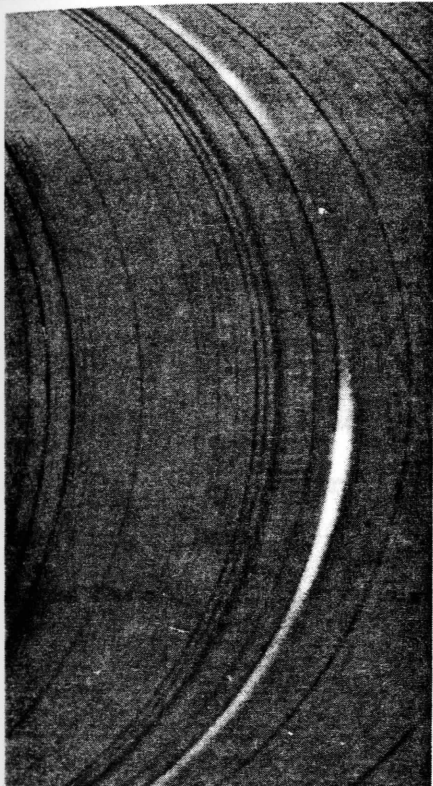


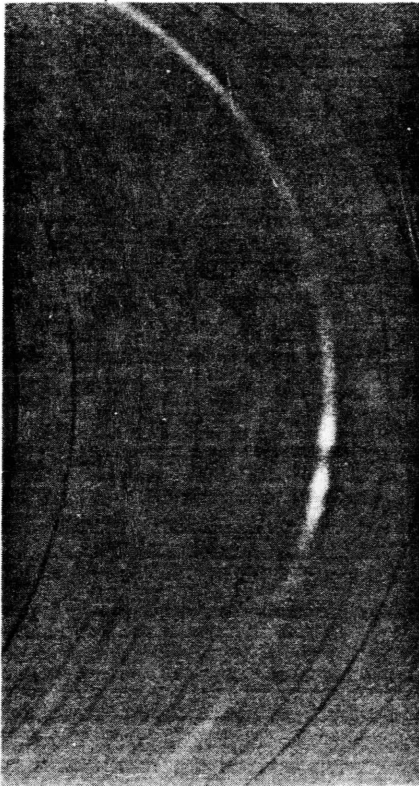
THE
DIRECTOR'S QUARTERLY REPORT

1955-4

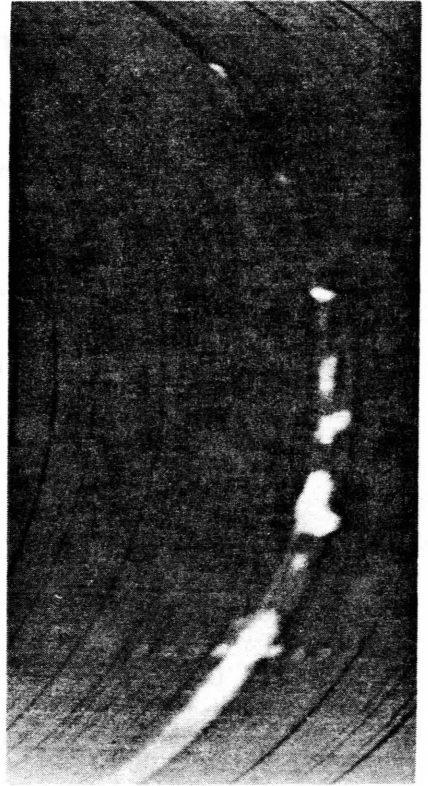
1 SEPTEMBER 1955 -- 31 DECEMBER 1955



5303 A



6374 A



H-ALPHA

Sections from a coronal spectrogram*

HIGH ALTITUDE OBSERVATORY
OF THE
UNIVERSITY OF COLORADO,
BOULDER AND CLIMAX, COLORADO

The following report is for private use and information only. It describes unpublished work of a number of investigators and should therefore be treated as of the nature of a private communication, pending correction or publication. Public reference to this material should be withheld unless specifically approved by the authors of the work, or unless the material has subsequently been published.

SUMMARY

The first of January 1956 brought a major advance in the research program of the Observatory. On this date we launched our new Institute for Solar-Terrestrial Research, a privately sponsored program of basic research. The Institute's research will assume, in the years ahead, a pivotal position in the activities of the Observatory.

