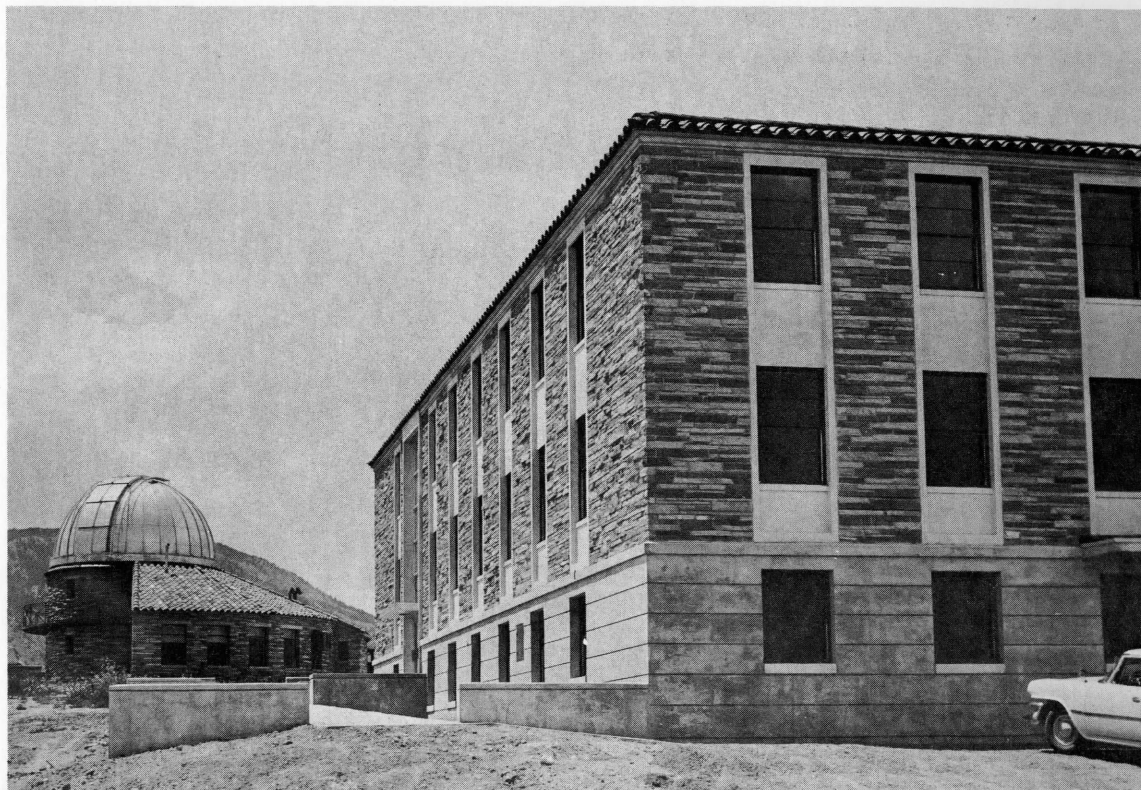


**THE
DIRECTOR'S REPORT**

1 January through 30 June 1960



High Altitude Observatory and Astro-Geophysics Building
August 1960*

*High Altitude Observatory
of the
University of Colorado
Boulder and Climax, Colorado*

The High Altitude Observatory is an independent non-profit research and educational institution closely associated with the University of Colorado. Its major research objectives are study of the sun and the sun's effects on the earth.

*Cover: Pictured is the new High Altitude Observatory and Astro-Geophysics Building of the University of Colorado, scheduled for occupancy in August 1960 (see page 5). The adjacent building is Sommers-Bausch Observatory.

SUMMARY

The new National Center for Atmospheric Research located in Boulder with Roberts as director will bring to the Boulder scientific community a strong research program in meteorology. This new program will provide added stimulus to the already strong research programs in physics of the upper atmosphere, ionosphere, geomagnetism, aurorae, and sun. The anticipated merger of HAO with the National Center will represent a major development in the overall history of HAO. Our research programs and our graduate teaching program in the University of Colorado are not expected to change substantially as a result of this merger. HAO and NCAR, however, will bring to each other added strength in their research facilities and in their ability to master the complex problems posed by an expanded horizon that envelopes the sun, interplanetary space and the terrestrial atmosphere. Recent research has tended to emphasize that these three entities form a continuous medium and a uniting together of research programs related to them seems both natural and necessary. HAO, several year ago, incorporated these three disciplines in her research programs. Thus, the association with the new National Center will not represent a major change of emphasis to our existing research programs.

Studies of radio noise from the sun and Jupiter yielded important new results during the period of this report. Jupiter's sporadic emission was found, like that of the sun, to exhibit a dynamic spectrum in which the wavelength of maximum intensity drifts rapidly with time, sometimes towards

shorter wavelengths. In addition, the sporadic emission from Jupiter was found to show evidence of being triggered-off by solar activity.

The so-called "hot spots" in the solar corona as evidenced by the long-lived enhanced radiation at cm wavelengths were found to be better described as regions of high density at normal coronal temperatures.

Our expanding interests in geophysics and meteorology were pushed forward this year by studies of the wave structure in noctilucent clouds, solar "quiet-day" geomagnetic variations, the equatorial electrojet, precipitation in the Colorado River Basin and the river flow at Lee's Ferry.

I. HIGHLIGHTS

The New National Center for Atmospheric Research

One of the most significant developments in the history of the High Altitude Observatory was accomplished in June 1960 with the naming of Walter Orr Roberts as director of the new National Center for Atmospheric Research. The new Center is expected to have close formal ties to HAO, and Roberts continues in his post as director of HAO. New nation-wide emphasis will be placed on basic research in the field of meteorology as a result of the creation of the new National Center. HAO will continue, as in the past, its emphasis in the cross-field disciplines of astro-geophysics.

Permanent headquarters for the new Center will be located in Boulder. The influx of scientific personnel as the Center grows will bring new stimulus and strength to HAO research programs and to the rest of the Boulder scientific community as well. The announcement of Roberts' appointment was made by Dr. Alan T. Waterman, Director of the National Science Foundation, and Dr. Henry G. Houghton, Chairman of the University Corporation for Atmospheric Research (UCAR), which serves as the managing corporation for the Center. Dr. Waterman also announced a NSF contract of \$500,000 with UCAR to assist in establishing the Center.

The creation of the National Center for Atmospheric Research through the recommendation of the National Science Foundation represents the culmination of several years of scientific and administrative planning. The initial recommendation for the establishment of such a center was made by the Committee on Meteorology of the National Academy of Sciences. The following comments are extracted from a news release by the National Science Foundation announcing the new Center.

