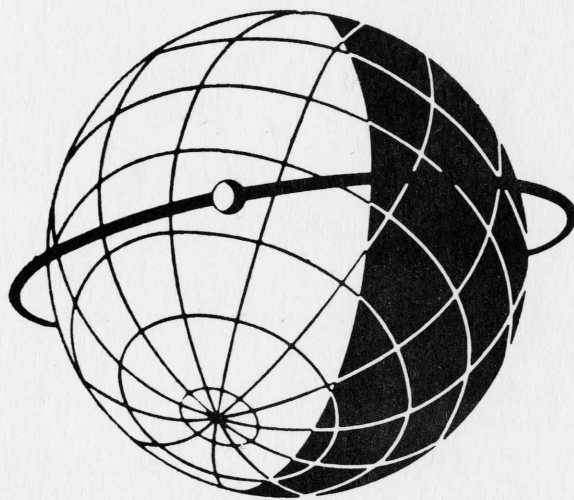


THE
DIRECTOR'S QUARTERLY REPORT

Second Quarter 1957

Third Quarter 1957

1 April to 30 September 1957



*The IGY Symbol**

*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: The IGY symbol. "The IGY will bear fruit in immense numbers of books and articles enshrining and discussing the observations. It has been decided that these may bear a distinctive symbol; perhaps the satellites will also bear it. Only a few outstanding aspects can be illustrated by the symbol. The symbol chosen shows the earth, half sunlit, half dark, illustrating in the simplest way the influence of the sun. The south pole is shown, to emphasize the specially great advances the IGY will bring to Antarctic knowledge. The satellite is shown, to illustrate the most novel and striking of the many new instruments to be used during the IGY."

Sydney Chapman

SUMMARY

Space missiles are at least partly responsible for the fact that this report covers two quarters instead of one.

Because of Sputnik I, Sputnik II, and other activities chronicled below, I fell so far behind in finishing up the April-June report that I decided to combine it with the July-September one.

Solar activity jumped to an astonishingly high level during the half year of this report. Preliminary reports suggest that the final data may show that the summer months have the highest sunspot numbers ever recorded.

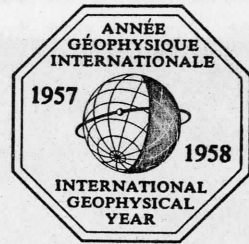
HAO passed several milestones during this time. The long-planned IGY began July 1st. To celebrate it the sun cut loose with flares, strong corona and a vigorous first of July magnetic storm with aurora and high altitude X-rays in the following days. (See Figure 3.)

Another milestone was the completion in September of the HAO radio interferometer located north of Boulder. (See Figure 1.) Before it could even be tested out on radio stars, the Russians launched Sputnik I (officially known as Satellite 1957 α 2 *). The radio beams of Sputnik

* By international agreement artificial earth satellites are listed by the year, and the Greek letter corresponding to the order of firing in that year; the subsequent numbers list the order of brightness of the parts involved in the firing: thus, 1957 α 1 is the 4 October rocket body, 1957 α 2 the satellite itself, and 1957 α 3 the detached door.

turned out to be ideal signal sources for the radio telescopes; the telescopes, in turn, turned out to be ideal instruments for tracking the satellites. Thus Warwick, Lee and others on the HAO staff have put in sleepless nights and frenzied days making and analyzing yards of record tapes and have come to interesting preliminary conclusions about the ionosphere.

HAO served as co-host (with the University, the National Bureau of Standards and the City of Boulder) for the Twelfth International Congress of URSI (International Scientific Radio Union) in August and September. In radio science, as in so many other new scientific fields, we are witnessing a phenomenal growth of knowledge about effects of variable solar activity. This all emphasizes once again the importance of the field we have chosen to call astro-geophysics, of which a major branch involves radio propagation problems.



I. HIGHLIGHTS

A. The International Geophysical Year

"Our great globe the earth, on which we dwell, rolls onward, like the other planets, around the far greater sun. The sun moves together with its family of planets and comets among its fellow stars of the Milky Way. This turns majestically around its centre. Beyond lie myriads of other galaxies. Light and radio waves traverse the vast intervening spaces. The recognition of this immense perspective in space is one of the collective triumphs of the human race.

"The earth is small by such standards, but to us it is great. It has seen the rise and fall of continents, and the wonderful drama of the evolution of life, culminating in the development of man, the lord of the earthly creation. Much has been done to trace out the earth's eventful history. We seek also to glimpse what the future holds in store for the earth and our race.

"Man's search after knowledge has brought to light many aspects of Nature that our senses alone cannot detect--such as the magnetism of the earth, and the wonders of the atom. Man has also been quick and resourceful to use this knowledge for his own purposes--with untold promise for our good or our destruction. Much of this knowledge has been gained in the laboratory, but our knowledge of our planet cannot be completed only there. We must traverse it and measure it on the spot, in its many parts and in many ways. The task of mapping the earth is almost done, but the air and its ways, the seas and their ways, affect our lives deeply, and we must continue to observe and try to understand the laws they follow. This kind of knowledge is called geophysical." 1)

1) S. Chapman, "The Advancement of Science," No. 52, p. 259, 1957, taken from a discourse delivered to the Sheffield Meeting of the British Association for the Advancement of Science.

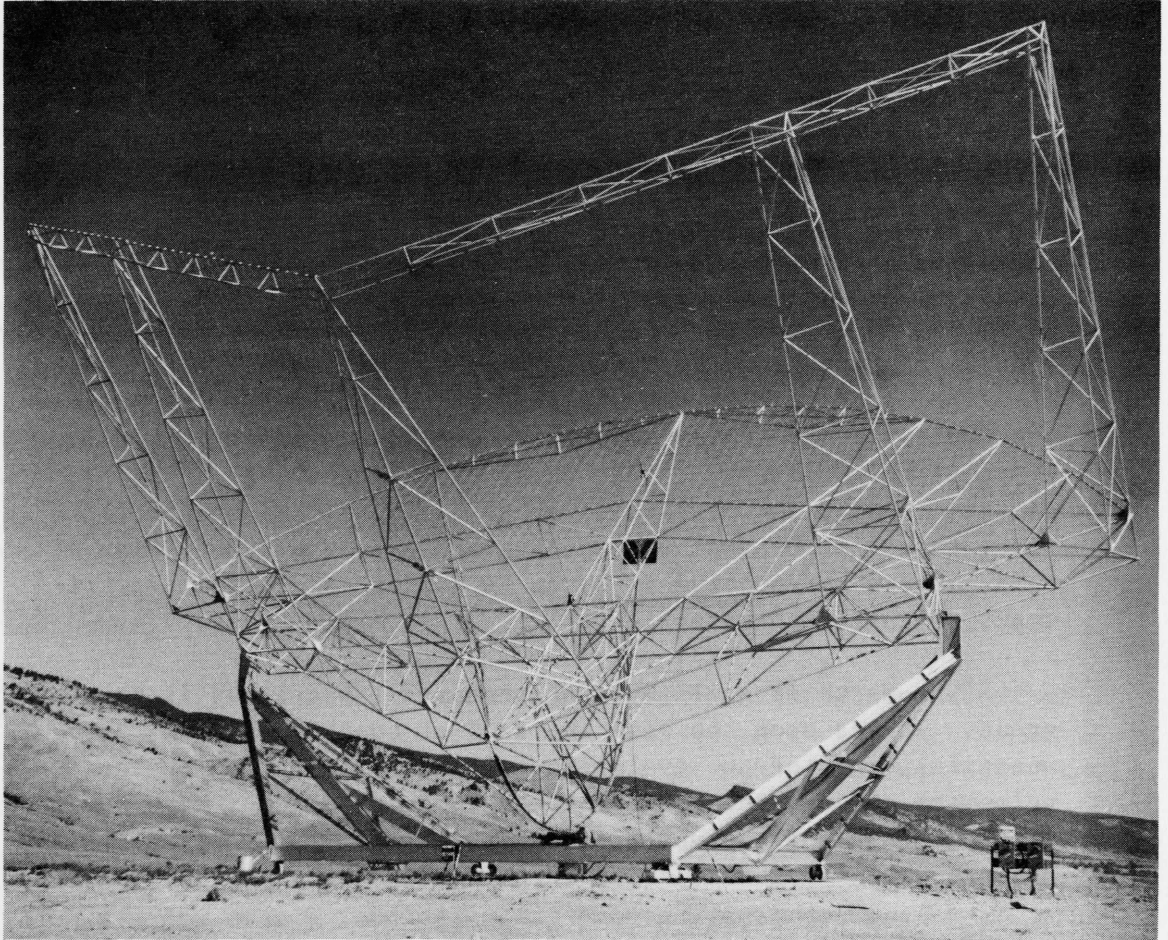


FIGURE 1

One of HAO's two new radio antennas located at the radio astronomy site north of Boulder. With this instrument and its twin located 900 feet away we hope to learn more about the nature of effects in the ionosphere produced by solar flares. These twin antennas, which together make an interferometer, were designed to measure radio signal absorption and refraction by picking up signals from radio stars. However, the signals from the Russian satellites recorded by the antennas may also give valuable ionospheric information. (See Figure 2.)

Thus Professor Sydney Chapman defined the field of geophysics now in the focus of world attention as the result of the start, on July 1st of the International Geophysical Year, generally called by scientists simply by its initials, IGY.

