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HISTORY

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the SACRAMENTO PEAK OBSERVATORY 1947—1962

OFFICE OF AEROSPACE RESEARCH U S AIR FORCE

THE

SACRAMENTO PEAK OBSERVATORY

1947 - 1962

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FOREWORD

The Sacramento Peak Observatory of the Air Force Cambridge Research Laboratories, Office of Aerospace Research, does not fit easily into the various set categories commonly used in discussing Air Force research programs. Its work in the broad area of solar phenomena and their terrestrial relations is both in-house and contractual, with the further complication that some (not all) of the contractors do their work just as much inside the observatory "house" as do those staff members employed directly by the Air Force. In the matter of applied vs. basic research, the Sac Peak mission is officially documented as applied research in support of the very specific and practical objective of predicting solar phenomena likely to disturb aerospace operations. Yet in order to attain this objective, Sac Peak must conduct many investigations of solar physical processes which are so fundamental in nature that they are scarcely distinguishable from what is generally thought of as basic, or unapplied, research. Hence a part of the observatory workload might well be redefined as <u>applied</u> basic research. Fortunately, however, one thing is clear. Sacramento Peak Observatory is an Air Force research installation whose work has won general recognition as equal to the best that is being done anywhere else in the same field. For this reason, among others, the history of the observatory is a topic well worth examining. The topic may also serve as a case study in Air Force research operations; and it is not too much to say that it constitutes a small but still necessary chapter in the general history of American astronomy.

This history does not pretend to be a definitive study of the scientific contributions made by the Sacramento Peak Observatory. Instead, it is intended to fall somewhere between the rigorously technical and the merely popular levels. The resulting treatment may not be completely satisfactory to any one group of readers; but it will, I hope, at least prove useful to both scientists and administrators, and to anyone else with an interest in the Sac Peak program.

In the preparation of this history, valuable assistance has been received from a great many individuals at Headquarters Office of Aerospace Research, at the Air Force Cambridge Research Laboratories, at the Sacramento Peak Observatory itself, and at the neighboring Air Force Missile Development Center. Without such widespread cooperation, this history could scarcely have been written. Above all, thanks are due to Dr. John W. Evans, Director of the Sacramento Peak Observatory; Major Joseph X. Brennan, Chief of the Geophysics Division, Directorate of Programs, Deputy Chief of Staff/ Plans and Programs, Office of Aerospace Research; and First Lieutenant James F. Allison, research and development staff assistant in the same Geophysics Division. These three men personally answered questions about Sac Peak and related topics, made available important source materials, and examined portions of the manuscript in semifinal form. To be sure, responsibility for the final version of the history -- and for any shortcomings that may be detected in it -- rests solely with the author.

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Chapter I

ORIGINS OF THE SACRAMENTO PEAK OBSERVATORY

> Solar activity is the driving agency for fluctuations (probably large) in the environment of space flight within and outside of the terrestrial ionosphere. Some of the affected characteristics are density of ionizing radiation, electrical conductivity, the magnetic field vector, and the density of gases and their kinetic energy in space. Solar activity further affects Air Force operations by inducing disturbances in the ionosphere which lead to the following results:
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> a. Partial or complete blackouts of radio communications for periods of hours or days.
>
> b. Fluctuations in the strength and direction of the earth's magnetic field, resulting in navigational errors in any magnetic navigation system.
>
> c. Strong auroral displays affecting visibility, particularly in polar regions.
>
> d. Global atmospheric circulation and resulting weather.

The preceding quotation, from a page of project documentation,[1] presents a typical justification for current Air Force interest in solar studies. It does not expressly identify the problem posed by showers of fast protons in space, the one phenomenon of solar origin that has attracted most attention in recent months, but that phenomenon is covered by the general reference to "density of ionizing radiation." Moreover, although the wording is at least in part space-oriented, the present Air Force program of solar research actually took shape in the years immediately following World War II, when the potential space applications were mentioned (if at all) mainly for the record rather than as a serious motive for spending the taxpayers' money.

Preliminary plans for the one Air Force facility exclusively engaged in solar research, the Sacramento Peak Observatory in southern

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1. R & D Project Card (DD Form 613), Project 7649, 1 March 1960, p. 1.

