

* Energy storage in solar active regions. The first precise measures of time variations of the solar constant show that active regions store energy for periods of at least weeks. Evidence also points to an energy linkage between spots and faculae which must be magnetic in nature.

* Fast acceleration to GeV energies. The energetic γ-ray and neutron data show that ions are accelerated to GeV energies within a few seconds in some flares.

* Flare-like phenomena in the corona. Limited X-ray observations of the corona showed instances of flare-like phenomena occurring far from the lower atmosphere, the traditional site of the Hα "chromospheric flare."

* "Evaporation". Observations and theoretical simulations have defined the hydrodynamics of the filling of flare loops from below with dense, hot new coronal material.

* Microwave maser action in flares. Decimeter wave observations reveal very bright "spike bursts" with rise times ~1 ms and high circular polarization - strong evidence of a cyclotron maser. Theory indicates that cross-field transport of energy by maser radiation may play an important role in the flare process.

* Location of microwave sources. Images from the Very Large Array (VLA) show that most of the > 100 keV electrons that produce centimeter-wave radiation are located near the tops of flaring magnetic flux tubes, and that the sources are smaller at the higher frequencies, often only 2 arc s at 15 GHz.

* Non-thermal phenomena in the transition region. As higher resolution has become available from rocket instrumentation, the smaller spatial scales reveal "microscopic" non-thermal phenomena closely related to the transfer of mass across the transition region between the cool and hot components of the solar atmosphere.

* Electric currents in the corona. Observations and theory have established that field-aligned current systems flow in the corona in active regions, and that these current systems may drive the energy release observed in flares.

* Very hot plasma. Electron temperatures exceeding 3 x 10^7 K, in Maxwellian plasmas, occur in many solar flares.

* Visible continuum in flares. The "white-light" flares occur more commonly than thought, essentially in every very energetic event. The transport of energy to the high-density region of white-light emission is an unsolved theoretical problem.

* Multiple acceleration mechanisms. Particle acceleration in flares and coronal phenomena appears to be associated with plasma turbulence or electric fields in the impulsive phase and with shock formation in the corona. In the former a "second step" of acceleration may produce a delayed high-energy component.

* High-energy neutrons. The first detections of direct neutron emission by the sun have opened a new channel of diagnosis for acceleration mechanisms in flares.

B. Scientific Survey

1. Non-thermal Energy Release

One of the most important results of the past solar maximum was the positive identification of the impulsive flare hard X-ray source regions with the footpoints of magnetic loops. These footpoints were shown to be cool, *i.e.* kT much less than the particle energy of the electrons producing the X-radiation. Under these conditions the ratio of bremsstrahlung X-ray losses to collision losses for the electrons is of order 10^{-4} - 10^{-5}, so the energy contained in the electrons must be a signficant fraction of the total flare energy. Thus, the acceleration of 10-100 keV electrons must be closely related to the primary energy release mechanism of a solar flare. It was also found that particle acceleration accompanies very small events, even below the subflare classification. These results, coupled with the properties of γ-ray emission as described below, point to the close identification of particle acceleration with energy release in solar activity.

In the 10 - 100 keV X-ray region, the Pinhole/Occulter Facility is capable of providing fundamentally different information on the mechanisms of flares and particle acceleration. With its orders-of-magnitude higher sensitivity and spatial resolution, the Pinhole/Occulter Facility will be able to identify for the first time the location of the initial flare energy release, and also to follow the propagation of the accelerated electrons through the solar atmosphere. Powerful diagnostic information in other wavelength regions can then provide information on the density, electron and ion temperatures, magnetic field strength and structure, waves, electric fields, turbulence, cross-field energy transport, and mass motions in these critical locations. With this information, we can approach the basic questions of identifying the energy storage region, its release mechanism, and and the particle acceleration mechanisms.

The very high sensitivity of the Pinhole/Occulter Facility opens up the possibility of studying particle acceleration in the tenuous corona; in type I and type III radio bursts, as well as in the shock regions responsible for type II bursts. For these and other studies, the Pinhole/Occulter Facility can provide wide-ranging diagnostic information through sensitive ultraviolet and white-light observations.

2. Particle Acceleration

One of the outstanding results of the last solar maximum has been the frequent detection of γ-rays from flares. Gamma rays, both lines and continuum, have been observed from over 150 flares at $>$ 300 keV. The γ-radiation provides the only direct means of determining the acceleration of ions and relativistic electrons at the flare site. In another striking discovery, the Solar Maximum Mission also directly detected the neutrons produced by nuclear interactions in flares. Because a neutron's transit time from Sun to Earth depends on its energy, the observed time dependence of the neutron flux is a direct measure of the neutron energy spectrum. Such observations extend our knowledge of the primary energetic-particle spectrum to energies > 100 MeV.