For HAO the onset of IGY was by all counts the most significant event of the half year. On that day we joined colleagues at stations in other nations in the most intensive program of coordinated scientific work ever attempted by man. Its purpose is simply to advance our understanding of the physical processes of "our great globe the earth." For this HAO has embarked on 18 months of concentrated observations of the activity of the sun. Simultaneously, from all parts of the earth, coordinated geophysical measurements are going on. When December 31st, 1958 comes, we shall have a monumental body of scientific data for scientific analysis, argument and interpretation over the decades to come. And I am sure it will be decades before the measurements are fully exploited.

HAO is deep in the program not only as an observing station, but also as an official IGY World Data Center where world wide records of solar activity are being stored and made available for research.

B. Sputnik and the World Struggle for Technological Supremacy

The age of space flight began on the 4th of October during mid-afternoon in Colorado. At that moment the Soviet Union fired a missile that, as I write these words (November 28th), has traveled over 20 million miles, the equivalent of 40 round trips to the moon. It has passed many times over the heads of almost every inhabitant of the earth in its more than 750 revolutions about the earth.

The feat ranks with the great scientific achievements of all time. It parallels the successful firing of the world's first A-bomb on July 16, 1945. And like the A-bomb, the satellite holds a fearful threat and an inspiring promise, depending on whether it is applied to peace or to war. Coupled with the A-bomb it wipes from the slate all rules about the security of geographical isolation for nations at war.

In this age of science it should not appear ironical that the earth satellite was a tool of IGY research and was launched under the aegis of a peaceful world-cooperative scheme for scientific research. For all knowledge is power, and all power can be applied for good or evil.

The challenge of the satellite must not be misconstrued. We cannot

afford to view it in terms of simply a guided missile race with the USSR. It is far more. It is a symbol of man's growing mastery of physical force. It shows the almost frightening rate of scientific advancement possible in all large nations if there is willingness to make the sacrifices necessary. It underlines the fact that we in America are in an all-out race for technological supremacy. It is a challenge to us to prove, as I am convinced we will do, that we can match the scientific imagination and determination of any nation.

The race is not a race for scientific knowledge alone. It is a race for intellectual achievement. I believe that the contest is to stimulate the best mental attainments of which our people are capable-- in whatever field of intellectual activity. We cannot, for example, build science programs in our colleges and universities at the expenses of the arts and the humanities. The world struggle will be won with music, the graphic arts, literature, and sports, as well as with science.

The race will be costly, but it offers superb rewards if we can prevent its degeneration into war. The benefits to mankind in food and shelter, in health and beauty are almost beyond calculation. I believe, moreover, that institutions like HAO have a major significance in building our scientific strength. HAO's independence of federal or state control, coupled with its close affiliation to both federal governmental research and state supported higher education, enhances its potential contributions to the nation's welfare.

C. Radio Interferometer Completed

A few days before Sputnik I we finally completed the mechanical and electronic work on our radio interferometer at the HAO "north site"--a pasture three miles from Boulder. (See Figure 1.) The interferometer is a device consisting of two large radio telescopes of a type known as "corner reflectors." Each of these is 80 feet long by 45 feet high. Located 300 yards apart, the two are connected electrically to operate as a unit, and point automatically and synchronously to any part of the sky. When both corner reflectors are aimed at the same radio star, the radio signals received by them will generally have traveled a slightly different distance before being picked up. The way the radio waves entering the two reflectors combine electronically thus depends on the star's position in the sky. The signals in the two reflectors add together or cancel each other depending on the angle to the star and the wavelength of the signals, thus allowing accurate measurement of the angle. This phenomenon, known as interference, gives the combination of telescopes the name "interferometer."

14 Oct. 1957

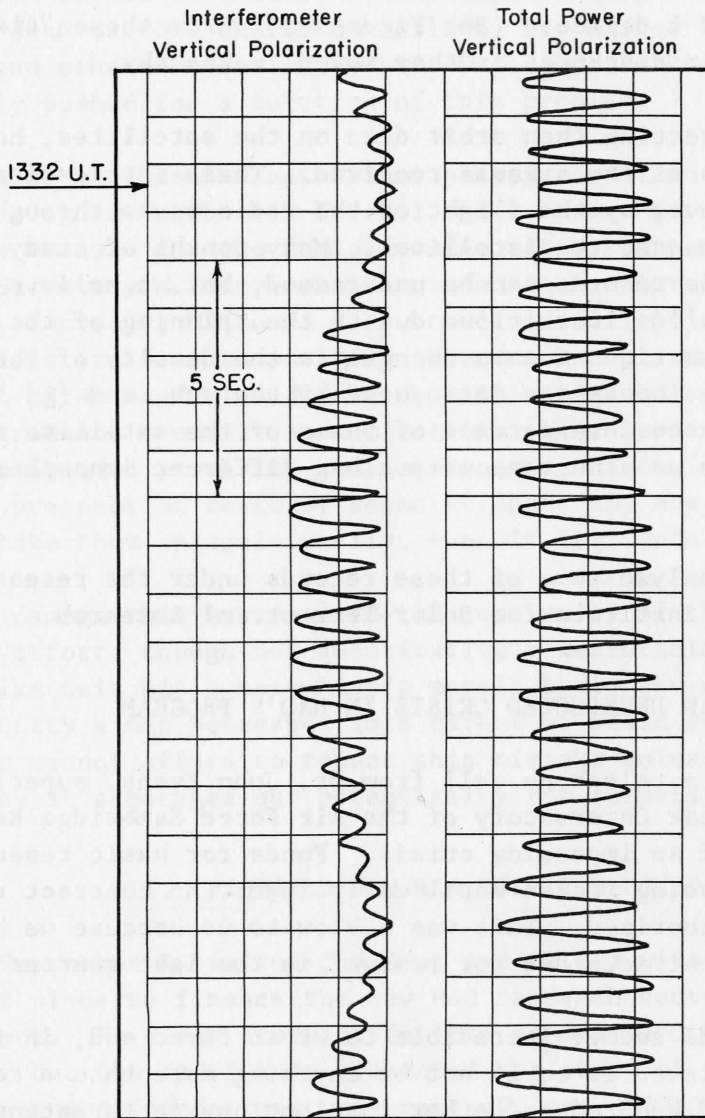


FIGURE 2

Records of the first Russian satellite, Sputnik I, made by the HAO's radio antennas at 6:32 A.M. on 14 October. Each horizontal line represents one second of time. The above graph, on the left, represents the strength of the signal of the satellite showing its rapid flutter rate just above one cycle per second, apparently caused by the ionosphere. The right hand record, made simultaneously shows the combined interference pattern of the same signals picked up separately by the two antennas and combined electrically. From the positions of the minimum fluctuation on such records we can deduce accurately the satellite's distance and direction.

When Sputnik I and II came over, we pressed the new interferometer into service and succeeded in getting records from the 20 megacycle radios of the satellites that revealed their apparent positions with an accuracy of about 1 degree. (See Figure 2.) From these "fixes" we could deduce their distances as they moved in the sky.

Even more interesting than orbit data on the satellites, however, were the intricacies of the signals received. These intricacies were introduced, we believe, by the flight of the radio waves through the ionosphere between us and the satellites. Many months of study are required before these records can be understood, but we believe we have evidence for: (1) fluctuations due to the spinning of the satellite, (2) fluctuations due to changes in the density of the electrical charge in the ionosphere introduced by the sun, and (3) fluctuations of signals due to interference of beams of the satellite radio signals traveling to us simultaneously along different ionospheric paths.

We may later analyze some of these records under the research programs of the HAO Institute for Solar-Terrestrial Research.

II. AN UNEXPECTED CRISIS IN HAO'S PROGRAM

In late August a telephone call from Dr. John Evans, superintendent of the Sacramento Peak Observatory of the Air Force Cambridge Research Center, warned us of an impending crisis. Funds for basic research in the Air Force were being frozen until early 1958. No contract renewals were going to be authorized. This was a blow to us because we had two long-standing contracts due for renewal in the last quarter of 1957.

The cut of funds seemed incredible to us at first and, in fact, still does. We believed it could not be anything more than a temporary mix-up. For HAO and hundreds of other institutions it threatened drastic liquidation of programs that had taken years to build. HAO was faced with curtailing severely a good part of its IGY data observation and analysis program and with abandoning the 1958 eclipse program! We also faced terminating appointments of members of our scientific staff. If it had not been for the flexibility of our support, in substantial part as a result of the Institute for Solar-Terrestrial Research, our straits would have been even more severe.

As several weeks passed I realized that the situation was of the gravest sort, striking to the heart not only of HAO's work but a major part of the whole nation's research. From about September 1st until November 1st, when renewals were finally promised, I spent more than half my time trying to find solutions to this problem. In this we had

the forceful support of Mr. Quigg Newton, President of the University. We enlisted the aid of a great many friends of the Observatory and the University--to all of whom we hereby express deepest appreciation. Senators John Carroll and Gordon Allott, Dr. Alfred Loomis, Mr. Hugh Odishaw and others of the IGY staff, Dr. Lloyd Berkner and many others vigorously pushed for a solution of this problem.

Whether the Russian satellites played a part in the return of a rational program in the Air Force I don't know. Nor do I fully understand the reasons for the funds freeze. It was apparently lifted by Defense Secretary McElroy, who rescinded an earlier order by his predecessor, Secretary Wilson. Even now it is not entirely clear whether these crises are over temporarily or permanently. Many laboratories are still threatened, I understand, with unplanned cutbacks, and I know of graduate students and scientific staff persons who have been forced to abandon promising and important research in mid-program. For these no prospect of restoral seems evident. By now it is probably too late to take them up again easily, even if the funds are restored.

