

QUARTERLY RESEARCH REPORT

High Altitude Observatory
of the
University of Colorado

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by
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I. Highlights of the Quarter

A. A Definite Solar-Weather Relationship.

The highlight of the quarter, in our areas of special interest, was Dr. Ralph Shapiro's new confirmation that the sun's corpuscular emission affects world-wide weather patterns. Nearly two years ago, in the summer of 1953, Dr. Roberts suggested to Shapiro that the solar activity in the first half of 1953 was of such a nature that solar-weather relationships should show up in particularly clear fashion. This was because the solar activity was well isolated, and there were definite regions of disturbance, but also there were large portions of the sun's disk where no disturbances existed. This meant that the earth's atmosphere would have a chance to settle down to a very relaxed state between "punches" from variable solar activity, and the responses to these punches would therefore stand out much more clearly.

Following this suggestion, Shapiro found what may, in historical perspective, be regarded as the most important clue yet discovered to solar-weather relationships. He found evidence that definite disruptions of the continuity of weather patterns over North America occurred abruptly at certain days, and that on the average these disruptions followed, by a constant time-lag, the outstanding increases of the sun's corpuscular emission.

What Shapiro did, briefly summarized, was the following. First he computed a "persistence correlation" index for each $3\frac{1}{2}$ day interval in 1953 which measured the tendency for barometric pressures over North America to start changing up and down by more than the usual values. When the index was high the pressures were slowly and smoothly changing; when the index was low the pressures were changing drastically. Shapiro found that in 1953 the large drops of the persistence correlation index occurred, on the average, about 10-14 days after the large disturbances of earth magnetism.¹ These latter disturbances have for many years been considered to be the result of the arrival of strong clouds of electrified particles or "corpuscles" from the sun. We have just published a paper, for example, relating these corpuscle streams to activity in the sun, and showing that there are two definite kinds of solar corpuscle streams.²

¹ R. Shapiro, *J. Meteorology*, 11, 424, 1953.

² Pecker and Roberts, *J. Geophysical Research*, 60, 33, 1955.

Thus, Shapiro established the first clear-cut relationship between weather changes and solar activity. Unfortunately the connection was, from the 1953 data alone, something short of overwhelmingly convincing. Many meteorologists privately confessed that if Shapiro's results were confirmed they would be of striking significance, but that results from so short a time period could not be trusted.

What Shapiro has now done is to extend this result to a period of 40 years, and to Europe as well as North America. He finds, with far greater statistical reliability, that the persistence correlation drops abruptly at about 12 to 14 days after the strong influx of solar corpuscular streams.

The new results are stated here in advance of any official announcement, and must be treated as in the nature of a private communication, pending full publication. However, we regard this as the most important result in this field in many years. Meteorologists and astronomers must now get together in a concerted effort to explain how the physical mechanism can work. This problem has many "posers" in it. But the practical stakes are high -- for the result will have vast importance for weather forecasters.

The importance of this new field of research is one reason we at the HAO are now so anxious to initiate a concerted attack on solar-weather relationships under our plans for an industry-sponsored "Institute for Solar Terrestrial Research". The sponsorship of our new program is now under consideration by the American Petroleum Institute and other industrial groups and foundations, and one-third of the necessary funds have been pledged by the American Gas Association.

B. The Sun's Vacuum-Ultraviolet Spectrum.

On the 22nd of February a group of Naval Research Laboratory scientists headed by Drs. Johnson, Malitson, Purcell and Tousey fired an ultraviolet spectrograph over 50 miles into the atmosphere above the White Sands National Monument in New Mexico. This rocket spectrograph was pointed at the sun by means of a clever electronic aiming device developed by the University of Colorado. The apparatus succeeded in safely bringing back to earth the first really useful photographs of the so-called "vacuum-ultraviolet" spectrum lines of the sun. These spectrum lines appear in the vicinity of 1000A, where the earth's atmosphere is very opaque, so that photographs must be made from above about 40 miles height for anything to show at all.