"Dr. Houghton of Massachusetts Institute of Technology and University Corporation for Atmospheric Research, commenting upon the importance of the actions, said: 'The increasing impact of weather on our national security, economy, and welfare requires that we obtain a much more complete understanding of our fickle atmosphere. This new Center, working in close collaboration with university scientists, will provide the facilities needed for the mounting of a basic research effort commensurate with the magnitude and importance of the challenging unsolved problems of the atmosphere.'

"'It has been generally agreed by the scientific community,' Dr. Waterman pointed out, 'that universities should continue to play the leading role in basic research in the atmospheric sciences. Deficiencies in the present program are well understood. The two actions -- appointment of

Dr. Roberts and the National Science Foundation contract with UCAR -- are outgrowths of extensive studies of ways to remedy these deficiencies and especially to provide opportunities for collaborative enterprises for major problems in the atmospheric sciences. Paralleling this development will be increased NSF support for atmospheric research at universities."

Member universities of UCAR are:

- University of Arizona
- University of California
- The University of Chicago
- Cornell University
- The Florida State University
- The Johns Hopkins University
- Massachusetts Institute of Technology
- University of Michigan
- New York University
- The Pennsylvania State University
- Saint Louis University
- Texas A and M College System
- University of Washington
- University of Wisconsin

Roberts has served as Director of the High Altitude Observatory since its inception in 1940. More recently he has served in addition as the head of the Department of Astro-Geophysics and as a professor in the University of Colorado. In accepting the directorship of NCAR, Roberts has taken indefinite leave-of-absence from his University positions. It is anticipated that the two corporations, UCAR and HAO, will eventually merge with HAO becoming one of the research divisions of UCAR. According to present plans, HAO will continue its affiliation with the graduate teaching program of the University of Colorado through the Department of Astro-Geophysics. The National Center will comprise a separate research division of UCAR. Two associate directors will be named to serve under Roberts, one in charge of HAO affairs and one in charge of NCAR affairs.

In the interim between the establishing of NCAR and the merger of HAO with UCAR, R. Grant Athay, member of the HAO staff since 1950, has been named associate director of HAO and has assumed charge of HAO activities. Donald E. Billings has taken the position of acting head of the Astro-Geophysics program. James W. Warwick served as assistant director for Astro-Geophysics until June 1960.

New HAO Quarters Nearing Completion

The new research building for the Boulder staff of HAO, located near the Sommers-Bausch Observatory on the eastern edge of the University of Colorado campus, was near completion at the end of June. Plans for the move into the new quarters in early August were well under way and on schedule financially as well as time-wise. These new facilities will materially boost the morale and efficiency of the Observatory staff during the coming years.

This major advance in HAO's operations was made possible by the generosity of the following contributors:

Preston R. Bassett
Boettcher Foundation
Amon G. Carter Foundation
Captain Mary P. Converse
Adolph Coors Company
Ward and Pauline Darley
Farr Farms Company
Max C. Fleischmann Foundation of Nevada
Harry Hoeffler
The Great Western Sugar Company
James Foundation of New York, Inc.
The Kresge Foundation
Martin Low
Alan McClure
McDermott Foundation
Nordberg Foundation
The Lawrence Phipps Foundation
El Pomar Foundation
Charles S. Sterne
Texas Instruments Foundation
University of Colorado, Associated Alumni
University of Colorado, Associated Students
The Van Hummell-Howard Foundation
Miscellaneous Contributions
Anonymous

The new building, to be named "High Altitude Observatory and Department of Astro-Geophysics Building," is owned by the University of Colorado, and provided by the University for use by the Observatory.

Conferences

Two conferences of major importance to HAO research programs were participated in by HAO staff members during the period of this report. The first was an international Conference on Solar Weather Relationships. Twenty-eight scientists from the United States and six foreign countries met for a week's discussion of the connections between the sun and the earth's lower atmosphere from April 15 to 22 at Lake Arrowhead, California. The University of California's Extension Conference Lodge was the site of the conference, providing the participants with a beautiful and sheltered retreat for their deliberations.

This conference on Solar Weather Relationships was jointly sponsored by the Institute for Solar-Terrestrial Research of HAO, the Geophysical Institute of the University of California, and the American Geophysical Union, and was supported principally by a grant from the National Science Foundation.

Present were meteorologists and solar physicists interested in known effects of variable solar activity upon the earth's upper atmosphere, and in possible effects of such solar activity on the lower atmosphere. Some of the topics discussed were solar activity and the interplanetary medium, the effects of variable solar activity on the earth's upper atmosphere, the synoptic and statistical evidence for solar effects on the weather, and stability and energy sources for the atmosphere and interconnections between the lower and upper atmosphere. A number of special sessions were scheduled to discuss the role of ozone in solar-terrestrial relations, the Bowen meteoritic dust hypothesis, and the connection between the recently observed stratospheric warming phenomena and solar activity.

The sessions were informal in nature with much discussion occurring during and after the contributions by individuals. The presence of the foreign participants was especially welcome; the seminar held in summer 1956 in Boulder was attended only by scientists from the United States.

The second conference was an in-house Conference on Solar and Solar-Terrestrial Phenomena held in Boulder May 26-28, with participants from Sacramento Peak Observatory, Ft. Belvoir and Boulder Laboratories of the National Bureau of Standards, and Kitt Peak National Solar Observatory. This was the initial conference of a series to be held each year at one of the participating institutions. Future conferences of this series will include the Astrophysics group from the Los Alamos Laboratories.

One of the highlights of the conference was a presentation by Dana Bailey, National Bureau of Standards, of the phenomena associated with the

recently discovered "polar cap proton events," the bombardment of the earth's atmosphere in the polar regions by energetic protons ejected from the sun at the times of major flares. Another was a report by Dr. John W. Evans of the new detailed observations of magnetic field strength in active regions of the sun now being made at Sacramento Peak Observatory. Dr. A. B. Severny of the Crimean Observatory, U. S. S. R., has reported that solar flares occur in special locations with respect to the magnetic fields of active regions and that marked changes in field strength occur in association with flares. If true, this is a vital new development in efforts to understand the causes and energy sources of flares. The suggestion is that flares derive their energy from the magnetic fields. The Sacramento Peak observations will pursue this intriguing problem, helping pave the way to a clearer understanding of the flare mechanism. A few of the other research programs discussed are summarized in Section VI of this report.