A second highlight of the period has been the quality of the performance of the new 5-inch coronagraph and spectrograph at Climax. The cover illustration is from the new instrument.

During the quarter, Dr. Gordon Newkirk, who had just completed a tour of duty with the U.S. Army, joined the research staff of the Observatory. Also during the period Dr. Sydney Chapman served on the HAO staff with the support and sponsorship of the National Bureau of Standards. At the close of the period he made plans to join us on a continuing basis, sharing his time between the HAO and the Geophysical Institute at the University of Alaska.

During the fall we attacked again the problem of origin of the intense heating of the sun's corona, a long-standing mystery. The anomaly that must be explained is the extraordinarily high coronal temperature at relatively short distances above the very much cooler solar surface. The

* Cover -- Sections from a spectrogram of 6 January 1956 showing emission lines of corona and prominence. (See page 3.)

problem has practical consequences in explaining terrestrial effects of the corona. Some new and speculative possible solutions for the problem are being formulated, principally by Dr. Billings and Dr. Zirin. We think there are possibilities of explaining the high temperatures as a result of the partial dissipation of the energy of motion of high-speed prominences, as they pass through low-lying regions of the corona.

We were most gratified by national recognition of our experimental work, last year, that led to the identification of the "yellow coronal line" as coming from a very high stage of ionization of calcium (Ca XV). This result was selected for Science Service by Dr. Harlow Shapley as one of the "Top Ten" achievements in American astronomy for the year. This honor was shared with Dr. David Layzer of Harvard College Observatory, who worked on the theoretical side of the identification.

I. HIGHLIGHTS OF THE QUARTER

Institute for Solar-Terrestrial Research is Launched

Private sponsorship has now been assured for a four-year program of solar-terrestrial research aimed principally at problems of the effects of the sun on weather. The support, amounting to \$150,000, has come from sponsors with three principal areas of interest: (1) the natural gas industry, (2) the oil industry, and (3) the air transport industry. Our hope is that from the work of the Institute will come improvement of weather forecasting based on analysis of variations in the emissions from the sun. In particular, we believe that the best hope for long-term forecasts, seasons or years in advance, lies in the field of solar-weather research. Public announcement of the plans of the Institute will be made in April or May.

To launch the Institute we are inviting a group of meteorologists and solar physicists to meet for a cross-field seminar of six weeks duration, during the summer. The "pros and cons" of the evidence for solar-weather effects will be explored at length. The seminar will have as its aim to explore and outline, so far as it is possible, the promising avenues of future research, and to assess the likelihood of progress in the various directions. We do not expect answers to forecasting problems, but rather plans that promise to lead us eventually to answers. From the seminar, we expect, will come ideas that will guide the future research progress of the HAO Institute as well as the research thinking of the participants after they return to their home institutions.

A principal method of operation of the Institute will be to stimulate other groups to undertake given directions of research and analysis in their own laboratories. In this way we believe that the benefits from the Institute can be extended many times beyond the relatively modest research that our own funds would otherwise encompass.

Line Profile Studies with the Climax Coronagraph

The cover illustration of this report shows one of the best series of spectrograms from the new 5-inch Climax coronagraph-spectrograph combination described in our last report. It is illustrative of the extremely high quality of the new observations from this instrument. The spectrum lines shown were made at the edge of the sun, with a spectrograph slit that is designed to fit the solar curvature. The same points along the three arcs represent emission from the three different atomic gases at the same points along the edge of the sun. Longer wave radiation is to the right; shorter to the left. Each picture represents a small range of the spectrum.

At the left, in the photograph labelled "5303 A", is the spectrogram of the "green coronal line" corresponding to the light emitted from the corona by atoms of iron from which thirteen electrons have been stripped by the extraordinarily potent physical processes that go on in the solar corona. In the center of the illustration is shown the "red coronal line" at 6374 A, corresponding also to iron, but here with only nine electrons removed. At the right is shown the spectrum of a prominence (H-alpha) at the same time and position. The irregularly shaped lines are symptomatic of the large velocities (Doppler effect) possessed by different parts of the prominences, compared to the smooth shapes of the coronal lines, which suggest that the corona is at rest or in much more uniform motion.