The spectrograms show about a dozen new spectrum lines near the important "Lyman-alpha" line of hydrogen gas in the sun's atmosphere. Many riddles are posed by the new photographs. Lines of the sun's spectrum

requiring very high temperatures are mixed with lines of moderate temperature. Moreover, the Lyman-alpha line seems to be the same brightness from all parts of the sun's face -- a result that is quite unexpected, to us at least. We had expected relatively small areas to contribute most of the light at this wavelength, giving the sun's face a patchy look. The spectrum suggests that this is not so.

A success like this fully justifies the many years of hard labor and great expense that have gone into this research. The results will keep theoreticians busy for some time. We are particularly interested in some of the implications of the uniformity of the brightness and the high temperature lines. These results bear quite directly on a number of our findings from the Khartoum eclipse analysis. We shall probably speak more about this in later reports.

II. High Altitude Observatory Research Program

A. General.

During February the HAO's full name was changed from the High Altitude Observatory of Harvard University and the University of Colorado to the High Altitude Observatory of the University of Colorado, formalizing the growing strength and independence of the HAO's research program. In the future, vacancies in the HAO Board of Trustees will be filled on nomination by the Regents of the University of Colorado. All present Trustees continue in office. No staff changes were made at the time of the change.

During the quarter, plans were completed for Dr. R. G. Athay to spend the coming academic year on the research staff of the Harvard College Observatory. Drs. James W. Warwick and Constance Sawyer Warwick now of the Harvard College Observatory staff accepted appointments to the HAO staff effective about June 1st. It is probable that we shall offer a position to Dr. Harold Zirin also of the Harvard College Observatory staff, to fill the gap left when Dr. Eugene Parker now of the University of Utah decided to go to the Institute for Nuclear Studies of the University of Chicago this June, instead of joining the HAO staff, as he had previously planned to do. Two graduate students from the Physics Department of the University of Colorado joined the HAO during the period. They will carry out Ph. D. theses under HAO supervision, and using HAO observational materials.

Plans are about complete for our summer seminar on Problems of the General Circulation of the Earth's Atmosphere. The seminar will begin about June 20, at which time Dr. Herbert Riehl, Department of Meteorology

at the University of Chicago, will join the staff of HAO for six to eight weeks. His appointment is supported by the Munitalpa Foundation. Dr. Jules London of the Department of Meteorology of New York University also has been invited to attend, and has accepted. In addition, four to five graduate students will be given scholarships or stipends for summer research projects at HAO and will attend our seminar. The seminar will also be offered to the University of Colorado as a for-credit course in the graduate school in the Department of Physics.

In January the Council of the American Meteorological Society approved our plans for a far more extensive solar-weather seminar in the summer of 1956, and agreed to serve as co-sponsors of the seminar. The AMS will also endeavor to hold a national meeting of the Society at the close of the seminar, to summarize the findings.

B. Specific Research Programs in Progress.

1. Solar Corpuscular Streams and their Terrestrial Effects.

In January solar activity rose abruptly, and it began to look as though the new sunspot cycle had commenced in earnest. January 16. brought the first large solar flare of the new spot cycle, and the first pronounced flare-region in well over a year. Associated with the rise of solar activity was a definite change in the relationship of visible features of the sun's disk and the times of major geomagnetic activity. Twenty-seven day recurrence weakened, and with it the quality of our 3-week advance forecasts of geomagnetic character worsened. In February they were entirely discontinued. We will continue our efforts to develop methods for prediction of these important solar-terrestrial effects, however. The results of Shapiro on geomagnetism-weather relationships make it important for us to put all possible effort into the solution of the problem of forecasting the strength of the solar corpuscular emission.