The damage this has done to the continuity of the overall American research effort, though not quantitatively measurable, has been serious. Things like this hit a scientist's morale badly and emphasize the tenuous security a man possesses in a career of basic research. As a nation we cannot afford to repeat this mistake unless we are heedless of the way it sabotages our potentiality for scientific achievement.

III. PROPOSED NEW HAO RESEARCH BUILDING

In September I visited the East and talked with several friends of HAO about plans to finance the new HAO research center described in my last report. No clear prospect for the needed \$250,000 has yet materialized, but Low and I have presented the story of our need to several individuals and foundations. A grant of, say, \$50,000 conditional on our finding the balance, would go a long way to getting us under way. Advice and help are earnestly solicited!

IV. PROGRESS IN THE INSTITUTE FOR SOLAR-TERRESTRIAL RESEARCH

A. Solar Weather Studies

The first and most important aspect of our research on solar-weather connections during the half-year is not a spectacular one. It is the program to test the conclusions from our high altitude weather pattern studies in the fall, winter and spring of 1956-57. To do this we are extending the study to other years. We intend to test the specific find-

ings that:

- (1) Solar corpuscular emission, as measured by geomagnetic disturbances, triggers off upper level weather pattern changes. These show up about 8 or 9 days later as deeper troughs in the upper level winds and as longer contour lines of barometric pressure across North America, and
- (2) The effects are dependent on the kind of weather pattern in force when the solar emission arrives, being strongest when the contours are shortest to start with.

As a second aspect of our studies we have taken a preliminary look at a specific problem of possible solar influences on the frequency and distribution of hurricanes and other tropical storms. Particularly we are looking at the possibility that long-term trends in these frequencies result from long-term changes in overall activity of the sun. Results are still indecisive, but they suggest that the phenomena may be at least partially correlated.

A third aspect of this work has been a beginning on the problem of evaluating specifically the current state of knowledge about two problems of some practical importance:

- (1) What is the physical cause of the recurring Great Plains drought periods?
- (2) What are the realistic prospects for improvements in long range area-temperature forecasting?

On both of these problems we intend in 1958 to issue evaluative summary reports. In neither area do we anticipate conducting any extensive original research at this time, but we do intend to state what directions of research look to us most promising.

During September we noted another striking example of a weather change of large proportions apparently related to an abrupt rise of geomagnetic disturbance. A sun-induced magnetic storm and auroras of spectacular proportions occurred on September 1 and 2. A major weather change over the U.S. set in about September 12th and 13th. The results were perhaps most strikingly demonstrated by the abrupt changes in United Air Lines' minimum time flight trajectories.²⁾ August tra-

²⁾ HAO Solar Research Memorandum No. 96 (18 October 1957) describes these events in detail, and shows the degree to which they fit our earlier studies.

jectories showed little variation during the month, with two tracks fitting almost the whole span of time. After the Labor Day solar rise the track selection became more variable, and by 9 September the tracks were exactly opposite to those of August, so that August east-bound tracks had become west-bound tracks and vice versa.

Our visiting summer staff included Dr. H. Riehl of the University of Chicago and Dr. Julius London and Dr. Bernhard Haurwitz of New York University. Dr. Riehl's visit was supported partially by his own research programs and partially by the Munitalp Foundation. Drs. London and Haurwitz were partially supported by the Institute and partially by their own research programs.

We had many valuable discussions of the validity and implications of our 300 millibar studies, as well as other ideas concerning further studies of solar-weather relationships. In addition, these men pursued basic research problems in meteorological fields related to the work of the Institute.

B. Analysis of K-Corona

The spring quarter was one of the wettest in the history of the Rockies. With it went unusually poor observing weather and scanty records from the K-coronameter. Nevertheless, Axtell and Newkirk both obtained data of importance from the new instrument.

Axtell's data completed the job of taking observations of the K-corona for his thesis program. He has adequate material for his planned study of the changes in the corona at various heights. His efforts are now directed towards interpretation and write-up. Axtell's fellowship was completed by late summer. He will finish his thesis this fall and winter while he holds a teaching appointment at the Colorado School of Mines.

The balance of the K-coronameter program is now carried on by Newkirk and the Climax staff under other research programs of the HAO as described below.

V. OTHER RESEARCH PROGRAMS OF HAO

A. Staff

One of the happiest events of the half-year was the return to our staff of Dr. Sadami Matsushita from the Geophysical Institute at Kyoto, Japan. He has taken a two-year appointment, and brought his charming wife with him. They will be joined later, we hope, by their two

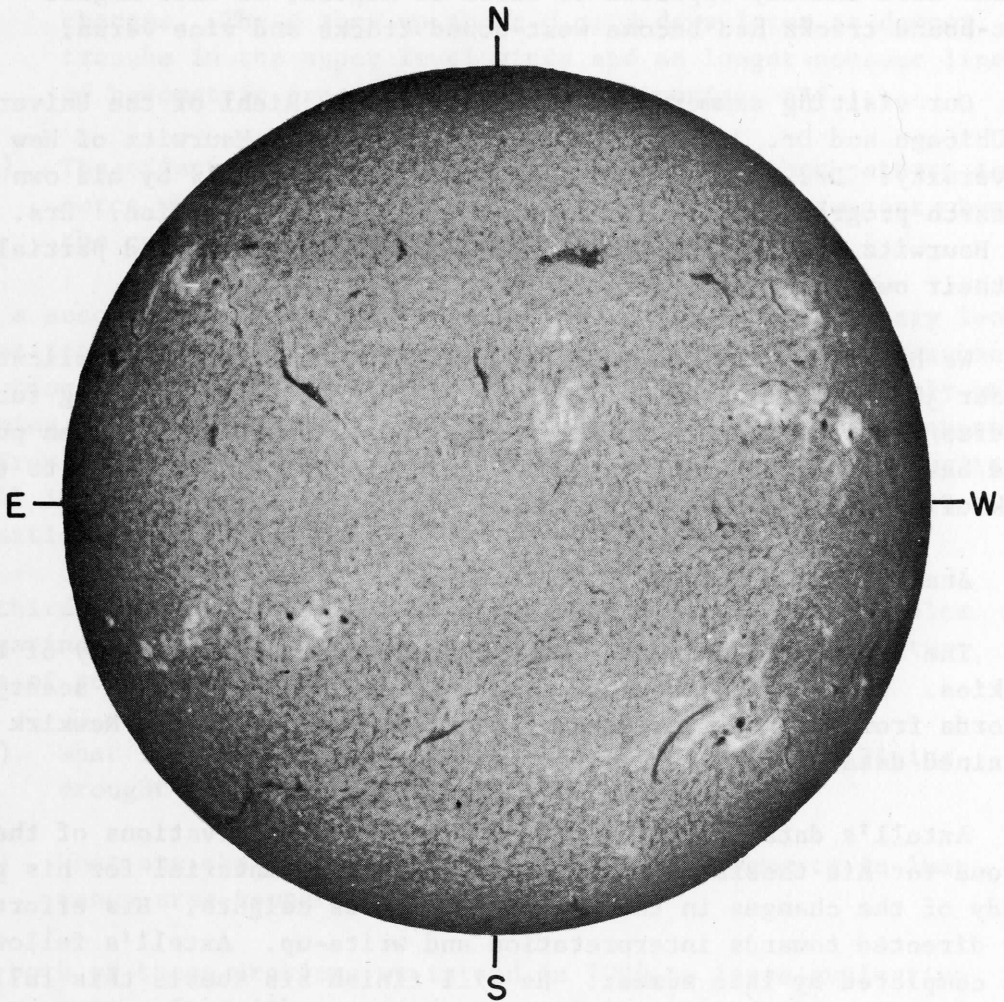


FIGURE 3

Picture of the face of the sun in the light of hydrogen (H_{α}), taken at the Royal Observatory of Belgium and sent to the Us IGY Solar Data Center at HAO by Dr. R. Coutrez. The extremely high level of solar activity is evident in this print. The long dark filaments are prominences seen against the face of the sun. The dark spots are sunspots surrounded by brighter areas called plages. It is in such plage regions that flares usually occur.

The large region in the northwest produced several Class 1 and Class 2 flares in early July. Unfortunately the region of the Class 2 flare of June 30, which opened the IGY so brilliantly, had rotated off the disk on the 8th and thus cannot be seen on this picture. The 30 June flare, however, was seen by five European and Russian stations and we have full information on its size and behavior.

children. "Mat" will assist in our joint HAO-NBS research program, with emphasis on ionospheric problems and on the search for improved understanding of the problem of forecasting geomagnetic upsets.

During the period we also were pleased to have Dr. John Jefferies (of CSIRO, Australia) and his family join HAO from the Harvard staff. They were stationed first at Sacramento Peak Observatory, and then in August moved to Boulder where they will stay until next summer.

Other newcomers to the staff include Miss Sylvia Moscové, Mr. Alfred Hobart and Mrs. Alexandra Platts. Miss Moscové came to us from the field of meteorology, and will assist Hansen with the IGY Data Center. Hobart joined the observing staff at Climax, and Mrs. Platts the secretarial staff at Boulder.