Many important discoveries (see above) have resulted from the γ-ray observations during the 1979 - 1983 solar maximum. These discoveries and their analysis lead naturally to further questions not resolvable with the present information:

(a) The measurement of the detailed γ-ray line spectrum can determine the elemental and isotopic abundances of the accelerated particles and the interaction regions. Current γ-ray spectroscopy already suggests that the composition of the chromosphere differs from that of the photosphere. If substantiated by future observations, this result would have very important implications on the problem of mass and energy transport in the solar atmosphere and on the general subject of abundances in astronomical objects. Observations with an energy resolution better than few keV are required to measure individually the narrow lines of heavy elements such as Mg, Si, and Fe. The sensitivity of these observations should be at least as good as that of the Solar Maximum Mission detector.

(b) Gamma-ray observations with much higher sensitivity than that of the Solar Maximum Mission can determine whether essentially all flares accelerate ions, and can obtain the time history of the ion and electron interaction rates. For ions, this can be achieved by measuring time histories of strong nuclear lines and the 4 - 7 MeV continuum which is dominated by nuclear emissions. For electrons, the continuum emission in the 0.1 - 100 MeV range must be measured. These measurements will address the issues of the acceleration time and the relationship between the processes of energy release and particle acceleration.

(c) Information should be obtained from the line profiles. The 0.511 MeV positron-annihilation line, and the characteristic 3-photon continuum from orthopositronium that accompanies this line, provide excellent handles on the temperature and density of the ambient gas. As in item (a), high spectral resolution is required. Such measurements could also determine the shapes and central energies of a variety of nuclear deexcitation lines, thus revealing bulk motion or beaming of the energetic particles.

(d) The evidence of proton acceleration in the MeV range discussed above suggests that a substantial part of the total flare energy may be in keV-range protons. These particles would not be easily detectable by X-ray or γ-ray production, but they will undergo charge-exchange reactions with neutral hydrogen, and this would result in observable red-shifted Lyman-α radiation. Observations for such an emission component would be possible with the Solar Optical Telescope or the High Resolution Telescope Spectrograph on SUNLAB.

It is important to note that flares which produce large γ-ray fluxes occur infrequently even near solar maximum. Thus, extensive coverage (several months or more) of the Sun by high resolution γ-ray instruments is highly desirable. Long-duration balloon flights with such instrumentation would form ideal centerpieces for MAX '91 campaigns.

3. Origin of the Solar Wind

Although it has long been known that the solar wind must have its origin in regions of the solar corona in which ambient magnetic fields are "open" (connected) to the interplanetary medium, it was not until Skylab that a definite source region of the solar wind was well-identified: we now know that high-speed streams in the solar wind arise in coronal holes. Remarkably, a similar definite identification of the source regions of the lower-speed wind has not been accomplished to date. In fact, most of the central problems of the solar wind's origin and dynamics are far from solution today; these include:

(a) What drives and heats the solar wind? We now know that the classic thermal expansion model is inadequate to account for high-speed streams, but we do not have a universally-accepted alternative. For example, although Alfven waves are observed at large heliocentric distances, constraints on the available Alfven wave flux at the coronal base make it problematic whether these are the driver of the wind in the inner corona.

(b) What physics distinguishes between open regions leading to high-speed streams and the slower quiescent wind? There is no widely-accepted theory for explaining the large Mach numbers found in high-speed streams; we do know that momentum deposition beyond the first sonic point must play a crucial role. Thus this question is really another way of posing the problem of driving the wind itself.

(c) Why are there coronal holes? We do not understand the evolution of magnetic fields sufficiently to account for the formation of large-scale ($\sim R_o$) coherent structures of "open" magnetic fields. A theory for coronal hole formation would have to treat properly the magnetohydrodynamics of reconnection, as well as to account for the large-scale evolution of photospheric motions which leads to the sharply-reduced differential rotation rate in latitude of the large (equatorial) coronal holes.