Some months ago we studied in detail, for the present solar minimum, the great "chains" of solar prominences of quiescent type, previously regarded by Waldmeier and Kiepenheuer as the source of the near-minimum type solar corpuscular streams responsible for recurrent magnetic storms. We found evidence contrary to that of these workers. During this quarter we extended the analysis to the examination of the "dark filaments" seen on the sun's face in the light of the hydrogen spectrum. The work was done by Dr. Billings of our staff and Miss Leighton of the National Bureau of Standards. These filaments, if the previous authors were correct, should be even more closely related to the corpuscular streams than our "chains" of prominences. We found full confirmation of our earlier results, and an even stronger

contradiction of the results of Kiepenheuer and Waldmeier. These two new papers will appear as Research Notes in the Journal of Atmospheric and Terrestrial Physics.

2. Hypothesis for the Formation of Flares.

The most spectacular outbursts ever found on the sun are solar flares. Flares burst forth explosively on the solar surface, often in just a few seconds, and they spread out, in some cases, to vast hot areas many tens of thousands of miles in length. We have previously shown that the temperatures found in flare regions of the sun's corona often reach upwards of five million degrees Centigrade.

The origin of solar flares has remained a mystery. Most of the theories have involved electric discharges in the sun's atmosphere. The flares were likened, in some ways, to lightning discharges at the earth. These theories, however, fell far short of being satisfactory, as many astronomers have pointed out.

In preparation for the American Astronomical Society meetings in Princeton, Roberts and Billings worked further on the new hypothesis suggested by Roberts last fall. This hypothesis was the result of conversations Roberts had with Richard Hansen, the Observer-in-Charge at Climax, with Dr. David Layzer at Harvard College Observatory, and with Dr. Arnulf Schlüter of Göttingen.

Solar Research Memorandum No. 33 from the HAO describes our conclusions, and can be sent to anyone who wishes to have the details. Briefly put, we suggest that ordinary surge-prominences of the sun are the starting point for flares. We suggest that a flare occurs when a powerful surge prominence, of which our prominence films exhibit great numbers, is prevented from rising normally into the sun's atmosphere. What prevents this rise, we suggest, is a strong magnetic field "roof" formed by a nearby sunspot group. The roof has the property of trapping the surge material, and causing the uprushing material to collide forcefully with the material that has rebounded from the roof. Heat is generated in the process, we suggest, and this heat gives rise to the principal phenomena of the flare -- including its explosively sudden rise in temperature and brightness.

Energy-wise things seem to work out well, with about 10^{32} ergs of energy being available in a fair-sized surge prominence shooting through the solar surface with a normal surge velocity of about 300 km/s. Flares are estimated to have about this order of energy radiation. Moreover the strength of magnetic field needed to form an impenetrable roof seems reasonable.

Flares are associated with sudden, world-wide and complete radio fadeouts on many occasions, and they give rise to the best known of all solar-terrestrial relationships. Therefore it is of utmost importance for us to understand how they are formed, so that predictions of the occurrence can be made. To date, no success in their prediction has been achieved.

3. Solar Activity Observing and Reporting.

The solar activity program continued as in previous years. Solar activity rose abruptly in January and February, but in March again declined to a very low level. The new activity cycle is, however, now clearly under way, and the quarter-end lull can be expected to be relatively short-lived.

Miss Trotter and Dr. Roberts initiated several improvements in the format of our regular weekly and quarterly solar activity reports. Moreover, we combined our weekly solar activity reports with those of the National Bureau of Standards, thus eliminating the separate issuance of a flare report and a corona report, as had been done previously.

We also commenced reporting the intensity of the solar corona observed at Climax in absolute intensity, instead of arbitrary intensity. This now makes the observations from Climax immediately comparable with those made in Pic du Midi in France, and brings our practice into conformity with the long-standing 1948 recommendations of Commission 11 of the International Astronomical Union to all coronal observatories. During the year the Upper Air Research Observatory observations from Sacramento Peak will also be put into absolute terms.