We were forced, reluctantly, to accept the resignation of Dean Edward C. King as treasurer of the High Altitude Observatory. Dean King has been a close friend and valued associate in the Observatory for many years, and his wise counsel and wide experience in University affairs has made his help to us of enormous value. Dean King resigned because of his trip to Turkey on sabbatical leave from the University. It is with greatest pleasure that we have dedicated this issue of our report to Ed King.

Other people who left the staff during the period include Miss Sandra Klein and Mr. William L. Wright.

Summer visiting staff, in addition to Drs. Riehl, London and Haurwitz whose visits were mentioned above, included:

Drs. Charlotte and Jean-Claude Pecker, former HAO staff members, from Meudon Observatory. They spent the summer here.

Dr. G. Righini, Director of the Astrophysical Observatory at Arcetri, Italy, who spent a good part of his stay doing special solar observing at Sacramento Peak.

Dr. A. Dollfus, balloonist and solar astronomer from the Meudon Observatory in France, who conferred with us about problems of the sun's corona, prominences and luminous disk. Dollfus also discussed with us numerous instrumental solar problems.

Dr. Malcolm Correll, head of the Department of Physics at De Pauw University, who collaborated with Roberts in further development of a picture of the magnetic field structure in the atmosphere above a solar prominence (see below). Guest facilities were extended to Correll whose work was supported by a National Science Foundation grant to De Pauw.

Chapman returned, appropriately enough, at the start of the IGY on the first of July. He spent the subsequent four months in Boulder, and in numerous trips from Boulder to meetings and conferences. His presence is one of the most stimulating things that happens at HAO. During this visit he spurred the development, partially in collaboration with Tandberg-Hanssen, of new work on modes of diffusion of the gases in the corona. (See below Page 17).

During the period Dr. Richard N. Thomas also moved to Boulder to assume a post at the National Bureau of Standards that will permit far closer collaboration with HAO than was possible before. Over the past decade Thomas has been a dreamer and co-conspirator in HAO's research plans. It is most gratifying to have him with us in Boulder. He is associated in this new post with Dr. John Waddell, formerly of Harvard, and now of the Sacramento Peak Observatory staff.

Summer visiting students on HAO fellowships or other visiting arrangements included:

Mr. Robert S. Kandel, Harvard University, 15 June - 26 August
Miss Lise A. Vogel, Radcliff College, 15 June - 26 August
Mr. Nibondh Maigate, Brown University, 31 May - 26 August
Mr. Frank Haurwitz, Brandeis University, 7 June - 31 August
Mr. Carl K. Seyfert, Jr., Vanderbilt University, 1 June - 31 August

Our first graduate students in astro-geophysics took up residence in Boulder this fall. They are:

Mr. Stuart R. Pottasch, transferring from Harvard, and joined by his wife, Ans, who is on the HAO staff as a part-time assistant;

Mr. Hollis R. Johnson, with an M.A. from Brigham Young University;

Mr. Mohammad K. Alam, with an M.A. from Pakistan, who was a student of Mr. Ali Naqvi, in turn a student of Roberts at Harvard University;

Mr. Paul C. Arnold, from an undergraduate degree at DePaw;

Mr. John A. Eddy, from a B.S. at Annapolis and four years of naval service.

B. Conferences and Meetings Attended

So many conferences and meetings occurred and were attended by our staff during the period that I shall list only a few principal ones.

The main one, of course, was here at home: the Twelfth International Congress of URSI, the radio science union. HAO was a co-host, and a large number of the staff attended. The meeting brought an embarrassment of riches in the way of important and interesting visitors. A few of these visits are mentioned below.

Chapman, Matsushita and I also attended the International Congress of the Union of Geodesy and Geophysics in Toronto, where all three of us gave papers. On the same trip I gave an invited paper to a special symposium on the IGY at the Hayden Planetarium in New York City.

Billings and I attended the American Astronomical Society meetings in August at the University of Illinois. Bretz, Lee and Zirin attended the earlier meeting of the same society at Harvard in May. All delivered papers.

During the period I also assumed the chairmanship of the Solar Technical Panel of the U.S. National Committee for the IGY, replacing A. H. Shapley, who resigned under the pressure of other duties. I also took up a position on the Grants Advisory Committee of Research Corporation, and became vice-chairman of the American Geophysical Union Committee on Solar-Terrestrial Relationships.

C. Research in Progress

As customary, I shall outline only certain of the programs of HAO that made special progress during the report period.

1. Active Solar Region Analysis--Corona and Prominences

The remarkable spectra taken on 18 December 1956 at Climax are still under analysis, but preliminary results have been obtained. A total of 36 spectrum lines in a very disturbed region at the sun's edge have been analyzed in some detail. The preliminary results reported earlier ³⁾ have in most details been confirmed in final measurements. Spectra taken earlier and later show that the temperature derived from the relative brightnesses of the flare spectrum lines dropped from about 150,000° K to about 50,000°K in approximately 30 minutes. Coronal spectrum lines, of course, gave higher values at these times, as is usually the case.

During the period Watson also had the good fortune to obtain a good series of spectrograms of the H-alpha line of a flare that exhibited a striking flat-topped spectrum line. He photographed this against the face of the sun. However, the flare protruded over the center of a dark sunspot, so that the spectrum line can be studied with less interference from light of the sun's face.

³⁾ Director's Quarterly Report 1956-4, pages 7 and 8.

Analysis of the flare has just begun, and will be carried through primarily to discover the problems of analysis in hopes of better observations later, since this particular flare was not caught until well after its maximum. Flare spectrum analysis is a major IGY goal at HAO.

Bretz spent a good part of the summer at Sacramento Peak in an effort to obtain satisfactory observations of the spectrum of the plage regions near active sunspot areas on the sun's face. In September she succeeded in obtaining spectra that are under analysis now. We hope to have an evaluation of their quality in the next quarter.

Matsushita has put in a substantial part of his effort working on radio and geomagnetic effects in the auroral zone and the polar cap, with emphasis on the role of solar particle emission. He is speculating about a mechanism by which an ionized gas cloud, carrying with it a magnetic field, may affect the earth's magnetic field and also the paths of other gas clouds from the sun. Matsushita also is continuing studies of geomagnetic effects in the polar cap after the 23 February 1956 flare.

2. Solar Effects in the Ionosphere and Geomagnetism

The completion of the HAO radio interferometer is covered above under HIGHLIGHTS. Warwick and Zirín had great success, with the generous help of the Los Alamos Scientific Laboratory, carrying out the calculations of flare effects in the ionosphere. They are now preparing to write up the results for publication.

3. Solar Effects in Geomagnetism

Tandberg-Hanssen found what looks like a clear-cut effect of elevation of the ionosphere during magnetic storms. He used Washington, D.C., records of the height of the F_1 layer of the ionosphere, which is the next-to-the-highest layer normally present, and is produced during the day by chromospheric and coronal emission in the ultraviolet spectrum.

Dr. Eugene N. Parker had suggested that the atmosphere below the upper layers of the ionosphere might absorb solar particle emission during a magnetic storm, and be expanded by the resulting heat, carrying upwards the magnetic field lines. This might, he reasoned, produce the first effects in a magnetic storm. The affirmative result of Tandberg-Hanssen, thus, lends credence to the Parker explanation.

The rise appears to be about 10 kms. So far as we know this is the first study of this point. A paper summarizing this result has been sent to the Journal of Geophysical Research.

4. Solar Activity Observing

The bad weather continued, making 1957 likely to be the worst year of observing in the 17 year history of the Observatory. In spite of this, we recorded remarkable rises of solar activity in July and again in September.

Trotter completed an important summary paper giving all recorded Climax and Sacramento Peak values of the yellow coronal line emission observed in recent years. The paper will appear in the Astrophysical Journal soon.

5. Temperature and Motions in the Corona

As mentioned above, Chapman and Tandberg-Hanssen worked on questions of the thermal diffusion of gaseous atoms of different atomic weight in the corona. A quantitative study of a new idea about the migrations of atoms of different atomic weights in the sun's corona resulted, and may prove to be of great theoretical importance. This work should be completed during the coming quarter.

Schwartz's Ph.D. thesis work on theoretical calculation of the ionization probabilities for atoms of iron ionized thirteen times continued under Zirin's guidance.

Cooper undertook a program to study the possible correlation of temperatures derived from spectrum line widths with those derived from the relative intensities of the green and red coronal lines. (These lines result from different degrees of ionization of the iron atom.) This will extend earlier work of a preliminary sort.