The traditional difficulty in answering these questions has been the low UV and X-ray emissivity of the wind-dominated portion of the corona, that is in the presumed wind acceleration zone of $1.05 < R/R_{o} < 5$. The new generation of coronal telescopes, for example the Pinhole/Occulter Facility, will extend observations from Thomson-scattered photons (which determine the electron density) to observations of resonantly-scattered photons, which promises a flood of new diagnostic information. This will give us access to details of the electron and ion distributions, velocities, and wave motions. These data will allow us for the first time to confront models of wind acceleration in the inner corona with detailed observations.

4. The Radio Perspective

Radio observations give a different perspective of the phenomena of solar activity, ranging from the flare proper in the lower atmosphere to its coronal causes and effects, and extending beyond this to provide a connection to problems of stellar activity. In this a fundamental question of physics is: What is the nature of the energy release? We identify several key radio observational approaches to answering this.

(a) **Where is energy released?** Most of us expect that it appears near the apex of sets of magnetic loops, but there are dissenters who favor the transition region or below, or even subphotopheric or distant coronal sites. The VLA observations during the past maximum showed centimeter-λ emission (mildly relativistic electrons) above the neutral line and between Hα kernels, 2 -3 arc sec in dimension and with appropriate polarization for the gyro-synchrotron emission. Future observations with higher time resolution could show successive brightening as the energy propagates from its site of release.

(b) **What is the magnetic structure?** The microwave spectrum is very sensitive to B, and images at different frequencies can determine its distribution at different heights. Of particular interest are the new observations (for example from Owens Valley) that simultaneously give interferometric data and accurate spectral information.

(c) **Where are the electrons of 10 - 100 MeV whose presence is inferred from the whole-disk γ-ray observations?** They are closely related to the impulsive energy release; mm-wave observations could identify these particles, particularly if coupled with simultaneous hard X-ray imaging by the Pinhole/Occulter Facility.

(d) **What is the cascade of energy in a flare?** Does it proceed from non-potential fields to fast particles to hard X-rays and maser radio waves to soft X-rays to Earth? How do these radiative forms compare with the energy in shocks, mass motions, or the convection of field?

5. The Perspective of the Lower Atmosphere

Conditions in the chromospheric regime of a flare are best studied from optical spectra, accessible now to ground-based observations and a major target for higher-resolution Solar Optical Telescope observations in the future. The Balmer lines are particularly useful, although historically their analysis has resulted in anomalously small line-of-sight thickness in the emission regions, as small as 10 km. With previous (> 1 arc s) observations there were large dilution factors that hindered the analysis; the Solar Optical Telescope observations will improve the situation in proportion to the resolving power achieved. The assumption of a plane-parallel atmosphere normally made is undoubtedly an oversimplification, and Solar Optical Telescope observations will contribute to our knowledge of the three-dimensional forms. This information about the material at temperatures of 10^4 - 10^5 K and densities of 10^{12} - 10^{14} cm^{-3} will help in defining the hydrodynamic response of the lower atmosphere.

(a). **What is the structure of the background photosphere and chromosphere?** We know that magnetic flux is highly intermittent on the presently resolved spatial scales, and there is some evidence that this continues to be true to spatial scales of at least 0.3". This structuring strongly influences our interpretation of mean atmospheric models and hence affects the proper understanding of the interaction of fast particles and radiation with the lower solar atmosphere.

(b) **How is the energy required to heat the lower atmosphere impulsively delivered?** From timing observations, it is unquestionable that impulsive energy release in a flare extends throughout a broad range of atmospheric layers. Unfortunately, we cannot quantitatively account for the observed photospheric radiative loss enhancement by balancing it against any of the known energy transport processes. The theory depends crucially upon the assumed characteristics of the atmosphere, so that the resolution of this problem depends upon understanding the fine structure of the atmosphere.

In both of these problem areas the key to proper understanding lies in high spatial resolution observations of the lower atmosphere over as broad a wavelength range as possible: in the optical and UV (for direct observation of photospheric and chromospheric heating and emission, and velocity and magnetic-field distributions), and in the radio and X-ray (for testing for the presence of fast particles, and fixing the nature of their interaction with the background atmosphere). The shorter observing intervals associated with the MAX '91 campaigns also offer an excellent opportunity for comprehensive ground-based support, consistent with scheduling practices at the National Solar Observatory and the Very Large Array, for example. The forthcoming solar maximum should provide us with an opportunity to obtain extensive high-quality ground-based data such as: high-quality white-light and Hα images, simultaneous velocity and magnetic field distributions, coronagraphic observations of the inner corona and spectra-spatial data on the Hα line profile or on other spectral regions. The development of digital imaging readout systems and the necessary data-handling equipment is making dramatic strides at present, and we expect that a revolutionary capability for ground-based observations of solar activity will be available for the MAX '91 programs.