We began, moreover, operations with an automatic microphotometric spectrum-plate reading apparatus built about our high-speed electronic microphotometer. This will permit us to make completely objective coronal intensity measures with the Climax coronagraph, and will eliminate sources of error arising from photographic fluctuations and from changes in the background sky brightness. This represents the achievement of a long-planned and long-deferred goal. Tremendous credit is due Dr. Billings for pushing this through to success. All reported coronal intensities for the next quarter will probably be done by the new method.

Improvements in the telegraphic reporting of coronal data to Mr. Farthing of Trans World Airlines were undertaken. Farthing's work continued successfully, with the issuance of four TWA

Meteorological Technical Bulletins summarizing his findings. These are available directly from E. D. Farthing, at Trans World Airlines, 10 Richards Road, Kansas City 5, Missouri.

4. Physical Conditions of Solar Prominences.

During the quarter Dr. Billings analyzed spectrograms from a number of types of solar prominences. In this work he consulted closely with Dr. Harold Zirin of Harvard College Observatory. From a study of the amount by which the lines of the spectrum of prominences are broadened by the Doppler effect resulting from high temperature, Billings concluded that many prominences in active regions of the sun are at temperatures of at least 250,000° Centigrade. Zirin showed from the theory of formation of such spectrum lines, that it is not unreasonable to expect to see such prominences, in spite of the intuitive feeling that most astrophysicists have previously expressed, to the effect that prominences should cease to radiate at such temperatures. The effects of the large-scale motion of the prominences were separated from the temperature effects. To do this Billings took advantage of the fact that atoms of all weights should partake of large-scale motions equally, but that the temperature effects should depend on the atomic weight. Thus by observing spectrum lines of different elements, he was able to separate the amount of the Doppler effect coming from irregular motions of large portions of the prominence as a whole and that coming from temperature.

The results were presented to the American Astronomical Society, at its April 1955 meeting at Princeton, and will appear soon in the Astrophysical Journal as a joint paper by Billings and Zirin.

5. Eclipse Research.

The helium spectrum occupied our principal attentions during the period, so far as study of the 1952 Khartoum eclipse spectrum is concerned. We will report in more detail later on the interesting developments in this work. We are convinced that the only satisfactory explanation of the lowest layers of the solar atmosphere, the chromosphere, will be found in appealing to a physical situation in which there are alternating columns of hot and cooler gases.

Dr. Athay has found conclusive evidence for high temperatures for helium gases in the mid-layers of the chromosphere at which hydrogen must be much cooler. We conclude that the chromosphere must be made up of dense, cooler spicules surrounded by hotter regions. The hydrogen emission must come from the cooler columns, and the helium from the hotter.

Our thinking is also rapidly moving in another interesting direction. Last summer we concluded that the temperature in the chromosphere must first rise abruptly, then level off for a considerable range of heights, where the energy fed into the chromosphere is used up in ionizing the hydrogen. After saturation is achieved, the temperature must rise abruptly again. This picture was developed by Dr. R. N. Thomas of Harvard College Observatory and by Athay and the others working on the eclipse program. It now appears that an analogous phenomenon must occur in the hotter helium-emitting columns. Thus we may find there also step-like temperature rises. Moreover, it seems reasonable that the cause for the hotter regions is simply that energy is fed into them from below at a faster rate. There is some hope, we believe, for resolving the discrepancies between radio noise observations and optical observations by going in these directions of research.

The resulting model will bear a number of points of close resemblance to the earth's ionosphere, with its layered construction. The model may also turn out to be rather general, applicable to all kinds of stars.

We are now laying the first specific plans for attending the October 12, 1958 total solar eclipse in the South Pacific. Scientific preparations should get underway this fall. We will undertake the expedition, if things work out as planned, with the cooperation of the Upper Air Research Observatory and the Naval Research Laboratory.