Cooper and Billings studied the height gradients of coronal emission for over 1000 spectra from the routine height-gradient studies on Climax spectrograms. There was large scatter in the results, but the average values of the drop of brightness of the corona with height suggests a temperature of 1.8 million degrees K. (on the assumption that the corona is isothermal and in hydrostatic equilibrium, which seems to fit the data well). This value fits closely the temperatures obtained by entirely different methods. The spectra evaluated included all available regions where coronal

SOUTHWEST LIMB OF THE SUN AT ABOUT 240°, 24 JULY 1955

Recorded with the Climax coronagraph

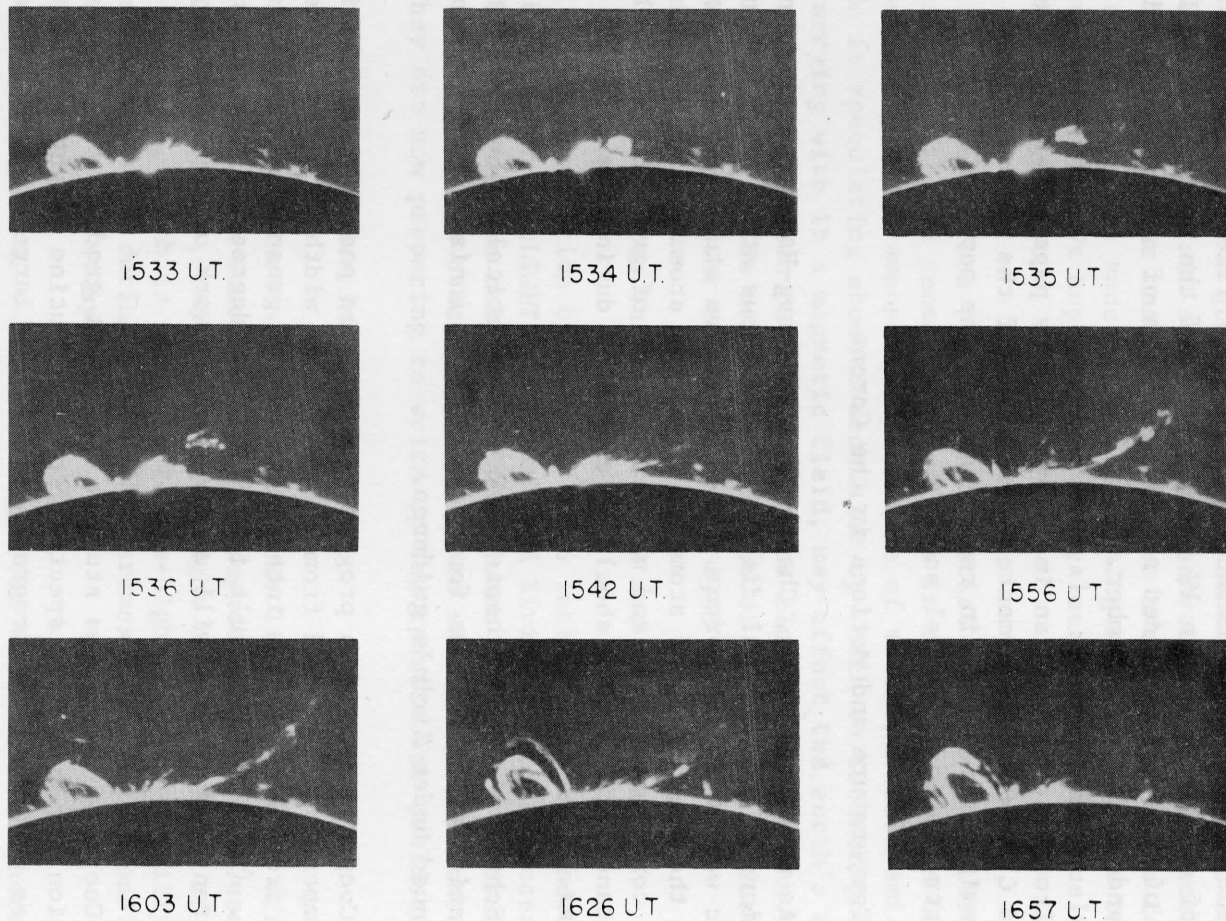


FIGURE 4

One of the most active regions of the early part of the present solar cycle maximum, showing looped coronal prominences characteristic of great solar activity. The very bright spot just to the right of the loop is the location of a flare. Note how, by 15:56, a violent ejection (spray prominence) shot outwards toward the right of the picture. All of these phenomena are typical of highly disturbed solar regions.

intensities were strong enough to study. Thus the values are mostly for moderate active regions.

C. Warwick completed a statistical study of the form of the coronal arches and streamers found on Sacramento Peak coronal survey photographs. She concluded that "open forms," in which the streamers diverge upwards, are associated with regions of great solar activity, and in particular with yellow coronal line emission, but not with any discernible effect in geomagnetism.

Newkirk completed his studies of the relationship of prominence and coronal motions from Climax and Sacramento Peak spectrograms, and found that in all 24 instances of coronal Doppler effect, the prominence spectra revealed associated loop prominences where velocities always equalled or exceeded the coronal velocities. The coronal Doppler effect, signifying coronal gas motions, was confined largely to the tops of the loop prominences.

The conclusion from this study is that prominences generally do not drag coronal gases along with them when they move along magnetic lines of force. When, on the other hand, prominences expand, carrying the magnetic field with them, the coronal gases are dragged along by the moving field.

6. Prominence Study

Billings and Carolyn Kober, a student assistant, completed a statistical study of the heights which prominences reach at different solar latitudes and in different years. The studies suggest a rather sharply defined upper height of about 30,000 kms to which a great percentage of prominences rise, but an abrupt drop in frequency of occurrence beyond this height. This limiting height displayed no change over the years, or with the number of sunspots. However, the number of prominences above this sharp drop-off did increase a good deal with sunspot activity.

Newkirk obtained a number of observations of prominence polarizations with the K-coronameter during the half-year. One set, taken during a solar surge, was of very good quality and will probably provide a reliable measure of the direction and quantity of polarized light. Further measures are now feasible if the weather and solar activity cooperate.

Roberts and Correll completed a study of the composite directions of motion of the prominence knots in a great active region in 1952. From the overall pattern they concluded that it was possible

to determine the shape of the atmospheric magnetic field above the region. They were led to conclude that it was like a dipole field, directed slantingly upwards from the solar surface. They also concluded that a solar radio noise storm and a geomagnetic storm resulted from radio noise and storm-producing solar corpuscles ejected from the sun along the axis of the magnetic dipole instead of radially out from the sun. The result, if it can be confirmed in other instances, has important implications in geomagnetic forecasting. However, the analysis requires detailed prominence movies and involves laborious trajectory measurements.

7. Sunspot Spectra

J. Warwick continued his efforts to interpret the spectra he obtained at Sacramento Peak last November but without reaching definite conclusions.

8. Chromospheric Spectra and Spicules

Athay obtained spicule spectra of excitingly good quality but their interpretation awaits the next quarter.

9. Measurement of Older Coronal Spectra

The work under this program moved nearly to completion. Its results will be described later.

10. Guide Book on Solar Activity

Princeton University Press expressed substantial interest in publishing our Guide Book but I remain the bottleneck because of the pile of unfinished business on my desk.

11. Eclipse Research

Athay worked on the monograph on the chromosphere that he is preparing with Thomas at NBS, and also did further work on the transition between the chromosphere and photosphere of the sun from the 1952 eclipse spectra.

Planning and model construction for instruments for the 1958 eclipse continued at a furious pace. Lacey has built a working model of the film advance mechanism that looks as though it will work in fully satisfactory fashion. This is probably the most critical element of the whole program.

12. IGY Program

The IGY World Data Center A for solar activity went into operation in temporary quarters in the Western States Cutlery building of HAO under supervision of Hansen, who is assisted by Moscové. There is already an impressive flow of solar data from all over the world.

We installed and began operating a new flare patrol instrument at Climax, built about a Halle birefringent filter of 0.5 Å band-width. The photographs from it are of good quality. We are also almost ready to operate a flare patrol in Boulder to help increase the completeness of IGY coverage. There are now about 40 birefringent filter solar flare patrols in operation in the IGY program.

We also completed and installed three indirect flare detectors that use sudden enhancements of atmospheric radio noise and sudden cosmic radio noise absorption effects. These are refined versions of the instruments described earlier.⁴⁾ The instruments are in operation at HAO Boulder, Sacramento Peak Observatory, and McMath-Hulbert Observatory in Pontiac, Michigan.

Newkirk worked with Dr. Walter Steiger in Hawaii on the development of a flare patrol there, and made a trip out to Hawaii to assist in final preparations for patrol operation.

13. Venus Aurora

Newkirk finished up the designs and plans for the coronagraph and spectrograph to observe Venus in an effort to detect an aurora. The installation of the equipment has been delayed, however by slow delivery of the basic spectrograph from a commercial supplier. We shall be seriously pressed for time if the spectrograph is not available soon.

14. Research facilities at Boulder

We finished up some improvements to our electronic microphotometer that are going to greatly increase its usefulness. We made a new plate drive mechanism that is of sufficient accuracy that we can trust equal intervals of time on the final microdensi-

⁴⁾ Director's Quarterly Report 1956-1, page 7.

tometer tape to correspond to equal distances on the original film. This precision has been necessitated by our wish for improved line profile studies, where the actual shape of the spectrum line is highly important.

15. Annual Research Review

The distinguished director of the Utrecht Observatory in Holland, Dr. M. G. J. Minnaert conducted the 1957 research review during his stay at HAO from July 14th to 27th. All of the staff had ample opportunity to describe their work in detail to Dr. Minnaert, and to gain the benefit of his criticism and advice. The research review is of utmost interest and value to us. In addition, Dr. Minnaert met with the Trustees of the Observatory for further discussions and evaluation of the program of the Observatory. He made several specific recommendations:

- (a) The HAO needs a more nearly adequate building for its work with all the Boulder staff under one roof.
- (b) The HAO library does not contain many works that it should have, and its periodical subscriptions are on the skimpy side.
- (c) More emphasis should be given to electromagnetism and hydrodynamics. A specialist in these fields should probably be added to the staff.
- (d) The Observatory is short on computing assistants and other general assistants, as those provided in European institutions by young apprentice machinists and technicians.