6. The Global Perspective

Although the study of high-energy phenomena is critical to our overall understanding of solar activity and provides a basis for understanding related astrophysical phenomena, we must not neglect the basic structure of the larger physical system (the active region), which is the seat of the energy made available to high-energy events, and whose evolution is the fundamental energetic process of interest. We must keep in mind the possibility that flares are simply one manifestation of a large-scale, much more energetic, longer time-scale (compared with the impulsive phase) evolution of the active region.

The basic structural characteristics and the means of energy storage of active regions are controlled by the magnetic field, so the first step in understanding active-region evolution (and thus high-energy phenomena) is to observe the field at various heights in the solar atmosphere. The large-scale structure and evolution should provide the framework in which the small-scale structures can be understood. Sunspots, in this context, are toward the smaller scale. The large-scale long-lived velocity structure of active regions is closely associated with their magnetic structure and evolution. Complementary velocity observations, say in the form of line-of-sight "Dopplergrams", are very important to the proper interpretation of magnetic observations. Together they characterize the driving function (in the photosphere?) and the response (in the chromosphere and corona?). Coupled with this observational program is necessarily a theoretical modeling effort guided by and complementary to the observations.

The velocity fields on shorter time scales and smaller spatial scales, which in active regions may be the analog of spicules, may control both the mass and energy balance of the background active-region corona. In this context it is important to observe the corona, at the limb, in several transition-region and coronal lines to examine the thermodynamic evolution of the non-flaring active-region corona.

Coronal mass ejections may reflect a global gravitational instability that releases a large amount of energy stored in the coronal magnetic field (eruptive prominences just go along for the ride). One aspect of this instability and associated mass ejection might be the creation of a temporarily open magnetic configuration that possesses a good deal of free energy and which is highly unstable to nonlinear (explosive) tearing. The natural relaxation of such a configuration could lead to both the impulsive and gradual phases of a large flare. The flare, in turn, could provide a detectable coronal signature: *e.g.*, a shock wave. If something like this is the case, it is important to obtain (1) observations of the corona from 1 - 5 $R_\odot$, and (2) observations of transients with high spatial and temporal resolutions plus plasma diagnostics. This can be accomplished by the Pinhole/Occulter Facility in combination with the SUNLAB instruments.

7. The Perspective of the Stars

Astronomers have long appealed to solar phenomena in attempting to understand transient processes in objects as diverse as dMe flare stars and accretion disks: in the absence of the spatial and temporal resolution available to solar physicists, this understanding has been strongly dependent upon a framework for the physics of transient energy release which derives directly from solar observations. As we understand the physics of solar transients better, this framework is continuously revised, and solar physicists must transfer this increased understanding to the rest of the astrophysical community. At a minimum, this effort will reduce the tendency towards modeling non-solar phenomena in terms of ideas that improved solar observations have shown to be inadequate. More optimally, strong contact between solar physics and more general astrophysics will place solar physics into the central role it ought to play, given its ability to constrain the physics of phenomena commonly invoked in astrophysics - reconnection, collisionless shocks, particle acceleration, stellar mass loss, dynamo action, *etc., etc.*.

8. The Solar-Terrestrial Perspective

Solar activity is the basic driver for processes in the interplanetary medium. Flares inject high-energy particles and shocks which propagate to the far reaches of the solar system, producing complex reactions in the atmospheres and magnetospheres of the Earth and other planets. The solar wind, too, plays a major role in modulating solar activity, and produces major changes in cometary atmospheric structures. The Solar Maximum Mission has already shown that the large fluxes of flare protons at Earth are <u>not</u> identical with the population of protons producing γ-rays; rather, the interplanetary protons are probably produced by flare-generated shocks. The origin and propagation of these particles and shocks, as well as the reasons why some flares produce large particle fluxes and others do not, are open questions. MAX '91 offers the opportunity to study these energy and momentum inputs to the interplanetary medium, through coordinated observations of flares, coronal dynamics, and radio phenomena. The International Solar-Terrestrial Physics Program (see below) will provide a well-coordinated program for studying the Earth's environment and its response to solar variability.

