

QUARTERLY RESEARCH REPORT

High Altitude Observatory
of the
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by

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SUMMARY

The highlight of the Quarter's work was the completion of the temperature determinations of the sun's chromosphere throughout its different layers by Dr. R. G. Athay and Dr. Richard N. Thomas. The results showed us, unexpectedly, that we must consider the chromosphere to be made of alternating hotter and colder spikes of gas, in both of which the temperatures rise in a step-wise fashion with height.

Three distinguished visiting scientists joined the HAO staff for periods from a few months to a year; Dr. Sydney Chapman of Oxford University and the Geophysical Institute of the University of Alaska, Dr. Herbert Riehl of the Department of Meteorology of the University of Chicago, and Dr. Sadami Matsushita of the Geophysical Institute, Kyoto University, Japan.

A major part of our summer research work was centered about solar-weather investigations. Definite advances in this field seem most likely. The physical mechanisms involved remain obscure, however.

Efforts to observe the sun's electron corona, and also to study its line-spectrum corona as a function of height in major active centers will occupy a substantial part of the HAO's efforts in the immediate future. These factors will be of special importance during the International Geophysical Year.

I. HIGHLIGHTS OF THE QUARTER

A. Temperature Steps in the Sun's Atmosphere

On February 25th, 1952 in Khartoum, Sudan, three members of our staff - Dr. John W. Evans, Mr. Robert H. Cooper, and Mr. Robert H. Lee - surmounted the difficulties of heat, dust, distance, and injuries, and the pressure of a far-too-tight schedule to obtain successful total eclipse pictures of the spectrum of the lowest layers of the sun's atmosphere, the chromosphere. Our aim at the eclipse was to obtain spectrograms from which we might determine the way the temperature of the chromosphere changed with height. Only now have we completed the principal phase of this task. The outcome is very different from what we expected and could scarcely have been foreseen at the time of eclipse.

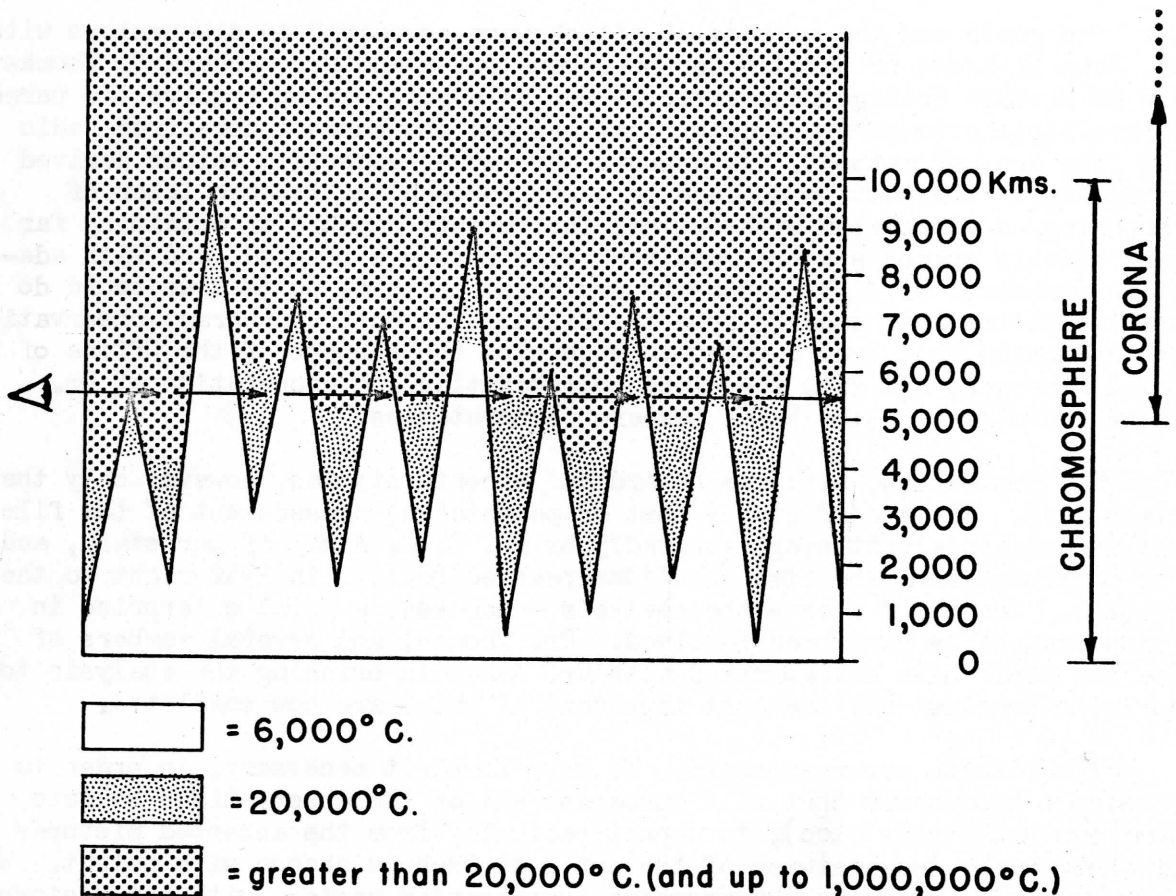
The goals and the methods of attack were conceived in discussions with Dr. John P. Hagen of Naval Research Laboratories and Dr. Richard N. Thomas now of Harvard College Observatory. Our main goal was to resolve the paradox of conflicting temperature determinations for the chromosphere from radio and from optical methods. To improve the rather uncertain values derived optically in the past we decided to carry through the immense labor of preparing an expedition with optical instruments capable of obtaining far more closely spaced spectrograms than ever before attempted, and with adequate standards of light intensity impressed on them, so that we could do precise photometric studies from the films. The entire program, observation and reduction, has been carried through with the support of the Office of Naval Research, and with the close collaboration and cooperation of Dr. Hagen and others of the Naval Research Laboratories.

