

**THE HIGH ALTITUDE OBSERVATORY
OF THE
NATIONAL CENTER FOR ATMOSPHERIC RESEARCH
BOULDER, COLORADO**

(Report from Solar Institute)

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1. Introduction

The High Altitude Observatory, a division of the National Center for Atmospheric Research (NCAR), was founded in 1940 under the auspices of the Harvard College Observatory (cf. Newkirk and Chronic, *Solar Phys.* **7** (1969), 331). Originally, the Observatory consisted only of a single observing station near the mining town of Climax, Colorado; however, following affiliation with the University of Colorado and finally as a research division of NCAR, operated by the University Corporation for Atmospheric Research (UCAR), a non-profit corporation of universities, the present Observatory has grown to conduct a broad program of both theoretical and experimental solar research. Principal fiscal support for Observatory activities comes from the National Science Foundation via UCAR.

The fourth Director of HAO – following Walter Orr Roberts, John W. Firor, and Gordon Newkirk, Jr., – is Robert MacQueen, and the Observatory currently employs a staff of 24 scientists and approximately 50 research and technical personnel. In addition, there are normally present approximately 10 additional visiting scientists and/or graduate students.

Scientific programs at the Observatory are carried out in three major research areas, and are organized in three sections: Solar Atmosphere and Magnetic Fields, Coronal and Interplanetary Physics, and Solar Variability. The sections are led by R. G. Athay, A. J. Hundhausen, and P. A. Gilman, respectively. Within each section both theoretical and experimental programs are carried out; particularly, the Observatory has attempted to mount a balanced program of ground and space observations as dictated by the scientific requirements of the specific area. Administrative and Support efforts are coordinated in a section led by E. M. Reeves.

With the closing of the Climax Observing Station in 1972, the Observatory was left with a single dedicated observing station, that at Mauna Loa, on the island of Hawaii. As noted below, that station has been recently equipped with a new *K*-coronameter (see Figure 1) designed to carry out observations of both transient coronal phenomena and continue the Observatory program of collection of a long-term synoptic view of the coronal form. Other observing efforts are carried out via cooperative ventures with the Sacramento Peak Observatory in Sunspot, New



Fig. 1. The installation of the High Altitude Observatory new generation (Mark-III) *K*-coronameter at the Mauna Loa observing station in April, 1979. The combination of high altitude (3400 m), frequent occurrence of clear skies, and high solar elevation, combine to make the site, on the island of Hawaii, an excellent one for coronal observations, despite the fact that it is near the summit of an active volcano.

Mexico, and involve instrumentation there. In addition, specific special purpose field instrumentation (for example, the eclipse coronal camera, see frontispiece, this issue, and space-borne instrumentation complete the observational efforts of the Observatory.

2. Solar Variability

The broad goal of the Solar Variability effort at HAO is to describe and understand the fundamental operation of the solar cycle and its influence on the Sun's output – radiation, magnetic fields and particles – over a broad range of time scales, from weeks and months to tens of thousands of years. The formulation of this goal and the resultant organization of activity within the area occurred in 1977, with the increased recognition within the solar community that the C-14 record and a variety of historical sources could permit the tracing of solar activity backward in time. In doing so it was demonstrated that variation in the Sun's activity on a time scale of centuries is much larger than had been previously realized, and that even the basic eleven-year cycle may not always be present. In addition, at approximately the same time it was becoming clear that a direct connection between coronal holes and

high-speed solar wind streams existed, so that the perspectives gained during the current solar activity cycle could, for example, be used to interpret the early geomagnetic record. Finally, further stimulus resulted from studies of the differential rotation of the Sun as driven by global convection, and the realization that these models should be placed in the context of long-term solar and stellar behavior.