III. THE MAX '91 PROGRAM

A. The "Campaign" Approach

The MAX '91 program should be built around well-thought-out investigations that can use the available resources in the most effective and productive fashion. A campaign team, selected early in the effort from interested theorists, experimenters, and observers, should govern the program from planning through data analysis. In a sense this approach extends the successful experience that the solar community has had with the "workshop" approach to coordinated science. The difference here is that the observational programs will also benefit from the input of theorists and others in the definition of the whole research, rather than after the fact in an essentially *ad hoc* manner. The results will appear in the literature, but we feel that it would be helpful also for each campaign to conclude with the writing of a monograph that reviews the program and the resulting science.

We can summarize the organizational goals of an observing campaign for MAX '91 as follows:

1. Elaborate the scientific objectives for the campaign, as selected in response to an Announcement of Opportunity.

2. Recruit an effective and broadly-based campaign team for the investigations.

3. Assure optimum use of the hardware selected for the campaign, consistent with the primary goals of the instrumentation.

4. Provide leadership and coordination in development, observations, analysis, and interpretation.

The specific observing campaigns will largely be built around Shuttle Sortie flights, many of which will depend upon the Solar Optical Telescope, SUNLAB, or the Pinhole/Occulter Facility to provide the fundamental high-resolution data. We recognize that an observing campaign-style organization is an excellent way in which to schedule multiple-use facilities such as the Very Large Array or the Gamma-Ray Observatory. The details of program implementation must be determined by NASA. We suggest here a framework for this purpose, based on the normal Announcement of Opportunity process. Each campaign team should be headed by a team leader, selected by Announcement of Opportunity based upon a proposal which details a campaign topic or topics and proposals for campaign organization. The Announcement of Opportunity should be rather general in its solicitation, in order to permit the freest possible response. In order to address the variety of leading solar questions requiring coordinated observations, and to provide adequate chance to observe a variety of active-sun and flare phenomena, we suggest the need for approximately six campaigns over the time period 1990 - 1993. Team members could be chosen from individuals who respond directly to the Announcement of Opportunity or by direct solicitation of team leaders during the detailed definition of the campaign. It will be important to achieve a broad and balanced participation so that the right expertise is available within each campaign team. Some individuals, including team leaders, may be involved in more than one campaign.

The campaign leaders and a Program Chair, selected by the same Announcement of Opportunity, would comprise the MAX '91 Coordinating Committee, which would also include a NASA Project Scientist. This committee would work with NASA and the team scientists to assure that the campaigns played together in a scientifically and programmatically sound fashion. The Program Chair would be granted the necessary authority to resolve schedule and program conflicts among the teams.

We recognize that not all solar investigations important for our understanding of activity will fit neatly into the campaign themes. Synoptic observations, for example, must go on continuously to provide the background data base for specific research topics. One or two weeks of Shuttle-based observations, while appropriate for diagnostic observations needed to answer specific research questions, nevertheless hardly make a good match to the 22-year solar cycle duration! Finally, rare and unpredictable events - such as the arrival of solar neutrons at the Earth as the result of an especially energetic flare - require continuous monitoring for successful observation. We must achieve a proper balance between sampling and continuous observations.

The participation of other funding agencies than NASA, especially in the area of ground-based observation, will be essential for the MAX '91 campaigns to succeed. The space observations require longer "lead time" in planning, however, and so the initial problems of organizing MAX '91 will come in the area of space research.

B. Instrumentation

Within existing or planned resources, both for space-based and ground-based instrumentation, there is expected to be a large and versatile capacity. We expect that the campaign teams will make the maximum use of these facilities, recognizing the success of the Solar Maximum Mission philosophy of broad-band spectral coverage of a given phenomenon. We list below the space instrumentation that would be suitable for many of the applications:

* The Solar Optical Telescope (see below)
* The Pinhole/Occulter Facility (see below)

* SUNLAB Instrumentation:
    - The High-Resolution Telescope/Spectrograph (HRTS) (Naval Research Laboratory)
    - The Solar Optical Universal Polarimeter (SOUP) (Lockheed)
    - The Coronal Helium Abundance Shuttle Experiment (Rutherford Appleton / Mullard)
* Other Spacelab Experiments
    - Solar Active Region Observations from Spacelab (SAROS) (American Science and Engineering / Leicester)
    - The Spacelab-2 Hard X-ray Telescope (Birmingham University)
    - The solar X-ray polarimeter (Columbia University)
    - The Solar EUV Telescope-Spectrometer (SEUTS) (NASA/Goddard)
* SPARTAN Experiments
    - The Lyα/White Light Coronagraph
* Rocket and Balloon Payloads
    - American Science and Engineering (X-ray telescope)
    - Stanford (X-ray telescope / Objective grating)
    - Lockheed (X-ray Spectrometer / Transition-region Camera)
    - Colorado (EUV Spectrometer)
    - Harvard-Smithsonian Center for Astrophysics (Normal-incidence X-ray Telescope)
    - California (High-resolution X-ray and γ-ray spectrometer)
    - New Hampshire (High-resolution γ-ray spectrometer)
    - Goddard Space Flight Center (High-resolution γ-ray spectrometer)
* New developments in instrumentation
    - Applied Physics Laboratory (Filter magnetograph)
    - Stanford (Imaging XUV spectrometer)
* Other major resources (possible refurbish/upgrade)
    - Solar Maximum Mission/instruments
    - Skylab instruments