The expedition, with its hazard and uncertainty was, however only the first step. The second step - that of painstaking measurement of the films - was undertaken almost single-handedly by Dr. R. G. Athay of our staff, and has continued from the time the films reached Boulder in 1952 right to the present. The third step - the analysis - has been a joint enterprise in which many of us have been involved. Dr. Thomas, and several members of the HAO staff have collaborated with Dr. Athay in bringing the analysis to definite conclusions, the most important of which are now completed.

The results are unexpected. We have found it necessary, in order to develop a hypothesis that will encompass all of the observations to date (our own and others' too), to depart radically from the accepted pictures of the way the temperatures of the sun's atmosphere change with height. We have concluded that the chromosphere is a complex region, with hot regions interspersed between cold ones, so that when one looks edgewise through the chromosphere he is looking through several of the alternating hot and cold columns of gas at a time. We call this a "spicule model" of the chromosphere, because the structure of the hot and cold columns seems to

coincide with the small spikes or jets that we termed "spicules" when we first noted them in the coronagraph at Climax, back in 1943.

But the chromosphere picture is even more complex than this: we find that within a given spicule, the temperature rises with height in a step-wise fashion. The values of temperature at the "steps" are either about 6000° or about 20,000° Centigrade. The transition regions are very narrow in height. Moreover, we find the interspicule regions to have steps just like the spicules, but with the steps both coming at far lower heights. The cause of the steps, we conclude, is that the chromosphere is temperature stable so long as the energy fed into it can be utilized in ionizing some particular element whose radiation is able to dissipate the energy fed in. But when full ionization sets in, with increasing height, the energy can no longer be radiated and it goes to produce rapid temperature rise until a new step is found where an element of higher ionization can again radiate. Our steps at 6000° and 20,000° correspond to neutral hydrogen and ionized helium - prime constituents of the chromospheric spectrum.



Idealized diagram to explain how an observer at the earth looking through the chromosphere, at an apparent height like 6000 kms., above, sees radiation from gases at both steps of temperature, and also at the higher coronal temperatures.