Within the Observatory, these initial motivations have matured into a research plan for solar variability comprised of five interrelated subject areas. These areas include efforts directed toward:

- (a) The modeling and observational testing of global circulation in the dynamo;
- (b) the documentation and diagnosis of solar radiative variability;
- (c) the development and verification of indirect measures of long term solar variability;
- (d) the understanding of the long term evolution of the corona and solar wind; and
- (e) the understanding of the geomagnetic response to solar variability.

Considerable effort, and progress, has been made in developing models to describe and explain the differential rotation of the Sun. Increasingly sophisticated computations for convection in a rotating spherical shell have been carried out, with the most recent model including a hydromagnetic dynamo based upon the earlier convection model. Current models implement a linear version of the governing equation for convection of a compressible fluid in a deep, rotation spherical shell. Complementing these model calculations are efforts directed toward interpretation of the global circulation of the Sun through analyses through a variety of sunspot motion records ranging from 17th century data to the present, and preliminary interpretation of large scale solar velocity information available from a new prototype instrument – called a Fourier Tachometer – developed in collaboration with Sacramento Peak Observatory. This latter observational effort is sufficiently encouraging to stimulate the development of a new version of that instrument which should be capable of observing the small amplitude and large spatial extent of the solar global circulation.

Efforts in progress at other institutions to measure the solar constant and spectral irradiance are sufficiently mature to make it unnecessary for HAO to enter this area experimentally; however, in the recent past, the area of the solar radiative variability was explored by a workshop – entitled the Solar Output – held in Boulder, Colorado, in 1976 and co-sponsored by NCAR, the National Oceanic and Atmospheric Administration, Sacramento Peak Observatory, and NASA. The edited and annotated workshop proceedings appear in the volume, *The Solar Output and Its Variation*, edited by O. R. White, Colorado Associated University Press, Boulder, 1977.

One startling result in the third area of effort within the Solar Variability Section – the examination of various measures of long term solar variability – has been the identification of a potential decrease in the solar diameter since the year 1836. Initial results, including analysis principally of meridian passage data from the Greenwich

Observatory, indicates that a nearly monotonic decrease of both horizontal and vertical diameters (with a magnitude between 1–2 arc sec per century and 0.5–1 arc sec per century, respectively) may exist. Whether this effect is real is a subject of controversy; clear resolution of the question is, however, so important that the Observatory has been stimulated to develop a new instrument for the measurement of the solar diameter, using modern electronic techniques to improve the accuracy of measurements. The instrument should be sensitive enough to determine the reality of the above trend after 2–3 years of operation from a site in Boulder.

A long series of *K*-coronameter observations of the form of the inner corona ended in October, 1978, so that a new generation instrument could be installed to carry on these observations. These data have proved to be a fruitful source for study of the long term evolution of the corona and its correlation with the interplanetary medium and geomagnetic measures. Work in this area has centered on the measurement of the behavior of coronal holes on the Sun throughout solar cycle 20 and the early phases of solar cycle 21, and a comparison of various changes evidenced from these coronal maps with solar wind properties and the galactic cosmic ray flux as measured at the Earth.

Finally, work in this section continues toward the development of techniques for inferring properties of the interplanetary plasma through geomagnetic responses. Specifically, the physical link between the interplanetary medium and the earth's ionosphere and magnetosphere has been explored, and extensive work has been carried out to best identify those correlations and to study the details of such correlations through objective statistical techniques.

3. Solar Atmosphere and Magnetic Fields

Research carried out within the Solar Atmosphere and Magnetic Fields Section of the Observatory encompasses a variety of topics related to the energy balance and structure of the solar atmosphere. The broadly based approach to these problems includes four general categories of effort: the development of diagnostic techniques; the theoretical modeling of solar features and events; observational programs from ground-based and orbiting observatories; and the interpretive analyses of observational data.