C. Observations from the Ground

Ground-based observations have two important roles in solar physics today: as a source of extended observations ("synoptic" data) that cover long intervals and support many investigations requiring statistical treatments; and as a source of innovative research on specific subjects, often involving new instrumentation. In the United States there is a small number of high-quality solar observatories that contribute in different ways to one or both of these areas. We list these here and anticipate that the MAX '91 program will involve them all in one or more campaigns:

* The National Solar Observatory
    - Sacramento Peak Observatory
    - Kitt Peak Observatory
* The National Radio Astronomy Observatory
    - The Very Large Array
    - The Very Long Baseline Array
* Big Bear Solar Observatory
    - Big Bear Solar Observatory
    - Owens Valley Radio Observatory
* Mt. Wilson Observatory
* Mees Solar Observatory
* The Solar Optical Observing Network (SOON/RSTN)
* The San Fernando Observatory
* The Stanford Solar Observatory
* The Clark Lake Radio Observatory
* The Santa Catalina Laboratory for Experimental Relativity by Astrometry
* The Mauna Loa K-Coronameter (High Altitude Observatory)
* Swarthmore College Observatory
* Space Environment Laboratory (NOAA)
* Mashall Space Flight Center magnetograph
* University of Arizona solar monitoring program

D. Extended Observations from Space

Several programs exist (or are in discussion) from which space observations of a synoptic nature may be available. These programs provide stable data bases that support statistical research work, as do the ground-based observatories. We list the possible missions here:

* Solar Maximum Mission (see below).

* Possible new DoD programs designed for solar-activity monitoring.

* SOLAR and WIND (see section on the International Solar-Terrestrial Physics Program below).

* NOAA Satellites. The Geosynchronous Operational Environmental Satellite series (GOES) produces very useful monitoring data on solar X-ray and particle emission. These data provide an essential reference system for research programs such as MAX '91.

* HESP (see below).

E. The Space Station

In the event that the Space Station becomes available for scientific use during the MAX '91 period it will be highly desirable to incorporate solar instrumentation as early as possible. Gamma-ray instrumentation would be a good candidate for initial use of the manned station, since it does not require precise pointing and can benefit from extended exposure. Subsequently, well-developed pointed assemblies such as SUNLAB could be deployed for extended observations. Finally, newer and more powerful instruments such as the Solar Optical Telescope and the Pinhole/Occulter Facility could be transferred to the manned station, following development in the sortie mode where the inevitable starting-up problems of new, powerful instruments will be worked out.

Because solar physics has profited greatly from the manned mode of space astrophysics - witness the Skylab successes - we anticipate enthusiasm on the part of solar investigators to use the resources of the Space Station. The details of such deployment must depend on the capabilities of the Space Station and its associated pointing systems, and must permit an orderly and phased transfer of instruments from other platforms to the Station. Much of the organization may be guided by the definition of the Advanced Solar Observatory. However it must be emphasized that any enthusiasm for the use of the Space Station for solar science does not imply a willingness to defer plans for the Solar Optical Telescope and the Pinhole/Occulter Facility until the Station becomes available. These instruments are crucial for the MAX '91 program, and their development must proceed immediately for the full success of this program.

IV. RELATIONSHIPS TO OTHER PROGRAMS

A. Solar Optical Telescope

The need for consistent, high-resolution definition of the magnetic and fluid properties of the photosphere and overlying atmosphere lies at the foundation of most programs of solar research. This motivated the selection of the Solar Optical Telescope (SOT) as a facility to be developed under the Spacelab program. The Solar Optical Telescope is a general purpose, 1.25-m telescope with provision for versatile and interchangeable focal-plane instrumentation. It will offer the first opportunity for observation of the Sun with an angular resolution sufficient to observe many basic physical mechanisms of solar structure and dynamics. The Solar Optical Telescope is a powerful instrument for the study of solar active regions, where strong and complicated magnetic fields control the mechanical and energetic evolution of the structures that we see.