It is most flattering that Dr. Minnaert was willing to give us the time he did and that he responded with such enthusiasm to the work in progress here. It is valuable to have criticism, but it is also beneficial to know that our work makes a favorable impression on one so well qualified to evaluate it.

VI. RELATED PROGRESS AT OTHER INSTITUTIONS

A. Basic Solar Research

A genuine milestone in solar research passed when Dr. Martin Schwarzschild of Princeton University succeeded in late summer and early fall in making three balloon flights above 50,000 feet with a

12-inch solar telescope designed to photograph the sun's face and thus to study the small solar granulations.

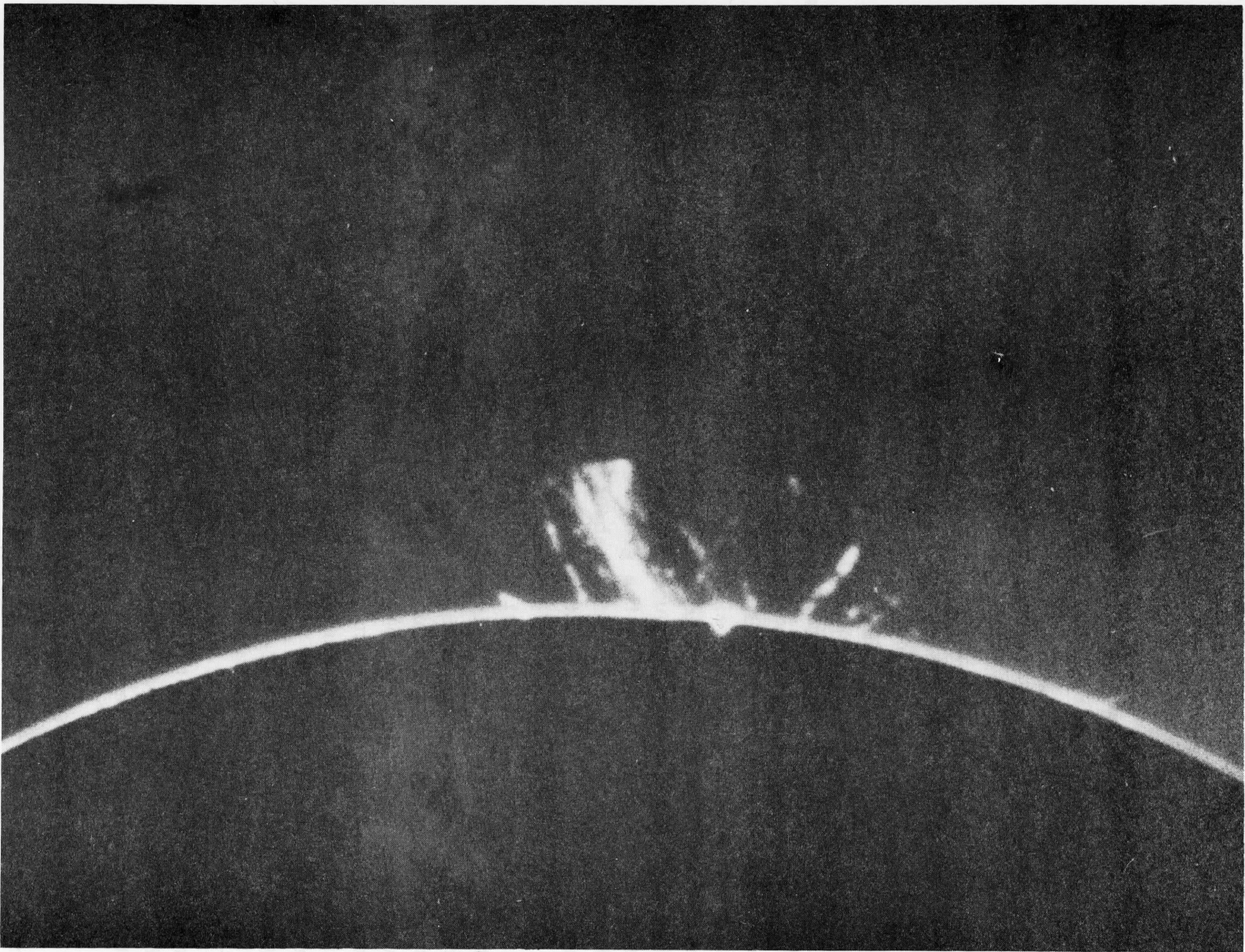
16,000 frames of films of the solar face were exposed, and a small number of photographs selected from these that reveal minute features of the sun's disk not previously observed. The results, at a glance, suggest that there is great asymmetry between the bright and dark granulation features. The bright features appear as extended areas compared to the interstices, and have irregular edges, often with polygonal form. The theoretical significance of the results is major, and an extended period of analysis followed by new and improved balloon flights is likely. Schwarzschild and his collaborators deserve hearty congratulations for their spectacular success with this new technique.

Dr. J. Kleczek of Czechoslovakia has studied the physics of coronal regions,⁵⁾ using data from HAO and other observatories. He considers that in a hot coronal region gases stream vigorously upwards and outwards from the vicinity of the associated sunspots. The hottest part of the region (as hot as 2.5 to 2.7 million degrees K) is found, he surmises, at the very core immediately above the sunspots, and low in the solar atmosphere. Here is the location from which the yellow coronal line (Ca XV) is emitted. Surrounding this is a cooler region of about 1.2 million degrees, in which the green coronal line (Fe XIV) is emitted. Farther outside is a region of about 0.6 million degrees where the red coronal line (Fe X) is emitted.

He attempts to reconcile these temperatures (derived from physical theory) with the HAO's values for the spectrum line breadths, which we have assumed to represent temperatures entirely, thus leading to hotter temperatures than those postulated by Kleczek. He finds little or no velocity necessary to explain the yellow line breadths (as would be expected, since he uses high temperatures there). The velocities then increase in the green line regions and still more again in the red line regions, indicating, on his theory, an expanding and outspreading of gases that cool as they move farther from the center.

We hope to be able to do some observational checks on Kleczek's model to see whether the different expansion velocities can be observed by different methods. Generally we are inclined, still, to prefer the temperature interpretation in our own work.

⁵⁾ J. Kleczek, Bulletin of the Czechoslovakian Astronomical Institutes 8, 68, 1957.



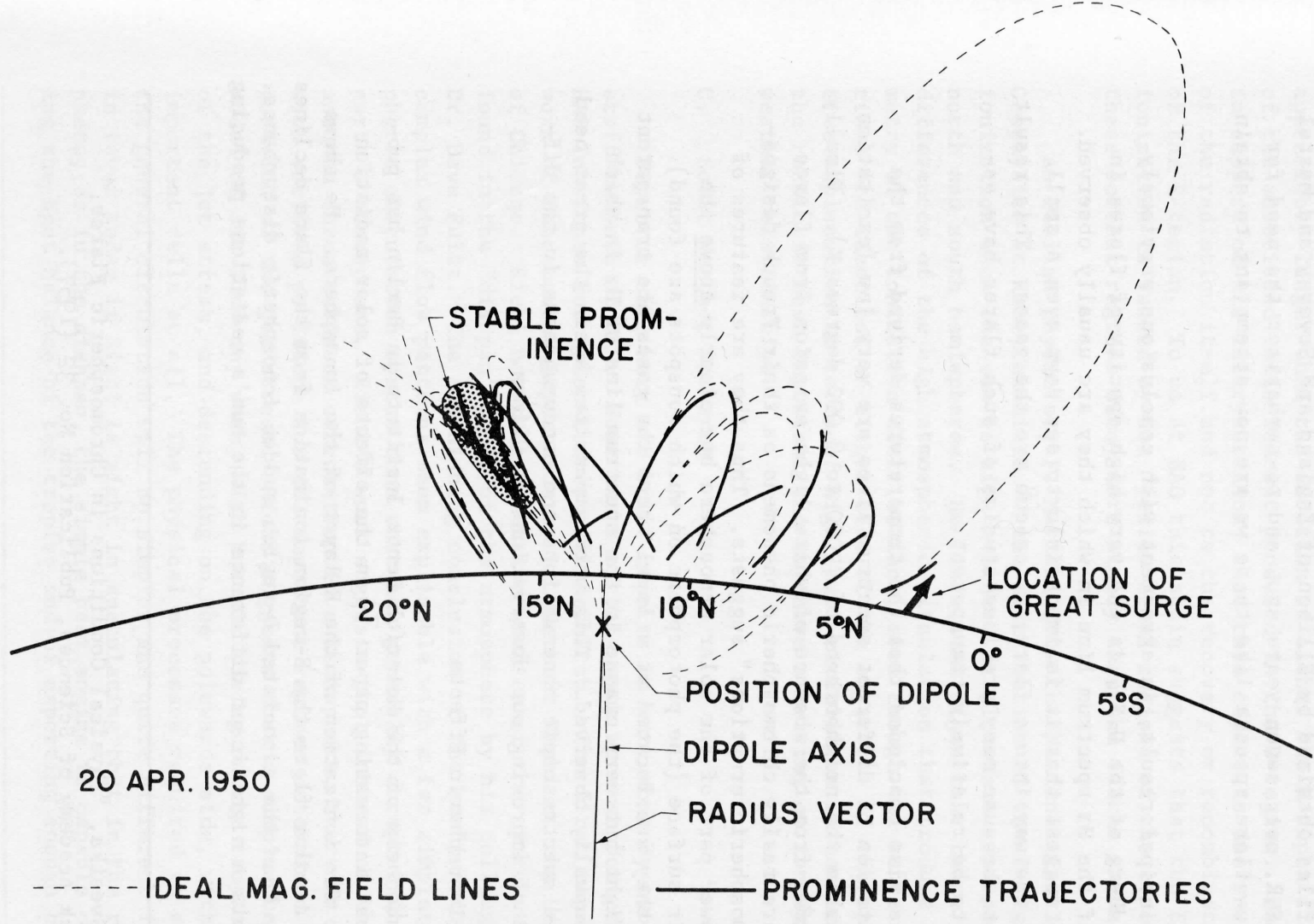


FIGURE 5

The prominence print (a) above shows the appearance of the west edge of the sun on 20 April 1950. The diagram (b) below shows the paths taken by individual clouds of prominence gas studied in the full length of the motion picture of which the upper picture represents a single frame. Correll and I made the assumption that these paths represent lines of the magnetic force field in the solar atmosphere, and found that the field could be simply represented by a dipole field. Moreover, there were apparent geomagnetic and radio noise effects when the axis of the dipole field was directed towards the earth.