6. Observation of the Electron Corona

Dr. Wlerick devoted his principal time, during the quarter, to determining the feasibility of detecting the electron corona of the sun to a height of one solar radius by means of a coronagraph and a photoelectric detector, which will register the electron corona's polarized light. He carried out experiments with the Climax coronagraph, and also studied carefully the problems of instrumental polarization and of the weak light levels of the electron corona.

The problem looks manageable, though difficult. We have therefore made plans to develop a photometer for these measurements. We hope to operate such a photometer during the International Geophysical Year, and have obtained IGY financial support for the construction of the instruments.

The observations should be of great importance in permitting us to detect the directions of ejected solar corpuscular streams, since these will be evident in the scattered light from the electrons that

accompany the corpuscular streams. At present the only observations of these streams are made at eclipse.

III. Related Progress at other Institutions

Because of the extreme length of this report, we will defer until the next report discussion of advances at other institutions, beyond the two very important advances mentioned in the "Highlights" at the start of the report.

IV. Conferences and Discussions

On January 20 and 21 Athay and Roberts attended a sustained conference at Boston involving the research staffs of the Harvard College Observatory and Drs. Gerson, Shapiro and Ward of the Air Force Cambridge Research Center. During these meetings the whole group considered in detail the state of knowledge in solar-weather, solar-radio and other solar-terrestrial research. This was a part of the meeting of the "Solar Associates", an informal affiliation representing, in addition to HAO, the Upper Air Research Observatory of the Air Force Cambridge Research Center, the Central Radio Propagation Laboratory of the National Bureau of Standards, and Harvard.

On January 18th and 19th Roberts conferred with Dr. Herbert Riehl and Dr. David Fultz of the Department of Meteorology of the University of Chicago concerning possible mechanisms for the production of atmospheric responses to solar-corpuscular emission, and concerning the problem of measuring the surface-height of the "dishpan" atmospheric circulation model of Fultz, in which it is possible artificially to induce motions directly analogous to the jet stream.

On January 28 and 29 Roberts conferred at the Naval Research Laboratory, and also delivered a lecture on the origin of solar corpuscular emission. He conferred with Drs. Bennett and Hulburt about the paths of solar corpuscles in the vicinity of earth, and with Drs. Freidmann and Chubb about X-ray emission from hot regions of the corona characterized by the emission of the yellow coronal line, and by the appearance of thermally broadened coronal emission lines. Chubb and Freidmann have found direct evidence of powerful X-ray emission from the sun during times of strong coronal emission. Their work is based on photoelectric measures from high altitude rockets.

Dr Billings visited Sacramento Peak from January 31 through February 2, at which time he discussed the observational programs of SP and Climax, the problems of absolute photometry of the corona, and other aspects of the cooperative solar observing program of the two observatories. On February 18-21 Dr. Roberts and Miss Trotter also visited Sacramento Peak to consult on the progress of the routine data reports, and to plan specific future research projects.

Dr. Roberts visited Harvard College Observatory again on 27th and 29th of March, at which time he discussed with the HCO staff and students specific plans for the coming summer research programs of the Solar Associate institutions. Roberts returned home via the April meeting of the American Astronomical Society.

V. Publications from HAO During the Quarter.

"The Prominence of July 25, 1951", K. Rothschild, J-C. Pecker, and W. O. Roberts, Ap. J. 121, 224, 1955.

"Coronal Line Intensities at the Khartoum Eclipse", R. G. Athay and W. O. Roberts, Ap. J. 121, 231, 1955.

"Corpuscles from the Sun", W. O. Roberts, Sci. Am., 192, 40, 1955 (semi-popular)

"A Semi-annual Periodicity in the Beginnings of Recurrent Magnetic Storm Series", J. H. Rush, Nature, 175, 517, 1955.

"Solar Corpuscles Responsible for Geomagnetic Disturbances", J-C. Pecker and W. O. Roberts, J. of Geophysical Research, 60, 33, 1955.

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