The past decade has seen the application of increasingly complex calculations in radiative transfer to multidimensional geometries, expanding rotating atmospheres and polarized radiation. Major efforts have been carried out in applying the effects of frequency redistribution to diagnostics of line profiles. These efforts have been a highlight of Observatory research for more than a decade, and it is now possible to compute the detailed transfer of radiation under conditions that are approaching real solar/stellar atmospheres. Probabilistic approaches to these complex problems have been generated in an attempt to synthesize ideas and clarify the concepts involved. An increasing ability to compute the transfer of radiation in non-simple geometries has allowed studies to be made of the properties of spicules, prominences, and other

regions of similar complex geometry on the Sun. Recently, substantial efforts have been expended toward the specification of curves of growth and line profiles in expanding, rotating, atmospheres, with particular emphasis toward the development of new diagnostic techniques applicable to such atmospheres.

A number of studies involving the interpretation of Ca K emission from stars have led to empirical relationships between the observed absolute emission and stellar age, temperature, magnetic field and angular velocity of Main Sequence stars.

The gradual realization that the transfer of radiation on the Sun is substantially modified by the presence of locally strong magnetic fields has led to considerable efforts to deduce the quantum mechanical formalism of radiative transfer in the presence of such fields, and thence to schemes for the interpretation of the signature of radiation arising under such conditions. Although much work yet remains in the interpretive aspect of such information, knowledge in this area has progressed sufficiently to warrant the development of a new polarimeter for specifying all four Stokes parameters of the solar radiation. This device, the so-called Stokes Polarimeter, permits Stokes parameters to be analyzed across appropriate line profiles within the spectral region of 4000 to 7000 Å. The specification of these Stokes parameters allows the orientation and strength of the magnetic field constraining the emitting atom to be determined; thus such an instrument holds promise of yielding the three-dimensional orientation and strength of solar surface magnetic fields. Recent (1979) upgrading of the prototype instrument allows rapid time variations in the field to be studied, and thus makes accessible a range of problems associated with solar activity.

Finally, members of the section have pursued close affiliations with both central experiments on the OSO-8 satellite (from the University of Colorado and Laboratoire de Physique Stellaire et Planetaire, respectively). The availability of these OSO-8 ultraviolet observations of lines originating in the chromosphere and transition region has permitted a detailed analysis of time series showing fluctuations in intensities and Doppler shifts. These important studies have shown that sound waves are indeed present in the middle chromosphere but the energy in those waves is insufficient to heat overlying layers by a large factor. Additional recent studies employing ultraviolet observations include analysis of flare spectra and active region evolution during the life of the OSO-8 satellite.

4. Coronal/Interplanetary Physics

The broad goals of the Coronal Physics Section are to achieve an understanding of the physical conditions determining the steady-state acceleration of the corona and solar wind, the role of magnetic fields in influencing this flow, and the role of transient disruptions in both the flow of the plasma and the balance of magnetic flux on the Sun.

During the past decade the availability of new data sets (principally from Skylab) and the utilization of extant sets (such as Mark II *K*-coronameter results) have

yielded an enormous wealth of information concerning the large-scale properties of the corona. For example, intensive studies have been carried out on the origin, nature and evolution of low-density regions in the corona – coronal holes. Under NASA sponsorship, HAO has conducted a workshop series on coronal holes which has resulted in the publication of a summary volume *Coronal Holes and High Speed Streams*, edited by J. B. Zirker, Colorado Associated University Press, Boulder, 1977. There now exist theoretical and empirical models attempting to explain the relationship between density, temperature, and velocity in the highly diverging magnetic geometry of coronal holes. A number of these studies have been carried out by Observatory scientists and currently studies of potential heating mechanisms in the extended corona that may be appropriate to the geometries of coronal holes continue to receive attention. More generally, studies of the energy balance in the flow of the solar wind, the properties of wave propagation in the interplanetary medium and examination of the properties of the solar wind expansion which may be relevant to other stellar atmospheres have all received attention.