II. INSTITUTE FOR SOLAR-TERRESTRIAL RESEARCH

Although the first four years of the privately-sponsored research of the Solar-Terrestrial Institute ended formally on 31 December 1959, activity was continued in 1960 with unexpended funds from the initial period. The principal scientific result of the preceding years was published in the first half of 1960 ⁽¹⁾. This result, as mentioned in earlier reports, indicates that troughs in the upper atmosphere passing through the Aleutian Island area about three days after sudden commencement geomagnetic storms tend to develop subsequently into larger troughs than average. The result has now been corroborated by two independent analyses of the data: one by Paul Julian at HAO and one by Waldmar Gutzman of the Department of Transport, Canada, using their own re-derivation of trough indices. Also, Julian has re-derived, from more complete geomagnetic and auroral data, the key days used by Macdonald and Roberts and later by Gutzman and Julian. New contingency tables computed for each of the preceding analyses using the revised set of key days exhibit the same trends as stated above.

HAO's participation in the Lake Arrowhead Conference reported in the preceding section on HIGHLIGHTS was carried out partly through support of the Solar-Terrestrial Institute. In addition four graduate students, G. W. Curtis, J. A. Eddy, L. L. House, and J. M. Malville, received fellowship support from the Institute.

In January 1960 sponsors of the Institute gathered in Boulder for our annual sponsors' meeting. The session was well attended with representatives from:

(1) Journal of Geophysical Research, 65, 529-534, 1960.

Humble Oil and Refining Company
Continental Air Defense Command
Cities Service Gas Company
American Gas Association
U. S. Air Force
Continental Air Lines
Lawrence Phipps Foundation
National Science Foundation
National Bureau of Standards
Geophysics Corporation of America
National Aeronautics and Space Administration
United Air Lines
Association of American Railroads
Texaco, Inc.
Radio Corporation of America
Public Service Company of Colorado
Denver and Rio Grande Western Railroad Company
Great Western Sugar Company
Northern Natural Gas Company
Gulf Research and Development Company
Texas Instruments
Continental Oil Company
Army Ballistic Missile Agency.

The scientific work of the Institute, and related work from other institutions, was reviewed for the participants by members of the HAO staff.

Future plans of the Institute, discussed during the Sponsors' Conference, call for an extension of the research programs for an additional four years. We have decided, however, to seek new sponsors from different branches of industry and commerce. We are happy to announce that we have received a grant from the Association of American Railroads under the new sponsorship. This reflects our desires to see the type of work carried out by the Institute sponsored by a wider cross-section of industrial disciplines. The first four years of the Institute, we feel, were productive in fundamental research and we deeply appreciate the generous help of our past sponsors. As is nearly always the case in this type of research, the applications depend upon advances in knowledge along several different avenues of science and are as unpredictable as the weather.

The anticipated merger of HAO with the National Center for Atmospheric Research (see page 4), which was foreseen early in 1960 as a possible development, has delayed our active soliciting of supporting funds for the Institute program. Not that we intend to forego this type of support if and

when the merger is accomplished, but rather that we feel obliged to present a clear picture of the Institute's organizational structure to our sponsors.

III. ASTRO-GEOPHYSICS PROGRAM

Warwick continued to direct the Astro-Geophysics program until the end of May. As previously noted, Billings undertook the directorship in June. We plan to continue to rotate this position among the various HAO staff members.

Courses taught during the spring semester were as follows:

Modern Astrophysics -- Newkirk
The Sun -- Warwick
Dynamics of the Atmosphere -- Haurwitz
Problems of the Solar Atmosphere -- Athay
Reading and Research in Astro-Geophysics -- Staff
Doctors' Thesis -- Athay

Hollis R. Johnson completed his thesis research during the Spring semester, and will receive his doctorate at the summer commencement exercises. Johnson will be the first student to terminate with his Ph.D. degree after starting his graduate training in astro-geophysics in our department. Our one previous graduate, Stuart Pottasch, completed just his terminal year in the department with previous training at Harvard.

Johnson's thesis successfully resolves one of the long-standing mysteries of the solar chromosphere, the unexpected appearance of helium emission lines requiring high energies for excitation (see Part VI, RESEARCH ACTIVITIES). His thesis research was carried out with Athay under a National Science Foundation fellowship.

Three students, O. R. White, J. M. Malville, and J. A. Eddy, have completed their comprehensive exams and have theses well under way. Several other students are beginning thesis research and are expected to complete their exams next spring.

VI. CLIMAX

Watson continued as observer-in-charge at Climax. Other observers are James, Ritchie, and Manning. The five-inch high-speed coronagraph and spectrograph continued to serve as the principal research instrument. The K-coronameter provided much valuable data on the white light coronal structure.

Several research programs are in progress with members of the Boulder staff of HAO and with graduate students in the Astro-Geophysics department. These programs are described in the following section on RESEARCH ACTIVITIES.

Early in 1960 a new flare observing instrument was mounted on the Climax spar for testing and adjustment. By June high quality flare observations were being obtained with this instrument, Figure 1, although all of the instrumental problems were not fully resolved. The instrument is unique in that it alternately photographs the solar disk, then the limb, with high enough registration that the two can be superposed to form a composite picture of the disk and limb. Exposure times are about .01 sec and the intervals between exposures about 10 sec. Thus, the instrument provides for high time resolution. The optical system is designed to permit a choice of image sizes of 25 mm, 37 1/2 mm and 50 mm. The camera utilizes 70 mm film in order to take advantage of the spatial resolution obtained under good observing conditions. This larger image size has proven to be a distinct advantage both because of the additional structural detail registered on the film and the convenience of working with a larger image.

The new large coronagraph and spectrograph for the 26-foot equatorial spar at Climax is under construction. Installation at Climax is planned for summer 1961. The optical components have been contracted to the Perkin-Elmer Corporation. Mechanical and electronic components are being fabricated in the HAO shops under the guidance of Lacey and Lee. Rush is supervising the overall design and construction work.

FIGURE 1

A sequence of pictures of the class 3+ flare of 6 May 1960 made with the new flare instrument at Climax. The flare, according to Sacramento Peak observations, began at 14h 04m U.T. It sprayed the earth with energetic protons which produced a sudden increase in ionization of the lower ionosphere in the polar regions, the so-called "polar cap absorption or polar proton events." Its spectrum at radio wavelengths showed intense continuum emission thought to arise from energetic electrons spiraling around magnetic lines of force.

The flare is a good representation of the "umbral" type in which the flare protrudes over the umbral region of a major sunspot. Attention has been recently directed to this type of flare as being more likely to produce polar cap protons than similar flares that do not infringe on the umbral area of spots by Dr. Helen-Dodson Prince (paper presented at Cleveland meeting of American Astronomical Society, December 1959).

Figures 3a and 3b are printed at lower density in order to show the umbral structure, and its changes, in the waning stages of the flare.