From such photographs we are attempting to gain new knowledge about coronal temperatures. The methods we use are fairly direct. The higher the temperature, the more atoms should radiate light from 5303 A, and the fewer, relatively, from 6374 A. Because of this, astronomers have generally considered that the ratio of the intensities of these two coronal lines reflect the temperature of the coronal region under study. Theories have been developed by Dr. M. Waldmeier, of the Swiss Federal Observatory, and others, by means of which the relative line intensities at given places in the corona can be expressed as temperature.

Another more direct temperature effect occurs, however. The spectrum lines are broadened by higher temperatures. The broadening is very simple to interpret if it can be established that the radiating gas clouds are not in motion. Up to now, detailed measurements of temperature in large numbers of coronal regions by the line-broadening method have not been possible, partly because of optical limitations of the available coronagraphs, and partly because of doubts that the gas clouds are generally at rest. Our present instrument gets around the coronagraphic limitations because of its flexible controls, its speed, and its high spectral dispersion; and our studies suggest that coronal gases, amazingly enough, are generally at rest. Figure 1 illustrates the line-broadening method of temperature measurement.

The two spectrum methods have now been used by Dr. Billings, assisted by Mr. Schwartz, who is working of these problems for his Ph.D. thesis, and by others of the HAO staff. They have used the very high quality spectrograms now being obtained by Mr. Hansen and the other observers at Climax. The results are most promising. We find that the two methods tend generally to show direct correlation, though the actual temperature values from the line-breadth method are the higher -- appreciably higher than those generally accepted for the corona. This result has several important consequences.

Firstly, the higher temperatures are significant for solar-terrestrial research; they imply that the X-ray and ultraviolet radiations from the intense emission regions of the corona may be appreciably stronger than previously suspected, and that their effects should thus be even more important in the ionosphere and upper atmosphere. Secondly, they imply that

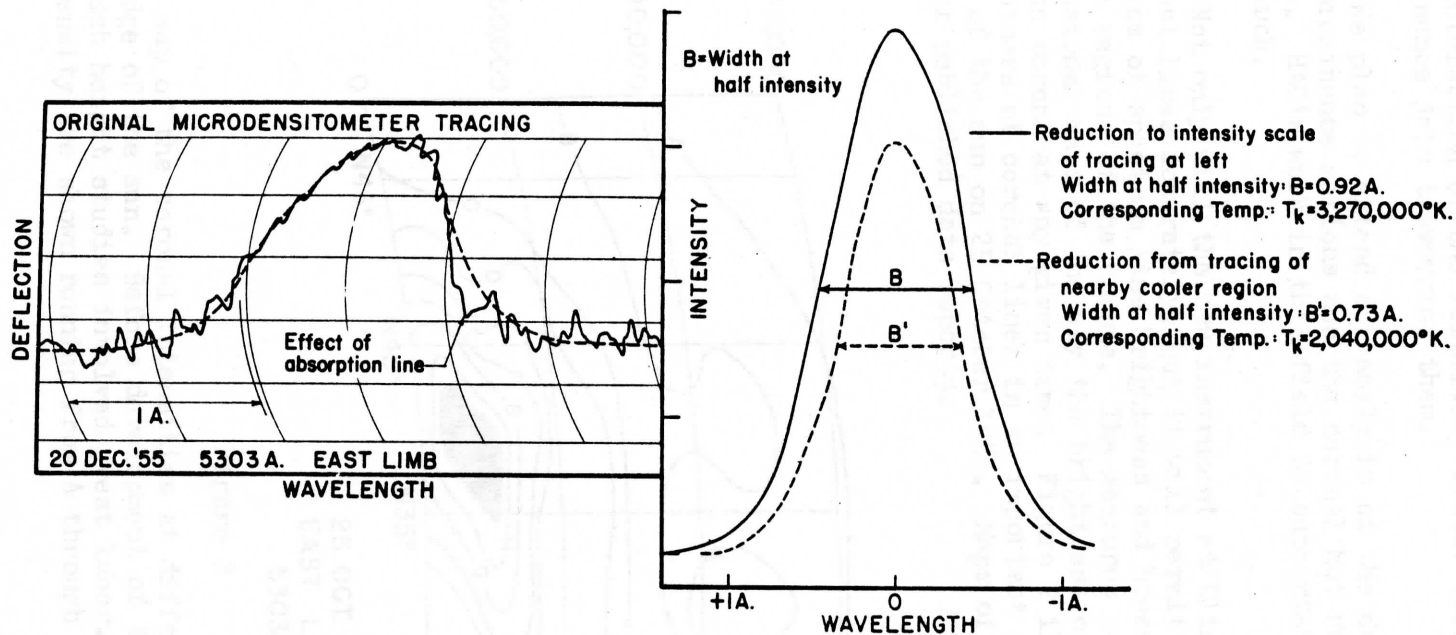


Figure 1

Diagrams illustrating the line-broadening method of determining coronal temperature:

At the left is an original microdensitometer tracing from a coronal spectrogram that exhibited strong emission in the green coronal line at a point 40° north of the solar equator. The irregular fluctuations result from film grain on the original spectrogram. Notice on the right "wing" of the line the depressing effect of an absorption line in the scattered light from the sun's face that is unavoidably superposed on the coronal line intensity. The dashed line shows the smoothed coronal line profile deduced from the tracing.

At the right we have redrawn two smoothed coronal lines on a true intensity scale; the higher being that shown at the left. The dashed line is from a nearby region a few degrees north of the first region. The widths of the lines at half-intensity measure the temperatures of the coronal regions where the lines originate, and it can readily be seen that the stronger line is also broader, and thus from a hotter region. The temperatures corresponding to the two widths are given on the diagram.

the corona is, in fact, a gas generally free from turbulent or other large scale motions, in spite of the very pronounced motions of the prominences that are found in the same general regions of the solar atmosphere. This fact has important consequences for the theory of coronal heating, and suggests to us that the origin of the coronal temperatures may actually be the interaction of the relatively static coronal gases with fast-moving prominence jets traversing them.

We plan to extend our analysis of the degree of correlation between the prominence motions and the coronal hot regions, as a check to these ideas. HAO's work in this field is supported by the Office of Naval Research.

Not only will the new instrument at Climax measure breadths of the coronal lines accurately, but it will permit us to make studies of the changes of spectrum line brightness and breadth at small steps throughout large regions of the corona. The measures can then be represented as two-dimensional maps of the way the brightness or breadth varies with position in the corona at any given time. Figure 2 illustrates how we mapped the brightness of coronal lines in an important coronal region at the east edge of the sun on 25 October 1955. Maps of this sort now appear regularly in our published data reports.

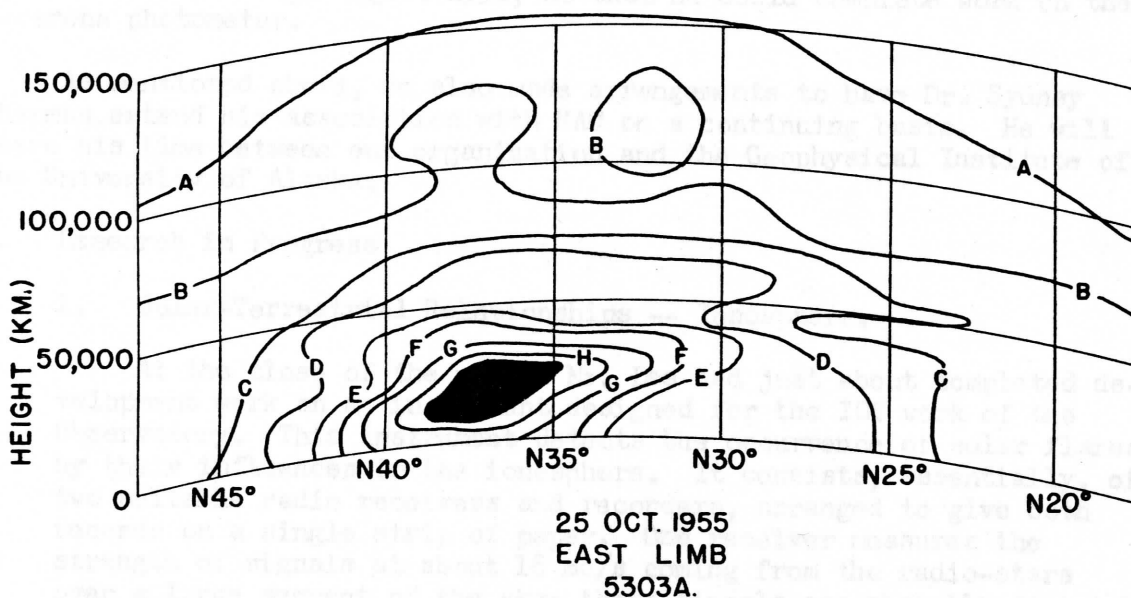


Figure 2

A map of the coronal intensities at different heights above the east edge of the sun. Before development of the new spectrograph at Climax, such height studies involved great labor. Contours of increasing intensity are shown running from A through I.