For about a year our thoughts about the chromosphere temperature problem have been gradually moving towards this conclusion. It will be reported soon in a joint paper by Dr. Athay and Dr. Thomas, to be submitted to the Astrophysical Journal. The importance of the model is that, to us at least, it seems to get around most of the difficulties of the older theories, which confronted us with the problem of figuring how a gas that couldn't continue to radiate as the temperature went higher could be shining forth from the same levels with gases that could only radiate at far higher temperatures. It also suggests a plausible explanation for the heating of the chromosphere and corona and its support to great heights against gravity - classical unsolved problems - in terms of ascending jets of gas whose kinetic energy supplied the driving energy of the chromosphere.

The model, moreover, has important implications for radio astronomers, who are faced with the difficult problem of explaining how the radio-noise is emitted from the sun, but these have not yet been explored in any detail.

We expect that the future will see extensions of this notion of temperature steps and a two-temperature chromosphere to the solar prominences. We rather expect to find that a good majority of the largest prominences normally found will be doing their radiation from the 20,000° temperature step.

II. HIGH ALTITUDE OBSERVATORY RESEARCH PROGRAM

A. General

During the quarter Drs. James W. and Constance S. Warwick joined the Observatory staff, and began their research programs. In the Quarter to come, James Warwick will concentrate his efforts on a research program designed to study solar effects on the ionosphere by evaluating the absorption and refraction of radio signals from discrete astronomical sources in space, at frequencies near the vertical D-region frequency (about 15 to 20 mc/s). Dr. Harold Zirin, who attended the clouded-out Ceylon eclipse on June 20th before terminating his appointment at Harvard College Observatory, accepted an appointment with us, which he will fill in August. Dr. Gordon Newkirk also accepted an appointment to be filled in November, when he is detached from military service.

Dr. Sydney Chapman began a year's stay with us in June. His visit will be sponsored by the National Bureau of Standards and probably also by the Geophysics Research Directorate of the Air Force Cambridge Research Center. His stay will be interrupted from July 15 to October 1st, when he travels in Europe in conjunction with his duties as international president of the International Geophysical Year.

Dr. Julius London spent three-and-a-half weeks in June and July, working with us on problems of possible solar-weather mechanisms. Dr. London led several seminars for us on problems of the physical processes by which

variable solar energy - corpuscular or radiational - can be brought low enough into the earth's atmosphere to have effects on weather. This is a big stumbling block to solar-weather theories at the present time. Dr. London's seminars were made possible by a grant from the American Petroleum Institute.

In June, Dr. Sadami Matsushita, of the Geophysical Institute in Kyoto, Japan, joined our staff for a four-month stay, sponsored by Research Corporation to give him an opportunity to work with our staff and observational materials and also to permit him to have close access to ionospheric data of the National Bureau of Standards. He will be working on problems of the formation of special radio-reflecting layers during magnetic storms and solar flares, and will also work on theories of geomagnetic storms.

Dr. Herbert Riehl joined our staff in June, to carry out solar-weather research, research on thunderstorm-cloud formation and motions, and to conduct a seminar on problems of the general circulation of the earth's atmosphere. His visit is sponsored by the Munitalp Foundation, and the Foundation has also supplied special photographic equipment for the photography of the thunderstorm cloud forms. In late June Dr. Vincent Schaefer and Mr. Vernon Crudge of the Foundation visited the Observatory for discussions of the scientific objectives of the summer program.

In early April, Drs. Gerard Wl^{er}rick, Athay and Roberts attended the Princeton meetings of the American Astronomical Society. At this meeting the Society also endorsed the Observatory's plans for a more extensive research seminar on solar-weather relationships planned for the summer of 1956.

In mid-June Mr. Cooper and Mr. Lee, of our research staff, assisted by Mr. James Axtell, a graduate student, and the observing staff at Climax, completed the mechanical and electrical work on the large 26-foot equatorial table in the new solar laboratory that we completed last fall with the generous help of over 35 private contributions. The instrument, provided to HAO by the Office of Naval Research, is now fully functioning, though optical components have not yet been attached. During the period, work was successfully completed on the dome-rotating mechanism, which protects the large equatorial. The mechanism was faulty as initially installed, but by the end of June everything was working beautifully, so that we accepted the contractor's work and closed out his contract.