THE COSMIC RAY FLARE OF 6 MAY 1960

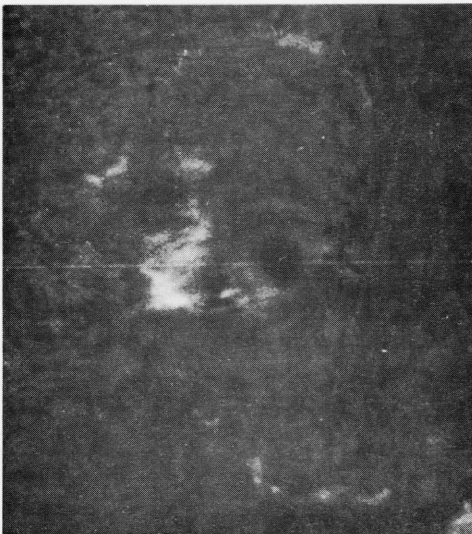
100,000 Km.



1. 15^h 02^m 45^s U.T.



2. 15^h 35^m 36^s U.T.



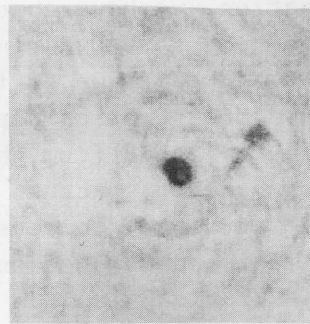
3. 19^h 22^m 43^s U.T.



4. 22^h 18^m 56^s U.T.



3a. Same time as 3.



4a. Same time as 4.

FIGURE 1

V. PERSONNEL CHANGES

New Staff

On 1 June 1960 Dr. Cristiaan E. Heynekamp from Utrecht, Holland, joined the staff of HAO on a one-to-two-year appointment. Heynekamp went immediately to work on the balloon project and will travel to Minnesota with the launching expedition this summer. Later he plans to work with the K-coronameter at Climax along with his continued work on the balloon project. His capabilities as both an instrumentalist and theorist will add substantially to our overall research effort.

In January 1960 Dr. Teresa Fortini of the Astrophysical Observatory of Rome, Italy, began a one-to-two-year stay at HAO under the auspices of the International Cooperation Administration. While in Boulder, Fortini will conduct joint research programs with personnel of both HAO and Sacramento Peak Observatory. She has outstanding capabilities both as an observer and as an interpreter of observational data. She has worked thus far with Warwick, Zirin, and Billings.

Other new employees at HAO include Lenore Stewart, librarian; Anna Jo Murrow, Janice Atkins and Harriet Hunter, secretaries; David Hultquist and Richard E. Skerjanec, electronics; Dale Hansen, machinist; and Deborah Graham Bouboulis, now full-time research assistant.

George Streander, Horst Mauter, Frank Schoeps, and Arnold Green were also employed by HAO but work at Sacramento Peak Observatory through a cooperative program with HAO.

Summer personnel arriving in June included a number of visiting professors and graduate students. Prof. Julius London of New York University spent his summer at HAO, as he has for the past several years.

In an effort to share our research facilities with some of the smaller, but excellent, colleges without graduate research programs located throughout the nation, we have encouraged capable scientists teaching at such institutions to come to HAO during summer vacations and begin research projects which they can continue during their academic year. This summer Dr. Dino Zei, head of the Physics department at Ripon College, Ripon, Wisconsin, came to HAO under a grant from the National Science Foundation to work with Warwick on sunspot spectra. Dr. Malcolm Correll, head of the Physics department at Depauw University has spent several summers at HAO under this program. This summer he concluded an extended visit of thirteen months while on sabbatical leave.

A further program through which we endeavor to bring research facilities to some of the smaller liberal arts colleges brought two summer visitors to HAO. Dr. Charles M. Fullerton, College of St. Joseph, Albuquerque, New Mexico, and Dr. Nathan K. Williamson, Newberry College, Newberry, South Carolina, came under the Research Participation for College Teachers grant from the National Science Foundation. Robert C. Lehman from Pennsylvania State College worked with Billings on an HAO contract.

Graduate students who came to HAO for summer employment from other institutions were Robert Brun, Frank Haurwitz, Verne Peterson, Hélène Ramseyer, and James Robb.

Terminations

Macdonald resigned from the staff of HAO to join AVCO, Research and Advanced Development Division, Wilmington, Massachusetts. He had been one of the principal HAO research personnel working on problems of solar weather relationships during his $3 \frac{1}{3}$ years with us.

Other terminations were Esther Arinaga, Stephanie McAlister, secretaries; Delight Dowell, research assistant; and William Wright, electronics.

General

Chapman returned briefly to Boulder from May 12 to 30.

Two HAO staff members were married earlier this year. Sylvia Moscové became Mrs. Sy Cohen and Deborah Graham became Mrs. Constantine (Gus) Bouboulis.

Leaves-of-absence were taken during the summer by Nancy Potter, Betty Tanner, and Barbara Robertson.

VI. RESEARCH ACTIVITIES

The research activities outlined briefly in the following paragraphs are representative of HAO's activities during the first half of 1960. Some of the programs mentioned are new; others are continuations of programs initiated earlier. Researches mentioned in preceding reports but not mentioned here are in many cases continuing. Similarly, not all new research projects have been included in this report in the interest of brevity.

A. Jupiter's Radio Emission

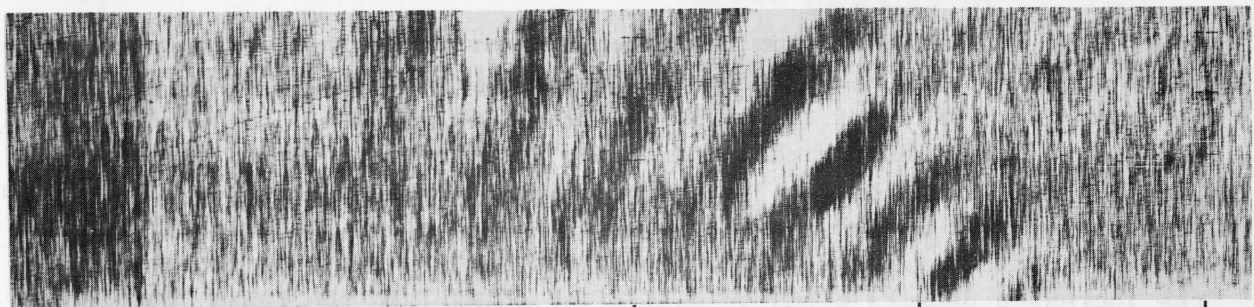
The radio astronomical program supervised by Warwick took a new turn this spring. After observing the sun's radio emissions and the radio stars, as well as several satellites, Warwick decided to try to observe Jupiter. This planet often emits very intense radio waves which have been studied extensively over the last five years or so at a number of observatories, including the National Bureau of Standards here in Boulder. However, using our radio spectrograph which sweeps in frequency from 7.5 mc/s to 41 mc/s (15-34 mc/s when Jupiter observations were started) we could bring to our observations a new technique, we felt, namely the observation of a wide band of frequencies simultaneously. This had never before been accomplished. We decided to try observations on February 1 and, with beginner's luck, on the early morning of the second day had our first case of a dynamic spectrum of Jupiter emission! Moreover, two days later we had another still more intense case, which showed amazing changes in the spectrum as time progressed.