Another Czech published an interesting paper on solar physics during this period. 6) It is an extensive booklet about observations of line profiles obtained by Ellison of England and Severny and Mustel of the U.S.S.R. over seven years ago, and re-emphasizes the need for extensive new flare spectra like those we are now attempting to obtain at Climax.

The principal result, in agreement with conclusions previously made by Goldberg of the U.S., is the very high opacity of flares in the light of the $H\alpha$ spectrum line in which they are usually observed. The results suggest that it is impossible to see down even a small fraction of the way into a flare, so opaque are the gases. This result is important, because many previous studies of such flares have assumed them to be relatively transparent.

Svestka also concludes that the temperatures derived from the atomic excitation of different spectrum lines are very low (excitation temperatures in the neighborhood of 7,000 to 8,000 degrees K). Finally Svestka argues from the absence of white light emission from flares that they are really chromospheric phenomena as their French designation "chromospheric eruptions" suggests. Thus they are features of the very lower part of the solar atmosphere but clearly above the opaque solar surface (the photosphere on which sunspots are found). This means they are located at a level where the gases are transparent for white light but very opaque in the spectrum line of $H\alpha$ in which flares are usually observed. This work emphasizes again the great need for accurate spectroscopic observations and encourages us in the difficult task of improving our observations at Climax.

B. Solar-Ionospheric Effects

J. Taubenheim of the Heinrich Hertz Institute in Berlin has published a most interesting paper 7) on the effects of solar radiation responsible for ionization of the E-layer of the ionosphere. He shows that after a solar flare the E-region ionization from the flare declines more slowly than the associated D-region sudden ionospheric disturbance. This suggests a significant difference in the sun's radiations producing

6) Zdenek Svestka, "Physical Conditions in Chromospheric Flares," Czechoslovak Academy of Sciences, Publication No. 32 (1957).

7) J. Taubenheim, Journal of Atmospheric and Terrestrial Physics, 11, 14, 1957.

the ionization of these two closely spaced ionospheric regions. The E-region decline takes, he suggests, three hours or so, which is appreciably longer than the duration of either the H-alpha flare or of the associated radio fadeout produced in the D-region. He shows, in support of his interpretation, that this effect is due to the decline of the radiation itself and not to the recovery or recombination time of the E-region. To us at HAO this again suggests that the E-region ionization is caused by hot "yellow line" regions of the corona, since these coronal regions decay more slowly than the flares themselves.

An Italian physicist, F. Mariani from the National Institute of Geophysics at Rome, examined ⁸⁾ the distribution of the F-region ionization when the sun is high overhead at alternate seasons in the north and south hemispheres. He finds some signs that there are differences of the high atmospheric circulation that produce an asymmetry of the ionization distributions, even though the sun's radiations are identical on either side of the equator. If the speculative explanation in terms of high level circulation is confirmed, the result is most important and may have a bearing on ionosphere-weather relationships.

C. Solar Weather Research

First of all, here are brief reports on work done by two summer staff members of HAO. Some parts of this work were supported by the HAO Institute for Solar-Terrestrial Research. The first report is on work of fundamental importance by Dr. Herbert Riehl of the University of Chicago. Riehl has made extensive studies of the circulation schemes found in the "dishpan" model of the atmosphere by his colleague, Dr. Dave Fultz. The astonishing conclusion of the studies is that the complex wind flow patterns seem explicable with a far simpler atmospheric circulation system than that now generally accepted for the earth's atmosphere. Riehl's work suggests that instead of the usually-assumed three cells of circulation in a hemisphere, there is but one, with variable positions for its important regimes determined by the position of the jet stream. Riehl suggests that a simple "heat engine" model of air flow may work, with hot air rising on the tropical side of the jet stream, and descending on the polewards side, with no other important cells at all. The physical processes required to maintain the general circulation will be simpler and quite different from those in favor today if Riehl is right in speculating that in the real atmosphere, as in the dishpan, the simple heat engine is capable of maintaining the heat balance of the tropics and of exporting enough heat to the

⁸⁾ F. Mariani, Jour. of Atmospheric and Terrestrial Physics, 10, 239, 1957.

high latitudes to explain their temperatures.

A second study of interest was that of Dr. Julius London of New York University who has studied the vertical, latitudinal and seasonal patterns of ozone distribution in the atmosphere. His principal results suggest:

- (a) The height of the maximum density of ozone increases in summer, and is higher (above 25 kms) over the equator than over the poles.
- (b) Lower down in the atmosphere there is a greater density of ozone over the poles. There is little seasonal change near the equator but a big effect over the poles, where winter and spring bring a pronounced maximum in density.

London has also taken a look at Alaskan ozone observations to see whether there is a detectable change with geomagnetic activity, and has found none. The variations of the ozone data were quite marked, but apparently quite independent of solar corpuscular emission effects.

An article in the Monthly Weather Review by H. W. Norton looks at sunspot-weather connections. ⁹⁾ Norton concludes that there are no connections between sunspots and the weather, at least in the comparisons of monthly average temperature at Greenwich, England, with monthly mean sunspot numbers for the past 100 years. The statistical methods used seem sound. What seems questionable is that anyone would expect to find positive results from the implicit hypothesis of a solar-weather relationship behind Norton's tests. The search for solar-weather connections must be far more sophisticated; were it not so, positive conclusions would have turned up long ago from the many studies that have been made.

A suggestion of a solar weather effect was found by Arnold H. Glaser¹⁰⁾, of the Agricultural and Mechanical College of Texas, who examined the large amplitude waves in the general circulation for the years 1946-47 and 1952-55 inclusive. He found that the years of high

⁹⁾ H. W. Norton, Monthly Weather Review, 85, 117, 1957.

¹⁰⁾ A. Glaser, "A Possible Sunspot Influence on the General Circulation," Journal of Meteorology, 14, 375, 1957.

sunspot number tended to have a fairly persistent picture with six long wave troughs around the northern hemisphere. In other years, and particularly in years of lower solar activity, he felt there was a tendency for a smaller number of long wave troughs and a lesser tendency for the troughs to persist at the same number. This certainly fits in general terms the picture of solar-weather connections that appears to be slowly emerging from many different studies.

VII. RECENT VISITORS TO HAO

1 May - August	Dr. Charlotte Pecker, Meudon Observatory, France
1 May - August	Dr. Jean-Claude Pecker, Meudon Observatory, France
7 May	Mr. Malcolm D. Ross, Office of Naval Research, Washington, D.C.
7 May	Captain N. L. Barr, Naval Medical Research Institute, Bethesda, Maryland
17 May - 17 August	Dr. Audouin Dollfus, Meudon Observatory, France
20-21 May	Dr. Eugene N. Parker, Enrico Fermi Institute, University of Chicago
21 May	Dr. Vincent J. Schaefer, Munitalp, Schenectady, New York
27-28 May	Dr. Irving I. Schell, Tufts University, Medford, Massachusetts
January - May	Dr. Kenneth G. Budden, Cavendish Laboratory, St. John's College, University of Cambridge, Cambridge, England
7 June	Mr. Willis Somervell, Project Applied Research Operational Weather Analysis (AROWA), Norfolk, Virginia
10-11 June	Dr. Frank K. Edmondson, Goethe Link Observatory, Bloomington, Indiana
10-15 June	Dr. Anne Underhill, Dominion Astrophysical Obs., Victoria, B.C.
17 June	Dr. William Vanderbyl, Kansas State College, Manhattan, Kansas
15 June - 31 August	Dr. Malcolm Correll, De Pauw University, Greencastle, Indiana
24 June - 24 August	Dr. Herbert Riehl, University of Chicago, Chicago, Illinois
25 June - 24 August	Dr. Julius London, New York University, New York
6 July - 13 August	Dr. Bernhard Haurwitz, New York University
9-10 July	Dr. John W. Evans, Sacramento Peak Observatory, Sunspot, New Mexico