The observing program for the first flight of the Solar Optical Telescope is being defined by the SOT Science Working Group. This program will include a significant complement of active region studies, which can be used as the basis for MAX '91 campaigns. While it would be a misuse of SOT-1 to use it as a "flare chaser," it nevertheless will provide observations of active regions with unprecedented angular resolution. Every effort should be made to refly the Solar Optical Telescope on the shortest possible turnaround schedule during the MAX '91 period.

B. The Pinhole/Occulter Facility

The Pinhole/Occulter uses an external occulting device to obtain high resolution hard X-ray images (~ 0.3 arc sec, FWHM) and to attain unprecedented levels of sensitivity and diagnostic capability for coronal observations. These observational capabilities are fundamentally new. They represent a major advance over previous observations of X-rays and coronal phenomena, and as discussed in detail above, provide the most powerful observational tool for a number of the MAX '91 objectives. The remote occulter is to be 50 meters from the detector plane; for coronal observations this results in a large shadow umbra that permits large-aperture telescopes and an observing capability much closer to the solar limb. The large collecting area will provide a revolutionary advance in coronal observations as well as in the hard X-ray imaging.

At present the Pinhole/Occulter has completed Phase A definition, with the possibility of a decision to develop an initial version of the observing capability in time for the maximum of 1991. The bulk of the engineering work will be done in-house at NASA Marshall Space Flight Center, with the initial detector-plane instruments (the equivalent of focal-plane instruments for an ordinary telescope) taken from the stable of previously-developed items (see section III.B above). As soon as funds permit, the initial configuration will evolve into a full-fledged Pinhole/Occulter Facility as new, sophisticated detector-plane instrumentation is developed and integrated.

C. The International Solar-Terrestrial Physics Program

The International Solar-Terrestrial Physics Program (ISTPP) represents a well-coordinated effort to study the solar-terrestrial environment. The interplanetary measurements to be made by the WIND spacecraft in particular would be very helpful for many of the MAX '91 objectives, since the corona appears to play a fundamental role - either in response or in cause - in the mechanisms of solar activity. The planned launch of WIND in early 1989 will make it ideal for participation in the MAX '91 program. The SOLAR spacecraft is presently scheduled for launch beyond the maximum and hence will not be available, unfortunately. The physics of solar activity that MAX '91 addresses lies very close to the physics of solar-terrestrial relationships. Hence the MAX '91 program is complementary to ISTPP, exploiting the Spacelab and other facilities described above instead of the development of new free-flying spacecraft. It will be most important for modern approaches to data-base management to be used in both programs in order to facilitate cooperative analyses.

D. SUNLAB and other Spacelab Flights

The SUNLAB consists of a cluster of high-resolution instruments (see Section III.B) for solar observations from Spacelab. Some of these instruments form a part of the Spacelab-2 mission, and we anticipate that the SUNLAB complement will fly repeatedly as it evolves, perhaps with the addition of new instruments. We anticipate that SUNLAB, Solar Optical Telescope, and Pinhole/Occulter Facility will represent the core instrumentation for MAX '91.

E. Solar Maximum Mission

The Solar Maximum Mission is an existing resource for investigations of solar activity. During the solar minimum period, it will be carrying out some flare-related programs, but will also be concentrating on problems of active-region development that will certainly influence the configuration of MAX '91 programs. All along, it will be returning continuous data from the ACRIM solar-irradiance experiment that is providing direct information about energy storage and release on active-region time scales and probably solar-cycle time scales. It is also possible that the actual hardware can be refurbished or reconfigured, either on the ground or in space, so that the Solar Maximum Mission satellite itself could contribute directly to some of the MAX '91 campaigns, possibly including provision of a longer-term platform for high-energy observations. We recognize that the Solar Maximum Mission instrumentation will be more than one decade old at the time of MAX '91, and that the Skylab instruments will be older than many scientists at that time, so that we think it unlikely that this hardware will be reusable without extensive modification and refurbishment.

F. The Upper Atmosphere Research Satellite

The Upper Atmosphere Research Satellite (UARS) and other vehicles will carry equipment for irradiance monitoring. This will be particularly valuable for studies of active-region development along the lines pioneered with the total solar irradiance monitor on board the Solar Maximum Mission. The timing of UARS is quite appropriate for MAX '91 coordination because its observations should span the crest of activity.