The program continued all spring and resulted by the end of May in several dozen beautiful spectra, showing surprising drifts of the spectral features both towards higher (in some cases) or lower (in others) frequencies, as well as stationary features (see figure 2).

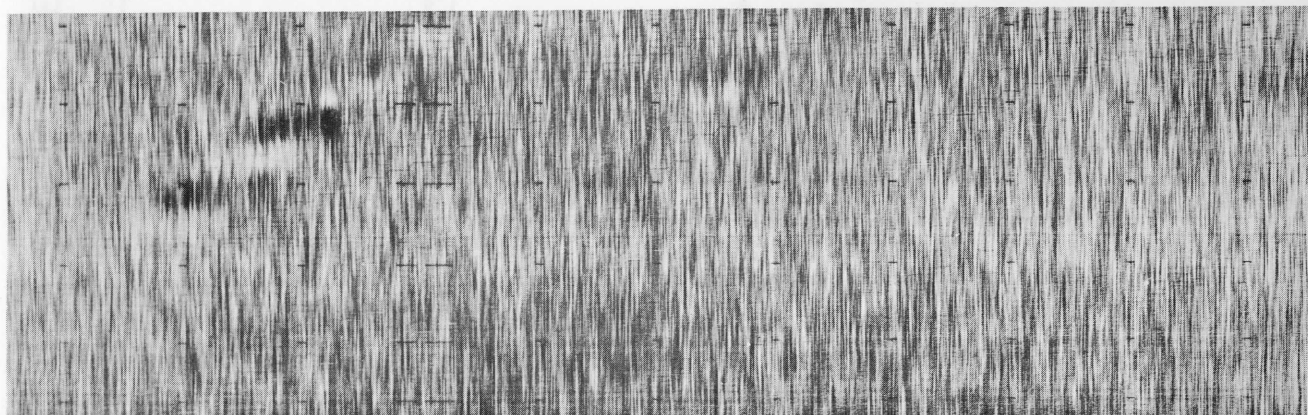
Still more surprising, the emission turned out to occur this spring very preferentially during the periods of high solar activity in early April and May, and within a day or so of especially violent outbreaks of solar activity. This close connection between observations of solar activity and the fluctuating radio emission from a planet other than earth is, we believe, unprecedented and may open up a whole new territory of astrophysical studies, namely (in analogue to solar-terrestrial relations) solar-jovian relations!

B. Solar Radio "Hot Spots"

At radio wavelengths the appearance of the sun is considerably different from its appearance to our eyes. The active regions appear as long-lived bright "hot spots" rather than the familiar sunspots, which are darker than the surrounding photosphere. The cause of these "hot spots" has been under discussion by astronomers for several years. Some concluded that the radio "hot spots" represent areas of high density and very high temperature (up to 10 million degrees). This conclusion was difficult to understand because the spectra of the corona made at Climax and Sacramento Peak show



0400 M.S.T. 0425 0500 0530 0600
4 FEB. 1960



0145 M.S.T. 0200 0230
11 MAY 1960

FIGURE 2

Two examples of the dynamic aspects of Jupiter radio emission from 15 to 34 Megacycles per second. The banded structures running diagonally across the record, whether light or dark, indicate an enhanced radio signal in which the maximum intensity shifts in wavelength as time progresses. Position and time relationships identify the sources with Jupiter. In the 4 February event, the signal shows two disturbances drifting towards shorter wavelengths, one rapidly and one slowly. The 11 May event shows a single disturbance drifting towards longer wavelengths.

no evidence of coronal temperatures higher than four million degrees, and these occur only in areas which exist for but a few hours at most.

Using observations from the K-coronameter at Climax, which detects the white-light corona, Newkirk has determined the geometrical structure and density distribution of the corona above active regions. He has found that these active regions are characterized by an increased density relative to normal coronal conditions. The increased density, furthermore, persists for many weeks, just as the enhanced radio emission does. By calculating the paths of radio waves through these regions Newkirk was able to show that the increased density alone is sufficient to explain the radio "hot spots" without any change of the coronal temperature over its usual value of about two million degrees (figure 3). The radio and the optical observations of the temperature in the corona are thus shown to be consistent with one another.

C. Coronal Line Profiles

Billings continued during this report period his work on the corona, concentrating on the problems presented by the great width of the coronal lines. The breadth of the green coronal line indicates a temperature in the everyday corona of about 2,500,000°. Greater breadths of lines imply greater temperatures if one believes that the gas motions that produce the broadening are the thermal motions of individual atoms rather than the motions of large scale features, such as turbulent eddies.⁽²⁾ Temperatures of the corona, determined by other means, fall about one million degrees short of this. Billings' main objective was to find the answers to a number of questions concerning these line widths which might provide a clue to their interpretation. These questions were: How does the width vary from point to point along the sun's perimeter? How does it vary with height and with time? Is the line broader or narrower at the places where it is bright than where it is faint? Is there any evidence for large scale motions in the corona that might lend credibility to the hypothesis that part of the line breadth results from such motions rather than entirely from thermal motions?