B. Specific Research Programs in Progress

1. Solar-terrestrial Relationships

Our efforts in the solar-terrestrial field were concentrated, during this period, on problems of solar-weather relationships, for the most part. Several definite advances appear to be in the making. In particular, we are impressed with the advances being made by Mr. E. D. Farthing of Trans World Airlines and Mr. Glenn Brier of the U. S. Weather Bureau. These were the subject of detailed discussions

in July, which will be reported in the next quarter.

We began working on a research forecast of geomagnetic disturbances with the National Bureau of Standards Project 8266 group headed by Mr. Alan H. Shapley. With this group we have attempted to work out objective methods of forecasting that we will be able to compare quantitatively with the observed behavior of geomagnetism. When we have accumulated more data we shall evaluate the results and report them here.

2. Solar Activity Observing

Our program of solar activity reporting continued as in the past, though we have improved the form of our weekly and quarterly activity reports, which are reaching an ever-widening group of research workers. This program will assume a highly important role during the International Geophysical Year in 1957-58.

We also began, during the period, to measure in regular fashion the height distribution of the intensities of the corona on days when pronounced coronal emission centers are found at the edge of the sun. This essentially adds a new dimension to the measurements of the corona. These measures should vastly increase our knowledge of the total emission from such regions, and improved solar indices based on such measures should be of great value in solar-terrestrial analysis, particularly during the International Geophysical Year.

3. Temperatures and Motions in the Corona

One of the most intriguing of solar problems is that of the meaning of the measures of temperature made in the solar corona. The corona is a vast, tenuous envelope of gases whose temperatures are variously estimated from a few thousands of degrees, Centigrade, to millions of degrees, depending on the method of measurement and the portions of the corona measured.

Dr. Billings, assisted by Mr. Carlos Varsavsky and Miss Sabine Hirsch, carried out a series of studies, under ONR sponsorship, to check the conclusions regarding coronal temperatures by the two most precise methods available -- one based on the degree of ionization of the gases involved, estimated from the strengths of different spectrum lines, and the other based on the widths achieved by various spectrum lines on coronal spectrograms from Climax.

The two methods appear to give temperatures that differ appreciably, but show temperature trends that are the same by the two methods -- i.e. the methods agree in showing higher temperatures in the same places in the corona. The outcome of this work will be of great importance in the theory of the heating of the corona and in the theory of the formation of coronal spectrum lines. We have recommended that Mr. Sanford Schwartz complete his Ph. D. thesis on this problem, and he has been working through the summer on the theoretical backgrounds of the two methods.

4. Measurement of Older Coronal Spectrograms

With the support of the Office of Ordnance Research we will undertake this year a program for measurement of older Climax spectrograms with our new automatic plate reading table on our electronic microphotometer. Many of these spectrograms have never been measured, and the data contained in them are of great value in coronal research and in solar-terrestrial analyses. Dr. Billings will supervise this program.

5. Eclipse Research

Plans are going forward for the 1958 eclipse. We hope to begin the first new development work shortly after the close of the next quarter. We have reported under Highlights, above, the outstanding results of our recent eclipse research. The results at Khartoum in 1952, at a time of low solar activity, should be compared with those obtained with equal or better resolution at high activity in 1958. Moreover, our experience at Khartoum has suggested a number of improvements that can be made in the scale, contrast, and photometric calibration of the spectrograms.

6. Observation of the Electron Corona

Work began in earnest on the new photoelectric photometer to detect the electron corona. Its design and construction is under the general supervision of Dr. Wlérick, with Mr. Lee carrying the prime responsibility for the electronic work. Mr. Axtell began work during the period, as a graduate student in the Department of Physics of the University, to carry out a Ph. D. thesis program with the new photometer. He is assisting in the development, and will soon lay out a specific program of experimentation and reduction to be carried out with the new instrument.