New Mexico, were laid as far back as 1947. By that time it was already well known that variations in solar radiation (in particular far ultraviolet and x-rays and showers of charged particles) were associated with such conditions as radio disturbances, geomagnetic storms, and southward displacement of the auroral zone. The recent conflict had produced numerous examples of the practical inconvenience to military operations that these conditions can cause, and, to cope with such problems in future, more basic knowledge of solar processes and their terrestrial effects could scarcely be amiss. Presumably for similar reasons, the Russians at that time were intensifying their own solar research activities.[2]

And yet the precise ancestry of Sacramento Peak Observatory can be traced back one step farther, to the establishment of a solar observatory at Climax, Colorado, in 1940. This observatory was built as an outlying station of the Harvard College Observatory and was in fact the particular brainchild of the noted Harvard astronomer Donald H. Menzel. Located at well over 11,000 feet, it was the world's highest permanent astronomical observatory; and it was specifically designed for solar studies. Indeed Climax possessed a coronagraph -- a device invented by the French astrophysicist Bernard Lyot to permit observation of the sun's outer atmosphere or corona without waiting for an eclipse -- that was the first to be built in the United States.[3] During World War II, the Climax station under the direction of Dr. Walter Orr Roberts, in collaboration with the National Bureau of Standards, performed important work for the armed services, forecasting radio conditions on the basis of solar observations.[4] Thus after the war, when the Air Force recognized the need to

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2. Cf. GRD, Summary of Technical Presentations, Part II (18-19 June 1951).

3. Mabel Sterns, Directory of Astronomical Observatories in the United States (Ann Arbor: J.W. Edwards, 1947), p. 45. In a sense, the coronagraph provides artificial eclipses. Or as Menzel has stated: "The coronagraph has multiplied the eclipse life of an astronomer by many thousandfold." (Our Sun [Cambridge: Harvard University Press, 1959], p. 241.

4. Sky and Telescope, August 1957, p. 464; interview with Dr. John W. Evans, Director, SPO, 27 March 1962.

organize its own long-range program of solar studies, it quite naturally turned for specialized assistance to the recently formed High Altitude Observatory (HAO) of Harvard and the University of Colorado, which had administrative headquarters and shops at Boulder, Colorado, and had taken over the management of the Climax station. In September 1947, to be exact, the Air Materiel Command awarded a contract to HAO for a study to recommend the best location for an Air Force solar observatory and to determine the instrumentation that would be needed.[5]

It might have been argued, superficially, that whatever money the Air Force proposed to spend could have been better used in expanding and improving the facilities already in place at Climax; but in the present case a certain amount of "duplication" was not only permissible but even essential. For one thing, any practical solar observatory is bound to have bad weather for observing at least part of the time. Thus an obvious criterion to follow in choosing the site for a new installation was that the usual seasons of good and bad weather for sun-watching should be "out of phase" with the seasons at Climax. Even more obvious was the requirement that the atmosphere above the new site should be exceptionally free from clouds or haze, dust, and other contaminants, and that it should offer good "seeing" quality -- i.e., an absence of jumpiness or shimmer in the solar image. To make the search more difficult, the desired qualities included some that are not often found together. Increase in altitude will normally mean greater atmospheric transparency

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5. "Solar Studies, Sacramento Peak," unsigned and undated manuscript dealing with the origins of the observatory, from the historical files of the former Air Force Cambridge Research Center (and now in the Historical Division, OAR); Claire Inch Moyer, Silver Domes, A Directory of the Observatories of the World (Denver: Big Mountain Press, 1955), p. 123.

   Since December 1961, the High Altitude Observatory has come under the jurisdiction of the University Corporation for Atmospheric Research, with headquarters at Boulder, Colorado. The Corporation was organized by a group of universities which include the University of Colorado (but not Harvard, whose direct association with the High Altitude Observatory had lapsed some years earlier).

but more cloud cover; and in the same manner heavy precipitation, while washing dust from the air, will also in most cases be associated with frequent cloudiness.

Various alternative locations were considered in the course of the site-selection survey, ranging from the Big Bend area of western Texas to the Sierra Nevada. But the site finally chosen -- Sacramento Peak -- was a strong favorite from the start. As far back as July 1947, following some preliminary discussions but before the actual signing of the Air Force study contract, Dr. Menzel together with Dr. Roberts of HAO had used an American Airlines experimental plane to carry out an air inspection of the general vicinity of White Sands Proving Ground, Holloman Air Force Base, and Alamogordo, New Mexico. Menzel and Roberts concluded that the section of the Sacramento Mountains in which Sacramento Peak is located would be especially promising for a solar research site. Further inquiries and inspection tended to confirm this initial reaction, and in September the collection of daily records of observing conditions was started at the Peak under the terms of the Air Force study contract.[6]