9-10 July	Dr. Gerhard R. Miczaika, Harvard College Observatory, Cambridge, Massachusetts
9-10 July	Mr. Joseph Nunn, Joseph Nunn & Associates, South Pasadena, California
9 July	Dr. Helen Dodson, McMath-Hulbert Observatory, Pontiac, Michigan
9 July	Dr. Seth B. Nicholson, Mt. Wilson & Palomar Observatories, Pasadena, California
3-10 July	Dr. R. O. Redman, Solar Physics Observatory, Cambridge, England
8-12 July	Dr. Harlow Shapley, Harvard College Observatory, Cambridge, Massachusetts
14-27 July	Dr. M. G. J. Minnaert, Zonnenburg, Utrecht, Germany
17-19 July, and 22 August-5 Sept.	Dr. Guglielmo Righini, Astrophysical Observatory of Arcetri, Firenze, Italy
3-10 July	Dr. R. O. Redman, Solar Physics Observatory, Cambridge, England
8-12 July	Dr. Harlow Shapley, Harvard College Observatory, Cambridge, Massachusetts
26-28 July	Mr. Hugh Odishaw, IGY Headquarters, Washington, D.C.
5-8 August	Dr. Max Krook, Harvard College Observatory, Cambridge, Massachusetts
13 August	Dr. Edward Teller, General Atomic, San Diego, California
13 August	Dr. Max Waldmeier, Eidgen. Sternwarte, Zurich, Switzerland
13 August	Prof. Dr. L. Biermann, Max Planck-Institut für Physik, Göttingen, Germany
13 August	Dr. William J. Otting, Jr., Hq. A.F.S.O.R., ARDC, Washington, D.C.
20 August	Dr. Clyde Cowan, Los Alamos Scientific Laboratories Los Alamos, New Mexico
20 August	Dr. Robert Fleischer, Rensselaer Polytechnic Institute, Troy, New York
30 August	Dr. S. F. Singer, University of Maryland, College Park, Maryland
26-27 September	Dr. Herman Wobus, Applied Research Operations Weather Analysis, Naval Air Station, Norfolk, Virginia
26-27 September	Commander James King, AROWA, Naval Air Station, Norfolk, Virginia
During URSI Meetings	Dr. W. N. Christiansen, CSIRO, Sydney, Australia
During URSI Meetings	Dr. J. S. Denisse, Meudon Observatory, France

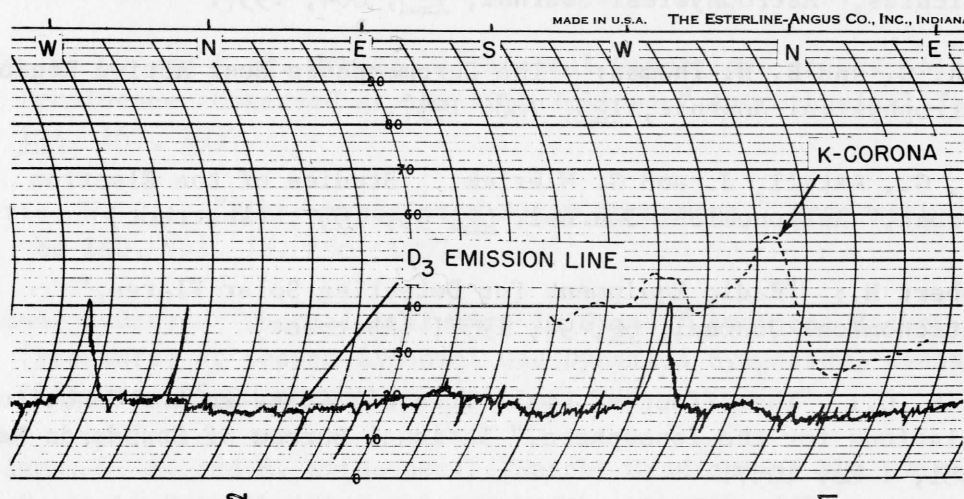
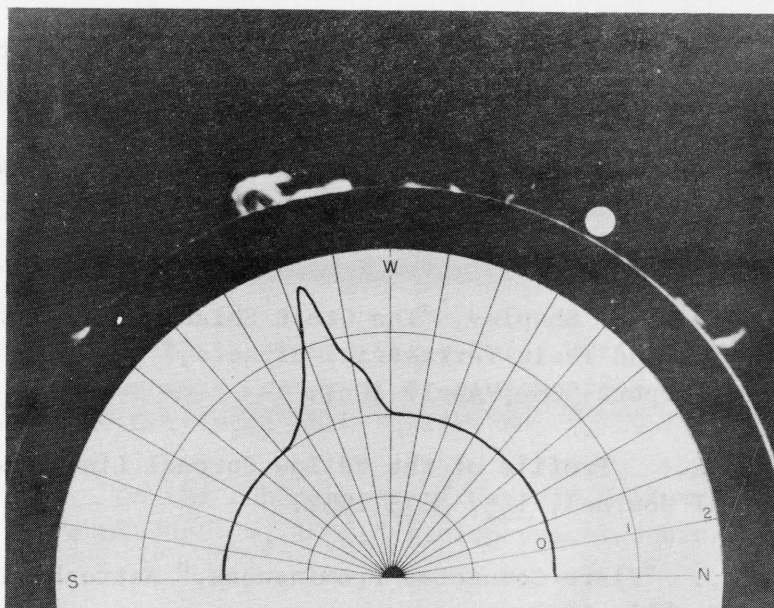


FIGURE 6

New results on prominence polarization. The K-coronameter now operated on the large equatorial at Climax can be used to measure polarization of the light of the corona or of prominences, depending on what filters are with it. The upper photo shows a brilliant prominence slightly south of the west end of the solar equator on 9 August 1957.

The associated graph shows the measured polarization of the prominence light (in the D_3 helium spectrum line admitted by a special filter). The lower graph, from the original in the instrument, shows the K-corona measured with a different filter. The large rise under W in the heavy lower line recording the D_3 helium emission shows the same strong prominence polarization traced in the diagram above. Note that it is at a different location from the principal corona polarization indicated by the arrow marked "K-corona."

VIII. PUBLICATIONS FROM HAO DURING THE HALF YEAR

- Billings, Donald E.: "Evidence of Closed Flux Loops in the Solar Atmosphere," Publications of the Astronomical Society of the Pacific, 69, 162, 1957.
- Roberts, W. O. and A. H. Shapley, "The Great Solar Regions of 9-24 February 1956, and Their Terrestrial Effects," National Bureau of Standards Report 5062, April 1957.
- Billings, Donald E.: "Profile of the Yellow Coronal Line, $\lambda 5694$," Astrophysical Journal, 125, 817, 1957.
- Warwick, James W.: "Flare-Connected Prominences," Astrophysical Journal, 125, 811, 1957.
- Athay, R. G. and R. N. Thomas: "The Numbers and Motions of Solar Spicules," Astrophysical Journal, 125, 804, 1957.
- Athay, R. G. and R. N. Thomas: "The Chromosphere Near Active Regions," Astrophysical Journal, 125, 788, 1957.
- Newkirk, G., Axtell, J. and G. Wlérick: "Studies of the Electron Corona," Astronomical Journal, 62, 95, 1957. (Abstract)
- Lee, Robert H.: "Radio Equipment for Detecting Solar Flares," Astronomical Journal, 62, 94, 1957. (Abstract)
- Budden, K. G.: "The Effect of Small Irregularities on the Constitutive Relations for the Ionosphere," National Bureau of Standards Report 5081, 1 May 1957.
- Budden, K. G.: "The Calculation of Wave-Guide Mode Characteristics for a Curved Earth," National Bureau of Standards Report 5085, 1 June 1957.
- Warwick, J. W. and H. Zirin: "Rocket Observations of X-Ray Emission in a Solar Flare," Nature, 180, 500, 1957.
- Roberts, W. O.: "Optical Evidences of Radiational and Corpuscular Emission from Active Solar Regions," International Astronomical Union Symposium No. 4, Radio Astronomy, Paper 62, 1957.

Wlérick, Gérard and James Axtell: "A New Instrument for Observing the Electron Corona," *Astrophysical Journal*, 126, 253, 1957.

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Athay, R. G., Menzel, D. H. and F. Q. Orrall: "Variations in the Thermodynamic State of the Chromosphere Over the Sunspot Cycle," *Smithsonian Contributions to Astrophysics*, 2, No. 4, 1957.

Athay, R. G. and F. Q. Orrall: "Physical Conditions in the Solar Limb Prominence Observed at the 1952 Eclipse," *Astrophysical Journal*, 126, 167, 1957.

Roberts, W. O.: "Flare-Associated Solar Phenomena," *Transactions of the IAU*, Vol. IX, 658 1957.

Chapman, Sydney: "Thermal Diffusion in Gases," *American Rocket Society*, (Presented at Second Biennial Gas Dynamics Symposium, Evanston, Illinois, 26-28 August 1957).

Billings, D. E. and R. H. Cooper: "Height Gradient of the Emission Corona," *Zeitschrift für Astrophysik*, 43, 218, 1957.

Walter Orr Roberts

Walter Orr Roberts
High Altitude Observatory
Boulder, Colorado
23 November 1957

It is a pleasure to acknowledge the many years of sympathetic and valuable counsel given to the High Altitude Observatory by Dean Edward C. King, who resigned as Treasurer as he left for a sabbatical stay at the University of Ankara in Turkey. Dean King's familiarity with the structure and function of the University and his intense interest in the goals of the Observatory have been of major importance to us in steering our course as an independent research institution closely affiliated with the University.

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