The photometer will detect, electronically, the faint polarized component of white light in the halo surrounding the sun in a coronagraph image. This polarized component arises from the electron scattering in the corona, and its day-to-day changes are of great importance. A somewhat similar instrument was used in 1930 by Dr. Bernard Lyot, who built the first coronagraph. Lyot's instrument was used for visual detection of the polarization, but the technique has not been applied in recent years. We hope that our device will be more sensitive than Lyot's.

The instrumental program is supported by the National Science Foundation under an International Geophysical Year grant. The experimental program of Mr. Axtell, on the other hand, is being carried under our RCA research contract.

III. RELATED PROGRESS AT OTHER INSTITUTIONS

A. Solar-Weather Research

Work is being started on solar-weather research at a number of other places. We feel that an important part of the stimulus for renewed interest in this field has come from the results of Mr. Farthing of Trans World Airlines and those of Dr. Ralph Shapiro of the Geophysical Research Directorate, Air Force Cambridge Research Center. Their work has led to the reasonably certain conclusion that genuine solar-weather effects of two sorts exist -- one from solar corpuscles and one from solar radiation. Much of the new effort at places like New York University, Pennsylvania State College and the University of Chicago will be directed towards the development of suitable physical mechanisms to explain these effects.

We are convinced that there is a big contribution for HAO to make in this work, and hope to complete our plans for financing an Institute for Solar-Terrestrial Research by early 1956, so that we can make a concerted attack on certain specific aspects of this problem. At present we have pledges for approximately \$110,000 of the necessary \$150,000. We have prepared a detailed description of what we would plan to do under this program, and will gladly send copies of the folder, which is extensively illustrated, on request.

New reports of solar-weather effects in large scale atmospheric circulation continue to appear. We will not attempt to review these, save to indicate that there is evidence of great interest in this subject from behind the "Iron Curtain." A half-dozen papers on the subject by Soviets, or by scientists in satellite countries have appeared recently.¹⁾ The reports are of considerable interest, but none seems to make advances beyond those already in progress here. For the most part, they are statistical studies of small but apparently definite effects of the sort that have been reported frequently in recent years by numerous workers elsewhere.²⁾

Dr. John Simpson recently collaborated with Drs. H. W. and H. D. Babcock in publishing a paper³⁾ describing the results of their analysis of recurrent geomagnetic storms associated with "unipolar magnetic field" regions detected by a new magnetometer that the Babcocks have developed at Mount Wilson Observatory. They point out that during 1953 a maximum of cosmic ray intensity occurred at the time when the unipolar magnetic field regions faced the earth. The work is most provocative, though our own work (with the NBS Project 8266 group) suggests that the unipolar field versus geomagnetism relationship is not a general one, but an accidental association of two 27-day-recurrent phenomena. Added time-samples will settle the point.

B. Solar Research

Important work has been done in several places on problems intimately

- 1) For example: Krivsky, Publ. Astrophys. Obs. Ondrejov, No. 35, p. 5, 1953.
Eigenson, Publ. Geophys. Soc. (USSR), 85, 287, 1953.
Hanslik, St. Meteorolog. Zpravy, 6, 31, 1953.
- 2) For example: Wexler, J. Met., 7, 370, 1950.
- 3) Phys. Rev., 98, 1402, 1955: see also H. W. Babcock and H. D. Babcock, Ap. J., 121, 349, 1955.

related to our research interests. We mention only a few of the most interesting.

One new result was found by Dr. A. B. Severny⁴⁾ of the Crimean Astrophysical Observatory, who studied the temperatures of prominences spectroscopically. His work is closely related to that of Dr. Billings and Dr. Zirin mentioned in our last Quarterly Report (1955-1, page 7). Dr. Severny found kinetic temperatures of prominences, using the breadth of the spectrum lines for the determinations. His values were about 14,000° C. We hope to do work of this sort ourselves this fall, with new spectroscopic equipment at Climax.

Dr. J. Rosch, director of the Observatory of the Pic du Midi in the Pyrenees Mountains of southern France, completed a most valuable research on the size and shape of solar granules.⁵⁾ His study is directly significant to our work with the RCA solar group, which will be reported in some detail in a coming Quarterly. Dr. Rosch took movies of small granules, and found their size, when the atmospheric conditions were critically good, to be very small -- spaced by less than 700 kms., which is well below the values usually published. The result suggests that the size of measured granules may be limited by the observing equipment and the quality of the atmospheric steadiness, rather than by the real minimum size of solar granules. The point merits intensive added study.