As more detailed information became available, the advantages of Sacramento Peak -- Sac Peak, to use the familiar term -- looked still more impressive. Sac Peak rises to an altitude of 9,253 feet, which is generally high enough to escape the dust conditions that sometimes afflict the Tularosa Basin area immediately below. It enjoys moderate rainfall, about twenty to thirty inches a year: just the right amount to permit a high ratio of sunshine and yet maintain a forest cover that avoids the rising air currents (and resulting atmospheric turbulence) associated with exposed sun-baked earth or rock. Sac Peak's main weakness appeared to be the local thunderstorm season in July and August, but during those months there would be a good chance of filling in the

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6. Walter Orr Roberts, Report of Progress I, 1 December 1947 (on contract W28-099 ac-364) and Decision Regarding Suitability of Weather at Sacramento Peak for Proposed Solar Observatory (Special Report, 10 July 1948).

gaps in Sac Peak data with observations obtained at Climax, while at other times of year Sac Peak could frequently make up for weather difficulties at the Colorado site. It was also anticipated (incorrectly, as long experience was to demonstrate) that Sac Peak at its best still would not match the optimum degree of atmospheric clarity obtainable at Climax, but it was quite evident that Sac Peak offered good observing conditions for many more days per year. Potentially, in fact, Sac Peak and Climax promised to make an excellent "team" of research sites, the former being ideally suited for continuing day-to-day observations while the latter could properly emphasize "special project" research requiring fine viewing conditions but only for limited durations.[7]

Sac Peak offered certain other advantages over and above its atmospheric and weather conditions. Its somewhat lower elevation, as compared to Climax, promised a milder climate and easier working and living conditions. At the same time, for administrative and logistical support a further advantage was proximity to Holloman Air Force Base, near the eastern edge of the Tularosa Basin. Also nearby was the Army's White Sands Proving Ground, on the western side of the Basin, which was the nation's principal firing range for research rockets in the early postwar period. Since rocket experiments at both White Sands and Holloman would include some related to solar research, this was another factor worth considering. Indeed, considerable weight was given to the fact that Sac Peak overlooked the White Sands-Holloman test-range complex and could therefore double as a tracking location for many different types of rocket and missile experiments.[8]

As early as 5 December 1947, Menzel and Roberts made a documented though still tentative recommendation that Sac Peak be chosen for the Air Force solar research site.[9] Before a final decision was made,

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7. A Comparative Survey of Sacramento Peak and White Mountain as Potential Coronagraph Sites (Special Report, 30 March 1948).

8. "Solar Studies, Sacramento Peak," p. 1; interview with Dr. Evans, 27 March 1962.

9. Donald H. Menzel and Walter Orr Roberts, A Proposal for the Establishment of a Solar Observatory Near Sacramento Peak (December 1947).

however, a strong rival appeared in the form of White Mountain, in east central California near the Nevada border. White Mountain was proposed as a possibly superior site by a number of professional astronomers and also by Navy spokesmen who were familiar with it by reason of (among other things) its proximity to the Naval Ordnance Test Station at China Lake, Calif. An inspection trip was made to White Mountain from HAO in February 1948, although there was not time for as thorough an evaluation of the site as was made in the case of Sac Peak. Data gathered on this trip, as well as from other sources, suggested that White Mountain might offer better observational conditions in some respects, but its advantages were distinctly hypothetical for lack of more comprehensive information. Certainly there was no real evidence of any over-all superiority, while the seasons of good and bad weather for viewing would be approximately the same as at Climax. Another consideration was the "desolate" White Mountain scenery, as contrasted with the many natural attractions of Sac Peak: at the very least, this would further complicate the task of recruiting and keeping a full-time scientific staff of the desired caliber.[10]

Thus HAO chose to stand by the original recommendation of Menzel and Roberts, and that recommendation won the further approval of the Research and Development Board of the Department of Defense as the result of a planning conference held in mid-April 1948 at Holloman Air Force Base. In practice this decision was final, even though technically it left the way open for reconsideration of White Mountain at a later date.[11] Then on 21 April 1948 the Air Force signed a new contract with Harvard University that was a logical extension of the September 1947 site-study contract. It called for the preparation of detailed plans for an "integrated" solar research facility which would combine observational,

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10. A Comparative Survey of Sacramento Peak and White Mountain; Roberts, Decision Regarding Suitability of Weather at Sacramento Peak.