One crucial assumption that is commonly applied to the interpretation of coronagraph or coronameter data is that observed density structures ‘map’ the magnetic field geometry of the solar atmosphere. This assumption is currently undergoing an experimental test through the interpretation of observations from a new instrument – the Coronal Emission Line Polarimeter – which examines the linear polarization present in the Fe XIII 10747 coronal line. From such observations the direction (but not magnitude) of the coronal field may be inferred, and the above hypothesis tested.

With the availability of Skylab coronal observations, the role of transient disruptions in the corona has been illuminated and major efforts have been expended toward understanding the origin, nature and effects of these events. HAO staff members have contributed substantially toward the specification of the physical characteristics of these events and also participated in the generation of empirical models describing such transient events.

Recent experimental efforts within the section have included a collaborative program with the Smithsonian Astrophysical Observatory to develop a joint coronagraph package capable of observing the intensity and profile of the $L\alpha$ resonance scattered line in the corona and the white-light coronal intensity. This program, which has been flown as a rocket payload and will be flown on a Spacelab mission under NASA sponsorship, has as its goal the specification of the density and the temperature of the coronal medium far from the limb of the Sun and, in addition, a specification of the coronal outflow velocity. Next, the Observatory has recently put into operation a combination of coronal instruments, including a Coronagraph/Polarimeter on NASA’s Solar Maximum Mission and a new generation (Mark-III) K -coronameter at the Observatory’s Mauna Loa Observing Station. The space-borne instrument is an upgraded version of the highly successful Skylab instrument. A major Observatory effort has been directed toward the development of the new Mark III K -coronameter, which features a more rapid temporal response

than the older version and, through the use of linear array detector technology, the capability of generating two-dimensional images of the corona to more than a radius above the limb of the Sun. These instruments, together with additional cooperating instruments at the Commonwealth Scientific and Industrial Research Organization (Australia), and at Sacramento Peak Observatory, will permit a major observational effort to be made on transient solar coronal activity during the peak of maximum solar activity in cycle 21.

Finally, a program now in progress promises to give a new perspective to our view of the large-scale coronal form. HAO is participating in a NASA-sponsored consortium comprised of the Naval Research Laboratory (Washington), American Science & Engineering (Cambridge, Massachusetts), Stanford University (California), and the Paris Observatory, in developing a small combination coronagraph/X-ray/XUV telescope package for flight on the NASA/European Space Agency International Solar Polar Mission. This instrumentation will be capable of studying the chromosphere, inner and outer corona from a unique vantage point in the solar system.

5. Facilities

As noted above, the Observatory continues to operate an observing station at Mauna Loa, on the island of Hawaii; additional instrumentation programs have been carried out in cooperation with Sacramento Peak Observatory, with the Stokes Polarimeter and KELP instrument located at SPO (Sunspot, New Mexico). New measurements of the solar diameter will be carried out from Boulder. Within the Observatory proper, laboratories and facilities exist for the construction and testing of space qualified instrumentation under clean conditions. And finally, numerous efforts within the Observatory utilize in a major way the centralized Computing Facility of the National Center for Atmospheric Research which currently includes CDC-7600 and Cray I machines and associated peripherals for sophisticated computational and data processing needs.

6. Summary

The High Altitude Observatory attempts to carry out a balanced program of theoretical and experimental research in solar, solar-terrestrial, and stellar-related physics. The scientific efforts are carried out within a sectional structure including the major areas of Solar Atmosphere and Magnetic Fields, Coronal/Interplanetary Physics, and Solar Variability. As one division of a National Center, the Observatory attempts to provide leadership through operation and sponsorship of seminars on specialized topics and organization of workshops to exploit data collections. In addition to the examples given, the Observatory, under NASA sponsorship, has organized a workshop series on solar flares, a central theme of which was the interpretation of Skylab results. This effort has resulted in the publication of a

volume *Solar Flares*, edited by P. Sturrock, Colorado Associated University Press, 1979. Through these efforts, and the participation of individual staff members on advisory committees and working groups within the national and international framework, the Observatory continues to play a role in the guidance of research in solar and related physics.