G. The Gamma-Ray Observatory

The Gamma-Ray Observatory (GRO), planned for launch in 1989, contains four very large instruments for γ-ray astronomy. A solar observing capability has been designed into the spacecraft and into the individual instruments, all of which can be expected to extend our knowledge of the solar γ-ray and neutron emissions. A burst and transient monitor instrument will provide continuous solar data with excellent hard X-ray and γ-ray sensitivity. In view of these capabilities, it is vital for the relevant MAX '91 campaigns to involve the GRO investigator teams at an early date. There is an initial plan for only two years of GRO observations, but an early and effective use of GRO solar data may be helpful in extending the GRO operational life further into the MAX '91 era.

H. The HESP Satellite

This potential Japanese solar-maximum satellite, derived from the Hinotori program of the past solar maximum, may be able to carry one or two U.S. experiments as a part of the U.S.-Japan cooperative agreement in space research. HESP will emphasize X-ray observations and will be able to provide continuity and monitoring capability that will effectively complement the MAX '91 research programs.

I. The International Solar Polar Mission

The International Solar Polar Mission is presently scheduled for solar polar passage near the time of the next maximum. The uniqueness of these out-of-the ecliptic observations is unquestionable, and we hope to learn a great deal about the interaction of various forms of solar activity with the outer corona and the interplanetary medium. Future missions building on this stereoscopic view of the Sun would be very attractive scientifically.

V. CONCLUSION AND RECOMMENDATIONS

The MAX '91 program described here intends to achieve important scientific goals within the context of the natural solar variability. The heart of the MAX '91 program is a series of campaigns oriented towards specific scientific problems, and taking place in the solar maximum period 1990 - 1993. These campaigns will take advantage of the load-carrying capability of the Space Shuttle to fly instruments with observational capabilities very different from those of the Solar Maximum Mission. These instruments presently exist (*e.g.* rocket or balloon), are under development (*e.g.* the SUNLAB instruments and the Solar Optical Telescope), or are planned for development by the time of the next solar maximum (*e.g.* the Pinhole/Occulter Facility). Various combinations of instruments appropriate to the specific scientific problem of a given campaign would be flown on a Shuttle sortie mission. Ground-based, suborbital, or other space observations would participate fully in the campaigns. The experimental and scientific program of each campaign will be defined by a team of experimenters, observers, and theorists to be solicited by an Announcement of Opportunity. Each campaign team will follow its program through to completion, and the continuity of attention to the campaign by the team and by the remainder of the community will allow for the best possible theoretical input at all phases of the program, rather than essentially after the fact as in past programs. We feel that this increased level of communication and information transfer will produce major rewards in the quality and relevance of the scientific results.

The first flight of the Solar Optical Telescope, while not fully dedicated to MAX '91, should be at least a portion of a MAX '91 campaign. Depending upon resolution of integration and payload questions beyond the scope of this report, we suggest that subsequent campaigns alternate between Solar Optical Telescope and a SUNLAB - Pinhole/Occulter Facility combination as centerpiece instrumentation. The latter will require the development of Spacelab capability for two simultaneous pointed platforms. The instrument configuration and the associated experiments to be flown elsewhere or carried out on the ground will be a matter for definition as a part of the campaign development.

Recognizing that the interval until the next maximum of solar activity is only about six years, we recommend that NASA proceed at once with the following steps of implementation:

1. Develop the Solar Optical Telescope on a schedule that will permit a first flight in mid-1990.

2. Implement a development plan for the Pinhole/Occulter Facility that will provide a hard X-ray version in early 1991 and a version including large-aperture EUV and visible-light coronal telescopes by 1992 - 1993. An Announcement of Opportunity should be issued to assure broad community participation in detailed definition of the facility and in the preparation of "focal plane" instrumentation.

3. Select a lead center for the MAX '91 program and proceed with definition of the MAX '91 program plan and development of necessary budget information, *etc.*, so that this activity may be included in the regular planning cycle of the NASA Solar and Heliospheric Physics office.

4. Issue an Announcement of Opportunity for the purpose of selection of the MAX '91 Program Chair, observing campaign leaders, and to acquire a list of interested participants.

5. Commission the MAX '91 Coordinating Committee to proceed with organizing the scientific definition of the program, including coordination with other agencies (*e.g.* the National Science Foundation and the National Oceanic and Atmospheric Administration) and international organizations (*e.g.* IAU, COSPAR). This committee should be functional by mid-1985 at the latest.

6. Soon thereafter, begin technical studies leading to accommodation of the needed Shuttle and other experiments.