II. HIGH ALTITUDE OBSERVATORY RESEARCH PROGRAM

A. Staff

In December we had the good fortune to be able to add to our scientific staff Dr. Gordon Newkirk, who returns to astronomy after a two-year tour of duty in the U.S. Army. During his Army duty he was attached to a research group at Fort Monmouth, doing work on atmospheric dust particle analysis -- a field with considerable relevance to our solar-weather researches. Dr. Newkirk completed his Ph. D. degree at the University of Michigan Observatory in 1953. As a graduate student he spent a part of his time in the solar program of the McMath-Hulbert Observatory. After completing the degree, he spent five months in the solar program at Sacramento Peak. At HAO he will assist in the solar data analysis program, and will carry on several special studies of his own, which will be reported later.

During the quarter we also completed arrangements to have Dr. S. Matsushita continue his stay at HAO through the summer of 1956. His research was discussed in the last report. The stay of Dr. G. Wlerick was also extended through August 1956, so that he could complete work on the K-corona photometer.

As mentioned above, we also made arrangements to have Dr. Sydney Chapman extend his association with HAO on a continuing basis. He will share his time between our organization and the Geophysical Institute of the University of Alaska.

B. Research in Progress

1. Solar-Terrestrial Relationships -- Ionosphere.

At the close of the period Mr. Lee had just about completed development work on an instrument designed for the IGY work of the Observatory. This instrument detects the occurrence of solar flares by their influences in the ionosphere. It consists, essentially, of two suitable radio receivers and recorders, arranged to give both records on a single strip of paper. One receiver measures the strength of signals at about 18 mc/s coming from the radio-stars over a large segment of the sky; these signals are abruptly diminished when a solar flare increases the absorption of the signals in the D-region ionization.

The other recorder also uses D-region effects of flares, but in this case the source of the radio noise is distant thunderstorms. The added D-region ionization at the time of a flare makes the region suddenly become reflective for very long wave signals (about 27 kc/s); thus during periods of increased reflectivity, the noise of distant thunderstorms at these frequencies increases abruptly. Since such thunderstorms are a primary source of static at these long wavelengths,

the abrupt increases suggest flare effects. Local thunderstorms and man-made radio noises both interfere seriously at times. But when both records simultaneously show an abrupt change, then we can be quite sure that a flare-effect has occurred in the ionosphere. The instruments are being test run early in 1956.

The devices are relatively inexpensive and we are making three. One will be used by the McMath-Hulbert Observatory, one by the Upper Air Research Observatory at Sacramento Peak, and one by HAO. The development of the instruments was supported by the U.S. program for the International Geophysical Year.

In December, Dr. Matsushita presented a paper giving the results of his research on "sequential sporadic E" ionization in the ionosphere. His presentation was before the U.S. National Committee Meeting of the International Scientific Radio Union, at Gainesville, Florida, in December, 1955. The work he presented was described in our last report.

Dr. J. Warwick's work on refraction and absorption effects in the ionosphere continued. Things are still in the planning and building stage. The first tangible measurements are still about a half-year away.

During his stay, Dr. Chapman developed a new and tentative hypothesis about the origin of at least a part of the energy transported through the earth's ionosphere. His theory considers the earth to be imbedded in the sun's corona, which he regards as extending throughout the 92 million miles from sun to earth. The theory then assumes that the energy transported into the ionosphere comes from actual heat-conduction in the corona -- a very novel and interesting idea. Dr. Chapman also is working on some ideas about the change of conductivity in the E-region of the ionosphere in response to possible X-rays from the very high-temperature active solar regions. These ideas bear on the problem of solar effects on geomagnetism near the earth's equator.

2. Solar-Terrestrial Research -- Weather.

During the fall, Miss Trotter and Dr. Roberts studied rainfall records for the plains area of Colorado, east of the Rockies. We had earlier suspected for this area that there was a 27-day recurrence in rainfall that might possibly be attributed to similar recurrence in solar corpuscular emission. We felt that there were signs of a trend towards the breakdown of strong zonal wind-flow following the corpuscular rises by about 14 days. The analysis suggested that the qualitatively noted effects were real, but the statistical sample was small, and we do not regard the results as conclusive.