Billings sought to answer these questions from the analysis of some very excellent spectrograms photographed at Climax, using statistical methods with the aid of an electronic computer for determining the line

(2) Director's Quarterly Report, Third and Fourth Quarters 1958, page 17

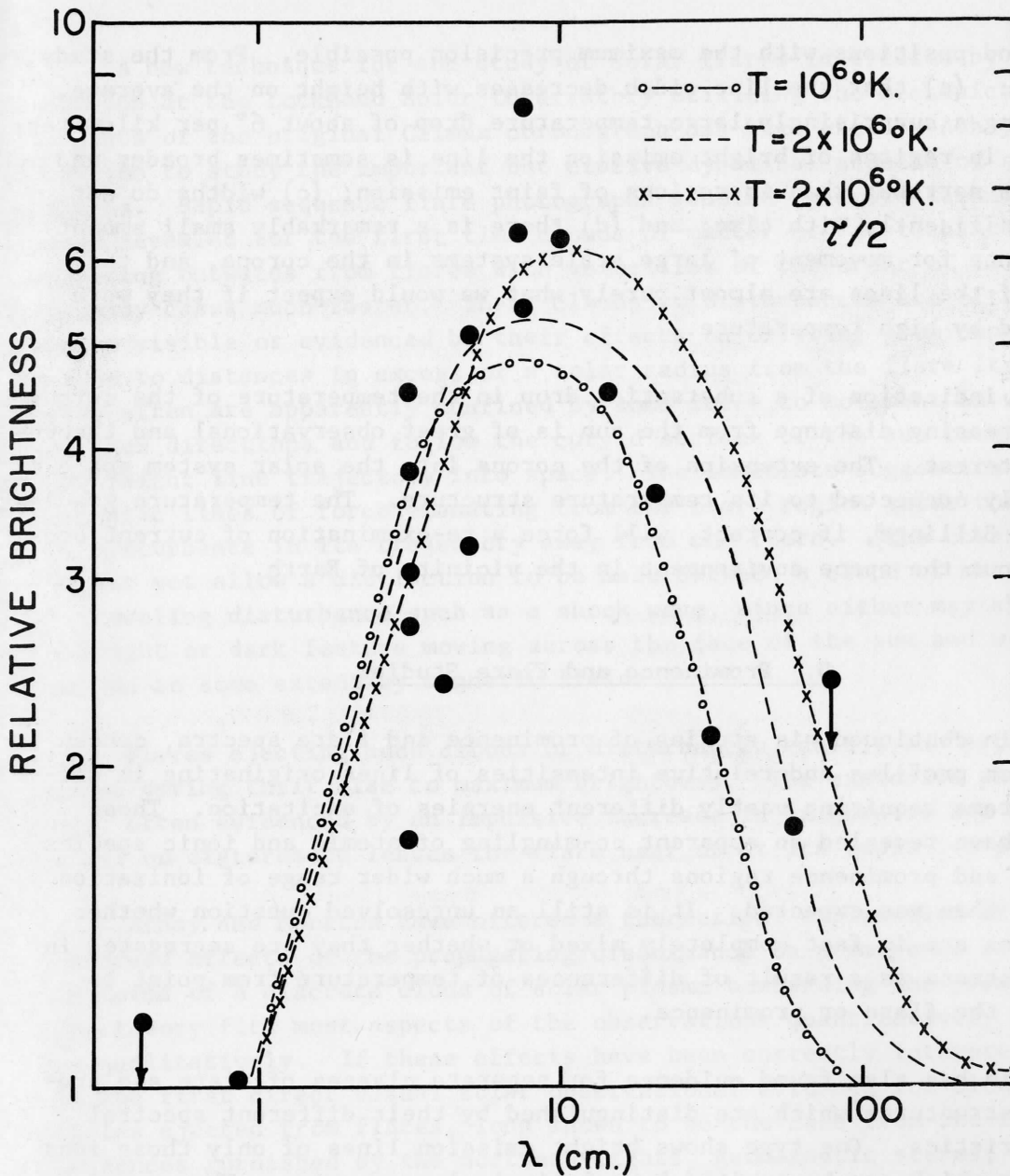


FIGURE 3

Spectrum of the solar radio "hot spots" — The ratio of brightness of the radio "hot spots" to brightness of the quiet sun is plotted against the wavelength of observation. The prints show various observations of the spectrum of the long-lived enhanced radiation of active solar regions at particular radio wavelengths. The three lines show the calculated spectrum for different temperatures and densities in the active region. The temperatures chosen for the calculations are typical of those in the normal corona. The densities, however, are those obtained from observations with the K-corona-meter and are considerably higher than the average coronal densities at the same height. The curve labeled $\tau/2$ has all coronal densities reduced by $1/\sqrt{2}$. The relatively good agreement between the calculations and observations indicates that the "hot spots" probably are due solely to the abnormally high densities in the corona above active regions and not, as was previously believed by many workers, an elevation of the coronal temperature to as much as 10 million degrees.

widths and positions with the maximum precision possible. From the study he found: (a) that the line width decreases with height on the average, indicating a surprisingly large temperature drop of about 6° per kilometer; (b) that in regions of bright emission the line is sometimes broader and sometimes narrower than in regions of faint emission; (c) widths do not vary significantly with time; and (d) there is a remarkably small amount of evidence for movement of large scale systems in the corona, and the shapes of the lines are almost purely what we would expect if they were broadened by high temperature.

The indication of a substantial drop in the temperature of the corona with increasing distance from the sun is of great observational and theoretical interest. The extension of the corona into the solar system space is intimately connected to its temperature structure. The temperature gradient found by Billings, if correct, will force a re-examination of current concepts about the space environment in the vicinity of Earth.

D. Prominence and Flare Studies

Zirin continued his studies of prominence and flare spectra, concentrating on profiles and relative intensities of lines originating in different atoms requiring vastly different energies of excitation. These studies have revealed an apparent co-mingling of atomic and ionic species in flare and prominence regions through a much wider range of ionization energies than was expected. It is still an unresolved question whether these ions are in fact completely mixed or whether they are segregated in gaseous strata as a result of differences of temperature from point to point in the flare or prominence.

Zirin has also found evidence for separate classes of flare and prominence structures which are distinguished by their different spectral characteristics. One type shows bright emission lines of only those ions and atoms which can be excited by relatively low energies. The second type shows strong emission lines of ions requiring high energies of excitation and a markedly reduced emission from the ions with low excitation energies. This duality of spectral character is reminiscent of the temperature structure of the chromosphere proposed by Athay and Thomas a few years ago.⁽³⁾ According to their theory, the temperature of the chromosphere has only two possible ranges, one associated with hydrogen (low excitation energy) and one associated with ionized helium (high excitation energy).

(3) Astrophysical Journal, 123, 299, 1956.

A new technique for the study of solar flares instituted by G. E. Moreton at the Lockheed Solar Observatory utilizing the mechanical components of the original Climax coronagraph has been used by Athay and Moreton to study the important but elusive dynamical aspects of solar flares. Rapid sequence flare photographs studied by movie techniques have revealed for the first time clouds of matter or "disturbances" propagating outwards from flares with velocities of the order of 1000 km/sec, in many cases much faster. These clouds or disturbances are often directly visible or evidenced by their effects on existing prominence structures to distances in excess of a solar radius from the flare itself. They often are apparently confined by some force to movement in well-defined directions and follow the curved surface of the sun rather than a straight line trajectory into space. The immediate suggestion is that magnetic lines of force emanating from the flare region guide the cloud or disturbance in its trajectory away from the flare. (The observations do not yet allow a distinction to be made between a cloud of material and a traveling disturbance such as a shock wave, since either may show up as a bright or dark feature moving across the face of the sun and would be guided to some extent by magnetic fields.)