One of the most novel proposals for extension of this work is that of Dr. Martin Schwarzschild of the Princeton University Observatory, who has suggested a balloon telescope to be flown to 60,000 feet to surmount the turbulent layers of the earth's atmosphere, and to permit more precise photography of the granules. The proposal, in our view, is highly meritorious.

Another highly important paper was published late last year by Dr. Talbot Chubb and Dr. Friedman of Naval Research Laboratory on the role of coronal X-rays in the formation of the disturbances of the radio-reflecting ionosphere.⁶⁾ Their paper emphasizes the unreasonably large increases that would be needed if ultraviolet solar emission is held responsible for ionospheric upsets -- a widely supported view. They point out that if the normal layers are formed by solar ultraviolet, but the increases are caused by X-ray emission near 1 to 2 Angstroms, from the corona, the energy increases needed are far smaller, and the mechanism becomes simple to explain. The notion appeals to us from the entirely independent grounds that such X-rays might very well be generated in the hot (several million degrees C.) coronal regions that our line-breadth coronal studies seem to indicate. Further rocket or satellite research will answer this question.

4) Publ. Crimean Astrophys. Obs., 12, 33, 1954.

5) Comptes Rendus, 240, 1630, 1955.

6) Cambridge Conference Report, Roy. Phys. Soc., p. 58, 1954.

IV. CONFERENCES AND DISCUSSIONS

This report is already so long that we will not discuss the numerous highly useful, but small and informal, scientific conferences that went on in Boulder. We were fortunate, however, to have stimulating discussions with a great number of visiting scientists, including Dr. S. Rosseland of Norway and Dr. V. F. Weisskopf of M.I.T.

In May, Dr. Roberts spent two days in St. Louis discussing solar-weather relationships with representatives of the American Petroleum Institute Advisory Committee on Fundamental Research in Weather Forecasting. The meeting was also attended by a number of meteorologists including Dr. Hurd C. Willett of M.I.T., Mr. Reid A. Bryson of the University of Wisconsin and Mr. Archie M. Kahan of Texas A. and M. The meeting permitted some stimulating discussions, and also gave Dr. Roberts an opportunity to describe in some detail to the API members present the aims of our plans for solar-terrestrial research.

V. PUBLICATIONS FROM HAO DURING THE QUARTER

Pecker, J-C. and R. G. Athay: "CN Bands in the Chromosphere", Ap. J., 121, 391, 1955.

Roberts, W. O. and Dorothy E. Trotter: "Solar Prominences and Geomagnetic Disturbance", J. Atmos. and Terr. Phys., 6, 282, 1955.

Athay, R. G.: "The Helium Chromosphere", Abstract, Astron. J., 60, 150, 1955.

Billings, D. E. and Harold Zirin: "The Temperature of Prominences in Active Solar Regions", Abstract, Astron. J., 60, 155, 1955.

Roberts, W. O. and D. E. Billings: "A Hypothesis for the Origin of Solar Flares", Abstract, Astron. J., 60, 176, 1955.

Matsushita, S.: "The Thermodynamic State of the Outer Solar Atmosphere III. The Analysis of the Balmer Decrement Observed at the 1932 and 1952 Eclipses", Ap. J. Supplement, 1, No. 12, 479, 1955.

Athay, R. G. and R. N. Thomas: "IV. Self-Absorption and the Population of the Second Quantum Level", Ap. J. Supplement, 1, No. 12, 491, 1955.

Athay, R. G., D. H. Menzel, J-C. Pecker, and R. N. Thomas: "V. A Model of the Chromosphere from the Continuum Emission", Ap. J. Supplement, 1, No. 12, 505, 1955

Roberts, W. O., "New Methods and Instruments of Solar Observations", 8th Report, Commission for the Study of Relations between Solar and Terrestrial ~~Phenomena~~, p. 11, 1954.

Phenomena

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