During the period we also selected certain key dates on which we felt it worthwhile to initiate a search for effects of corpuscular

heating in the auroral zone from temperatures at the 50 mb. and 100 mb. levels in the very high stratosphere. These goals were discussed with Dr. Vincent Schaefer, of the Munitalp Foundation, who may be able to assist in having the analysis carried through.

During the period, Dr. Newkirk also made plans to extend his study ¹⁾ of solar halos, their relationships to surface weather on the one hand, and to solar effects on the other.

3. Solar-Terrestrial Research -- Geomagnetism.

Our joint geomagnetic forecasting efforts with the NBS research staff continued during the quarter. Our forecasting successes for the period were not particularly encouraging, however. Dr. C. Warwick began an objective analysis of our successes and failures. It will be completed next quarter. During the fall we held several conferences with Dr. Chapman to gain, for this effort, the benefit of his long experience in geomagnetism.

The month of December saw geomagnetic disturbances drop to extremely low levels, considerably below what we expected in view of the continuing rise of the solar activity cycle.

4. Observation of the Electron Corona.

Our K-corona photometer, designed to detect the polarized component of the sun's white light corona scattered by electrons, is essentially complete. Testing was started, here in Boulder, at the close of the period, though several instrumental "bugs" remain. We hope to have something definite to report by the time of our next report.

5. Solar Activity Observing.

Our new work in mapping active coronal regions highlighted the quarter; this work is described in the first pages of the report. We continued our program of data collection and publication, with the support of the National Bureau of Standards and the Upper Air Research Observatory. Data from Sacramento Peak and Climax make up the bulk of the reports. We are happy to find that the major discrepancies between coronal measures from the two stations are gradually being accounted for and eliminated. Miss Trotter is principally responsible for the data reporting. Some of the solar information is published in the new monthly CRPL F-Series, Part B, reports on Solar and Geophysical Phenomena, which commenced in October. Other data reports come from HAO daily, weekly, and quarterly.

1) Newkirk, G. A.: Signal Corps Engineering Laboratories Technical Memorandum, 1710, 14 November 1955.

6. Temperature and Motions in the Corona.

This work was also one of the highlights of our program this quarter, and I have discussed it at the start of the report. ONR sponsorship of this work is expected to continue in 1956 and 1957.

7. The temperatures of Solar Prominences.

Dr. Zirin and Dr. Billings have undertaken a definite program of work directed towards the problems of the temperatures of prominences. The problem in many ways is more difficult than that of the corona. Prominences are obviously very changeable and are of many types. Some move with large velocities, so that the breadths of their spectrum lines must be corrected for motion (Doppler effect) before they can be considered to give information on temperature. Even then the results are not entirely satisfactory. Moreover, prominences are so dense that the opacity of the emitting gas makes further complications.

Nevertheless, we believe that we have evidence for the existence, in some prominences, of very high temperatures (above $100,000^{\circ}$ K.). Dr. Zirin has developed a theoretical explanation of how the prominences can continue to radiate their spectrum lines in spite of these large temperatures, and he and Dr. Billings are working on additional spectroscopic observations to try to reach decisive evidence of the high temperatures. This work is supported by the Upper Air Research Observatory and the Air Force Cambridge Research Center.

8. Solar Granulation Analysis.

Dr. Wlerick has several reports on this work in preparation for publication. We will discuss these in a later report.

9. Eclipse Research.

Dr. Athay continued his stay at Harvard Observatory; when he returns in June the eclipse research will be continued here. We expect to terminate studies of the 1952 eclipse within a year. At Harvard, Dr. Athay is studying 1936 eclipse data as well as those from 1952. The 1936 films, taken by Dr. Donald H. Menzel of Harvard Observatory, have not previously been analyzed in any detail. Dr. Athay has collaborated closely on this work with Dr. R. N. Thomas and Mr. J. B. Zirker during his stay at Harvard.

10. Electronic Flare Pickup.

We are developing an electronic flare image pickup and screen for use during IGY. The device consists simply of an industrial television camera pickup and screen, coupled with a telescopic system, and a Baird Associates multilayer interference filter centered at the 3934 \AA K-line of the calcium spectrum, which is strongly radiated by solar flares.