Flares ejecting such clouds or disturbances exhibit an "explosive" phase during their rise to maximum brightness. The explosive phase is most often evidenced by an impulsive increase in brightness and area. The cloud or disturbance leaves the flare near or at its explosive phase.

Athay and Moreton have offered a theoretical explanation of the observed effects of the propagating disturbance on prominence structures in terms of a discrete cloud of solar plasma bombarding the prominence. The theory fits most aspects of the observations quantitatively as well as qualitatively. If these effects have been correctly interpreted, this is the first direct visual solar observational evidence for clouds of particles ejected from flares, long known to be the case from the indirect evidences furnished by the northern lights, geomagnetic storms, and more recently from radio noise observations of flare regions and from polar cap proton events (see page 10). Furthermore, the velocities observed are of an order of magnitude that is consistent with the lower range of velocities inferred from indirect evidences.

These important new observations of flares are continuing at Lockheed. Similar observations are planned with the new flare instrument at Climax and at Sacramento Peak Observatory.

E. Chromospheric Physics

Johnson's Ph.D. thesis completed during this report period culminated a theoretical study initiated by Athay and Johnson over a year earlier in an attempt to explain the long standing anomaly of helium emission in a supposedly "cool" chromosphere. The results of their calculations provided a detailed explanation of the helium spectrum and revealed that the temperature of the chromospheric regions producing helium radiation are of the order of $40,000^{\circ}$ to $50,000^{\circ}$ K.

Indirectly, this same study cleared up another long standing chromospheric anomaly, viz., its great vertical extent. Previously several theories had been advanced to explain the support of the chromosphere. All except one had failed the test of time and new observations. The one survivor was the theory of a "turbulent" support due to the random motions of turbulent eddies in the chromospheric gases. No other evidence for these eddies has been advanced. The successful explanation of the helium spectrum and the requirement that the kinetic temperature be as high as $40,000 - 50,000^{\circ}$ K removes the need for these turbulent eddies, and, in fact, makes them untenable. Although we had suspected for several years that this was the case, we had not been able to successfully demonstrate it. The extent of the chromosphere, in the new picture, is no longer anomalous, and no "artificial" support is required. Its great extent is due solely and quite naturally to its high temperature. Only the character of the problem is changed, however, and one must now ask "how does the chromosphere get so hot?"

A monograph, "Physics of the Chromosphere" by Thomas and Athay has been completed and will be published early in late 1960 or early 1961 by Interscience Publishers, New York.

F. Wave Motions in Noctilucent Clouds

Noctilucent clouds, which form at about 50 miles altitude, are often visible during the summer months at high latitudes. They appear usually just after darkness sets in on the ground and while they are still illuminated by sunlight because of their altitude. These elusive clouds have long been an enigma as to their origin and nature. Haurwitz has recently completed a study of the wave structure and motion in these clouds which sheds new light on these problems.

It is not yet known whether noctilucent clouds are made up of dust particles, probably of meteoric origin, or of water substance. Their altitude of about 50 miles coincides nearly with that of the mesopause, the atmospheric boundary where the vertical temperature gradient ends its last major decrease and begins to increase upwards. The physical nature

of waves at this boundary is similar to that of the wind-generated gravity waves on the surface of the ocean, the boundary between water and air. But the length of the waves at the atmospheric interface is much larger, about 10 km in the case of those observed in noctilucent clouds. Haurwitz has shown that the expected wave motions and wavelengths at the mesopause can produce the band structure observed in noctilucent clouds without requiring a striation of cloud substance as has been frequently proposed by other workers. This permits either the dust or water vapor origin as possibilities.

G. Geomagnetism

Matsushita has reanalyzed the variations in the earth's magnetic field on geomagnetically "quiet" days produced by the effects of the steady solar radiation, the so-called solar quiet day current system. His analysis shows that the center of the electrical current system producing the geomagnetic variations shifts north and south in phase with the seasonal motion of the sun. This is in contrast with all previous analyses, which indicated an opposing motion of the current system with respect to the solar motion. He also found that the current system is more easily described in a geomagnetic coordinate system than in a geographic coordinate system. The geomagnetic coordinate system utilizes lines of equal vertical intensity in the geomagnetic field, and the current system shows a strong tendency to parallel these lines.

In a separate analysis, Matsushita has found a seasonal variation in the intense band of electrical current encircling the earth in the high atmosphere at equatorial latitudes, the so-called equatorial electrojet, with maximum current flowing during the equinoxes.

H. Colorado Streamflow

A study of one of the nations most valuable national resources, Colorado River water, was undertaken last year by the HAO as outlined in the preceding Director's Report. The purpose was to investigate the possibility of forecasting the river flow by statistical means and to investigate the complicated basic hydrological processes linking river flow to precipitation, the ultimate source of river water. Weather records over the last 60 years in the Colorado River have been analyzed by Julian who has found a number of interesting and important results.

Precipitation records are confused in many cases by such factors as changes in location of rain gauges, construction of nearby buildings, etc. However, Julian has found that the stations where such changes have not

occurred show no systematic trend in the average annual precipitation in the basin. In spite of this, Julian finds that the riverflow records at Lee's Ferry show a gradual decrease in streamflow over the past 60 years. He explains this apparent lack of agreement between precipitation and riverflow records through an increase in evaporation brought about by a general increase in the temperature in the river basin and by increased usage of the water for irrigation, etc. The temperature increase shows up in the weather records as a statistical trend throughout the basin.

Riverflow records, themselves, show differing degrees of continuity from one year to the next (serial correlation) depending upon their basin characteristics. Tributaries to the Colorado located in high mountain basins show no significant correlation in run-off from one year to the next. Lee's Ferry, which collects water from the entire basin, however, shows a slight tendency for a year by year correlation. It is not large enough, however, to assure that it will be useful in predicting streamflow.

I. World Data Center

Considerable progress was made during this period on the multicolor solar maps for IGY to be published by Pergamon Press. Publication of these valuable maps will probably be accomplished in 1961.

Hansen continues to manage the Data Center activities. Its IGY functions are continuing during IGC essentially unabated.