Dr. Billings and Mr. Lee are carrying on the principal activity under this contract. The work is supported by the Naval Research Laboratory. We hope to obtain from it a simple device, which NRL can use on shipboard to announce the occurrence of flares, so that they can instantly launch balloon borne rockets for ultraviolet and X-ray spectrum analysis, before the flares have faded. Our own interest in such a device is to have a simple and inexpensive flare monitor that can give pictures of flares on television screens at suitable places in our Observatory.

Difficulties in obtaining satisfactory multilayer filters have delayed the work seriously. The present filters are just barely short of the necessary performance characteristics; Baird Associates is, however, quite confident of being able to prepare suitable filters shortly.

11. Measurement of Older Coronal Spectrograms.

In the Climax coronal spectrogram files are a number of high quality coronal spectra which have never been measured. Recently the demand for these data has been substantial. In response to this we have obtained the support of the Office of Ordnance Research for measurement of these older spectrograms by modern microphotometric techniques, similar to those we use today. The work is under the guidance of Dr. Billings and Mr. Cooper.

12. Guide Book on Solar Activity.

The HAO is preparing a guide book to the variable phenomena of the sun that make up the observable features of solar activity. The guide book will describe the indices of activity, and will also discuss their physical meaning. The work is in the hands of Dr. C. Warwick and Dr. Roberts, helped by the rest of the HAO staff.

III. RELATED PROGRESS AT OTHER INSTITUTIONS

A. Solar-Weather Research.

During October, Dr. Ralph Shapiro of the Air Force Cambridge Research Center visited us. He reported further on the outcome of his recent analysis of North American surface weather data for the period 1899 to 1945. The work is a confirmation of the tentative results earlier found in 1953 data from upper level atmospheric data (500 mb. level). Dr. Shapiro found convincing evidence for a real drop in the persistence of weather patterns (see discussions in Report 1955-1, page 1) after strong rises of solar corpuscular emission received at the earth. His index of solar corpuscles came from the fluctuations of the earth's magnetic field. He confirmed decisively that on about 14 days after a sharp rise of solar corpuscles there is a minimum persistence to weather patterns; this implies

that the times of most abrupt and large scale weather alterations occur at these times. To us it actually appears that persistence begins to drop from a rather high level by the fifth day after the corpuscular rise. The statistical results are sufficiently good that the hypothesis of chance coincidences becomes unreasonable; moreover, the same results are found in both samples when the data are divided into two independent sets. The material is very nearly ready for publication.

In the course of Dr. Shapiro's visit we also speculated about possible explanations of the effects. So far only the most qualitative hypotheses can be advanced. However, it seems likely that the effects are actually produced by corpuscular heating in the auroral zone, in spite of the physical problems of how such heat can show up low enough to affect weather. Moreover, the amounts of heat available are very small; yet the effects are very difficult to explain otherwise.

We also talked over the possibility that the persistence drops should be more frequent in spring, when the seasonal trend and the corpuscular heating are working together, as compared to fall when they are opposed. Dr. Shapiro's preliminary checks seem to show that this is the case, which further supports the notion that corpuscular heating is involved.

The program of solar-weather research conducted by Mr. E. D. Farthing of Trans World Airlines continues. Mr. Farthing has extended his analysis to Ceylon, but the results, while promising, still require further evaluation. Several publications of Mr. Farthing's work ²⁾ have recently been made, and they have stimulated new interest in the subject. They must still be regarded as highly promising, but not conclusive, because of limitations of the period of data included. Mr. Farthing has urged us to extend our indices of coronal activity to permit a wider period of comparison, and we hope to be able to do so, when time permits.

A report on a possible relation of solar activity to temperatures aloft came to our attention during the quarter. The report, by Lowenthal and Newkirk ³⁾ gives tentative data that suggest a heating effect in temperatures aloft, at the 5 and 10 mb. levels, in 1953-54, when coronal emission minima, in regions free from solar flares, are near the center of the sun. The effect is hard to explain; these quiet regions probably initiate some dynamic process, such as mixing, if, in fact, the relationship is real. The data are scant, however, and the results, at best, are only suggestive. We should mention, however, that during this period weak corona corresponded generally to increased geomagnetic activity of M-region type. At present, one cannot safely infer that geomagnetic activity and these temperature effects are related.

2) Farthing, E. D.: TWA Meteorological Bulletin, No. 55-7; Bulletin AMS 36, 364, 1955; Bulletin AMS 36, 427, 1955.

3) Lowenthal, M. J. and G. A. Newkirk: Signal Corps Engineering Laboratories Technical Memorandum 1692, 1 September 1955.

Two interesting additional publications of relevance to solar-weather effects came to our attention this quarter. The first, by Dr. D. R. Barber ⁴⁾ suggests that there are systematic increases in the brightness of the zenith sky with increased solar corpuscular emission. The spectral distribution of the light of the halos suggest that the particles responsible for the increased sky brightness are relatively large. It is hard to understand physically how such an effect can be real, and more thorough statistical analysis is merited.

The second paper, by Dr. J. Dubois ⁵⁾ suggests from the observation of the reflected earth-shine visible on the dark side of the moon, that the reflectivity of the earth undergoes slow systematic changes over periods of years, and that these changes show some signs of relationship to the 11-year solar activity cycle. The relation to the solar activity cycle, with minima in 1946 and 1954, is rather unexpected, if the reflectivity changes are to be explained as changes in the average earth cloud cover, since these dates do not correspond to extreme values of the solar activity cycle. The results emphasize that such work, (which has previously been urged by meteorologists, such as Dr. Harry Wexler of the U.S. Weather Bureau) is of great importance, but the conclusions of the present study should still be regarded cautiously.

B. Solar Research.

We defer again any discussion of solar research at other institutions, because of the length of this report.

IV. CONFERENCES AND DISCUSSIONS

On October 10 to 12, Dr. Ralph Shapiro visited HAO. The results of discussions with him are reported above.

Dr. Wlerick spent two weeks during October and November visiting several observatories and laboratories on the west coast for discussions of problems of solar granulation analysis. On the way he also attended the Conference on Solar Energy at Tucson, Arizona, on October 31 to November 1. Mr. Low also attended the Conference on Solar Energy and presented a paper there for Dr. Roberts.

There were several one or two day visitors to the Observatory during the quarter, and informal conferences and discussions were held concerning the particular work of interest to each. These included: Dr. Richard N. Thomas of Harvard College Observatory; Mr. E. D. Farthing of Trans World Airlines; Mr. William Draisen and Mr. John Bisbee of Baird Associates.

4) Barber, D. R.: J. Atm. and Terr. Phys. 7, 170, 1955.
5) Dubois, J.: L'Astronomie, June 1955, p. 242.

Dr. Athay of HAO, now on leave at Harvard, and Dr. Frank Orrall of Harvard College Observatory, spent several days with us during which time they used the HAO microphotometer for study of 1936 eclipse spectrograms, and discussed their work on the chromosphere with our staff. Dr. John W. Evans, Capt. Lewis Logan, Mr. George Stith and Dr. William Sinton of the Upper Air Research Observatory visited at the Observatory to discuss plans for the 12 October 1958 eclipse.

Dr. Zirin and Dr. Athay attended the American Astronomical Society meetings at Troy, New York, in November, and presented papers. Mr. Carlos Varsavsky, now a graduate student at Harvard College Observatory, who has been at HAO for several years as a part-time research assistant, also attended the AAS meeting and presented a joint paper for himself, Dr. Billings and Mr. Hansen on the observations from the new coronagraph-spectrograph at Climax.

V. PUBLICATIONS FROM HAO DURING THE QUARTER

Athay, R. G. and R. N. Thomas: "Temperature Gradients in the Chromosphere", P.A.S.P. 67, 339, 1955.

Leighton, H. and D. E. Billings: "Solar H α Filaments and Geomagnetic Disturbances", J. Atm. and Terr. Phys. 7, 349, 1955.

Billings, D. E. and C. M. Varsavsky: "Absolute Calibration of the Climax Intensity Scale for Coronal Lines", Zs. fur Ap. 38, 160, 1955.

Roberts, W. O.: "Indirect Measurement of Solar Energy Variations in the Extreme Ultraviolet and X-ray Region", presented at the Conference on Solar Energy, 31 October 1955, Tucson, Arizona.

Roberts, W. O.: "World Climate and Solar Change", invited paper to American Chemical Society, Southwest Meeting, 2 December 1955, Houston, Texas.