VII. RECENT VISITORS TO HAO

31 December - 8 January	Harlow Shapley, Harvard College Observatory, Cambridge, Massachusetts
4 February	David R. Layzer, Harvard College Observatory, Cambridge, Massachusetts
11 February	Victor Regener, University of New Mexico, Albuquerque, New Mexico
12 February	Lewis Grant, Colorado State University, Ft. Collins, Colorado
20 - 22 February	Vincent Schaefer, R. D. 3, Schermerhorn Road, Schenectady, New York

22 February Howard T. Orville, Washington, D. C.

5 March Carl W. Borgmann, Ford Foundation, New York

14 - 18 March I. G. Poppoff, Stanford Research Institute,
Menlo Park, California

15 - 29 March Werner Schwerdtfeger, Meteorologist in the
Argentine Navy, Buenos Aires, Argentina

16 - 30 March John Firor, Carnegie Institution of Washington
Washington, D. C.

28 March Gail E. Moreton, Lockheed Aircraft, Burbank,
California

2 - 6 April Fritz Moller, Meteorological-Geophysical
Institute, University of Mainz, Germany

May Waldmar Gutzman, Canadian Meteorological Service,
Toronto, Canada

17 May John Lindsay, National Aeronautics and Space
Administration, Washington, D. C.

22 - 25 May Kurt Bullrich, Department of Meteorology,
University of California, Los Angeles,
California

1 June Walter B. Langbein, U. S. Geological Survey,
Washington, D. C.

1 June Terah Smiley, Tree Geochronology Laboratory,
Tucson, Arizona

1 June Eugene Peck, U. S. Weather Bureau, Salt Lake City,
Utah

1 June Nicholas C. Matalas, U. S. Geological Survey,
Washington 25, D. C.

1 June Vujica M. Yevdjovich, U. S. Geological Survey,
Washington 25, D. C.

1 June John W. Harshbarger, Geology Professor,
University of Arizona, Tucson, Arizona

3 June	J. A. Ratcliffe, Cavendish Laboratory, Cambridge, England
6 June	Marshal H. Wrubel, Department of Astronomy, Indiana University, Bloomington, Indiana
8 - 9 June	Harold Strids, Air Force Research Directorate, Bedford, Massachusetts
10 June	Johannas Ortner, Astronomical Observatory, Kiruna, Sweden
10 - 17 June	Walter Kertz, Gottingen, Germany
14 - 17 June	S. F. Smerd, CSIRO, University Grounds, Sydney, Australia
20 - 21 June	Max Woodbury, College of Engineering, Research Division, New York University, New York
21 June	Jack Zirker, Sacramento Peak Observatory Sunspot, New Mexico
22 June	Henry G. Houghton, Massachusetts Institute of Technology, Cambridge, Massachusetts
28 June	Harlan Smith, Yale University Observatory, New Haven, Connecticut
28 June	Arthur L. Bennett, Georgia Institute of Technology, Atlanta, Georgia

VIII. PUBLICATIONS FROM HAO DURING PERIOD

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- Steiger, W. R. and S. Matsushita: "Photographs of the High-Altitude Nuclear Explosion 'Teak'," *Journal of Geophysical Research*, 65, 545-550, 1960.
- Macdonald, N. J. and W. O. Roberts: "Further Evidence of a Solar Corpuscular Influence on Large-Scale Circulation at 300 Mb," *Journal of Geophysical Research*, 65, 529-534, 1960.
- Newkirk, G. Jr., G. W. Curtis, D. K. Watson, R. Manning, J. Shelby; "The Inner Solar Corona during June 1959," *Nature*, 184, 1308, 1959.
- Athay, R. G. and H. Johnson: "The excitation of He I in the Solar Spectrum," *Astrophysical Journal*, 131, 413-428, 1960.
- Roberts, W. O.; "The Physics of the Sun," Physics and Medicine of the Atmosphere and Space, ed. Benson and Stronghold, John Wesley and Sons, Inc., New York 1960. Chapter 37.
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- Matsushita, S.: "Studies with IGY Data from U.S. Geomagnetic Stations," *Journal of Geophysical Research*, 65, 1423-1435, 1960.
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- Zirin, H. and E. Tandberg-Hanssen: "Physical Conditions in Limb Flares and Active Prominences. IV. Comparison of Active and Quiescent Prominences," *Astrophysical Journal*, 131, 717-724, 1960.
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- Roberts, W. O. and H. Zirin: "Recent Progress in Solar Physics," *Journal of Geophysical Research*, 65, 1645-1659, 1960.

- Gantvoort, N. C. and D. E. Billings: "Prominence Characteristics in Regions of Bright Coronal Emission," *Astrophysical Journal*, 132, 213-217, 1960.
- Athay, R. G.: "Rocket and Satellite Observations of the Solar Ultraviolet Spectrum," *Nature*, 186, 1036, 1960.
- Chapman, S.: "The Thermosphere--The Earth's Outermost Atmosphere," Physics of the Atmosphere, Ch. 1, ed. J. A. Ratcliffe, Academic Press, 1960.
- Lüst, R. and H. Zirin: "Condensation of Prominences from the Corona," *Zeitschrift für Astrophysik*, 49, 1960.
- Hansen, D. and D. Gordon: "The Limb Flares of 13 October 1958," *Astronomical Society of the Pacific*, 72, 194-199, 1960.

IX. DATA REPORTS AND SPECIAL PUBLICATIONS FROM HAO

A. World Data Center Publications

- IGY Solar Activity Report Series No. 9, April to June 1959, "Intermediate Reports of Surges and Active Prominence Regions."
- IGY Solar Activity Report Series No. 10, July to September 1959, "Intermediate Reports of Surges and Active Prominence Regions."
- IGY Solar Activity Report Series No. 11, October to December 1959, "Intermediate Reports of Surges and Active Prominence Regions."
- IGY Solar Activity Report Series No. 12, 25 June 1960, Dodson, Helen W. and E. Ruth Hedeman, "McMath-Hulbert Observatory Working List of IGY Flares."

B. Solar Activity Reports

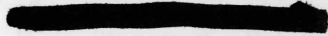
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- Trotter, Dorothy E. and Walter Orr Roberts, 1959 Solar Activity Summary II, 25 March through 15 June 1959, Report No. HAO-47.

Trotter, Dorothy E., Betty Tanner, and K. E. Sue Klein, 1952 Summary of Solar Limb Prominences, 26 December 1951 through 11 January 1953, Report No. HAO-48.

C. Reports from the Institute for Solar-Terrestrial Research

Macdonald, N. J. and Robert W. Knecht: "A Possible Effect of Lower Atmospheric Divergence on the Local Maximum Electron Density in the Ionosphere," Technical Report No. 8, Institute for Solar-Terrestrial Research, March 1960.

R. Grant Athay


High Altitude Observatory
Boulder, Colorado
15 December 1960

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