11. Report of Progress III, 1 June 1948 (on contract W28-099 ac-364). A more detailed study of White Mountain made subsequently confirmed that it would be an excellent place for a coronagraphic station although still no better than Sac Peak -- and logistic problems would have been greater (interview with Dr. Evans, 27 March 1962).

analytical, and data-reduction activities, all on a larger scale than at any comparable observatory; design, development, and fabrication of the required optical devices; and, concurrently, theoretical studies of solar structure and characteristics. The theoretical work was to be performed by Harvard astronomers at Cambridge, Mass., while the other work was largely subcontracted to HAO. Menzel and Roberts together (Menzel as an additional duty while visiting Europe under other auspices) made a special tour of European solar research sites, in quest of ideas and techniques that might profitably be incorporated in the planned Air Force observatory. The entire contract effort, meanwhile, was monitored on behalf of the Air Force by the Geophysics Research Directorate of the Air Force Cambridge Research Laboratories, and in particular by Dr. Marcus O'Day.[12]

Preparations for the new observatory went hand in hand with -- in fact drew heavily upon the results of -- pilot studies that were conducted on the spot at Sac Peak. Occupation of the site goes back to the second half of 1947, when two observers camped there in a trailer to assess the suitability of the site itself.[13] Observations continued during 1948, but it was only in the first part of 1949 that a regular scientific program of solar research was started. At that time a Harvard/HAO team which now numbered three observers began recording of coronal and limb prominence activity using a 4¼-inch coronagraph mounted on an eight-foot equatorial spar. This was the nation's second successful Lyot-type coronagraph, having about the same aperture as the one at

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12. "Solar Studies, Sacramento Peak," pp. 1-2; Walter Orr Roberts, Report of Progress II, 1 November 1948 (on contract W19-122ac-17).
    Neither the Geophysics Research Directorate nor its parent organization had these titles at the time the contract was signed, and in fact they went through several changes of designation during the period covered by this chapter. The only practical solution is to call them consistently by their current names -- which, it is hoped, may last forever.

13. Alamogordo News, 24 June 1954.

Climax but substantially more compact in design.[14] The following year a six-inch telescope (later converted into another coronagraph) was added to the Sac Peak instrument complex. It was mounted on a ten-foot spar and was principally used for taking motion pictures of solar prominences through a birefringent filter.[15]

Meanwhile, design and engineering work continued on a new 16-inch coronagraph, which was to be the observatory's most important single item of equipment. This coronagraph, together with an identical instrument planned for Climax with Navy support, would also be the world's largest. Shops were organized at Boulder in the fall of 1950, with joint Navy and Air Force funding, to construct the optical parts, while the Westinghouse Electric Corporation contracted to build the 26-foot equatorial spars on which they were to be mounted. A great many individuals assisted the work in one way or another, including even the inventor of the coronagraph, Bernard Lyot. The latter served as a consultant in selection and testing of the glass blanks (which were made in France) for the optical components.[16]

Also during this period, a flare-patrol system was put in operation at Sac Peak. Although solar flares (or sudden localized increases in the brightness of the luminous gas) do not significantly affect the total amount of visible radiation, geophysical and other evidence indicated that flares were associated with radio noise emission at a high intensity

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14. HAFB, Progress Summary Report on U.S.A.F. Guided Missile Test Activities, 1 August 1949 and 1 February 1950; Cambridge Field Station, AMC, Historical Data...1 January 1949-30 June 1949, p. 138; Harvard University, Final Report for the Establishment of a Solar Observatory at Sacramento Peak, New Mexico (29 May 1953), p. 4. The exact designation of the Progress Summary Report sometimes varied, but for convenience it will be cited consistently by the same short title.

15. HAFB., Progress Summary Report, July-September 1950; interview with Dr. Evans, 27 March 1962.

16. Harvard University, Final Report for the Establishment of a Solar Observatory, p. 20; Sky and Telescope, August 1956, p. 437; "Solar Studies, Sacramento Peak," pp. 2-3.

level and with large production of corpuscular, x-ray, and/or ultraviolet radiation. But there was little reliable information either on the precise relationship between flares and geophysical phenomena or on the brightness, size, and position of the flares themselves. Unfortunately, visual observation of solar flares is hampered by subjective differences in classification and is inherently tedious: there is the long period of waiting, all for what Dr. John W. Evans has termed "the brief excitement of each flare discovery." As a partial solution, the Mount Wilson Observatory began operation of an automatic flare camera in 1936, taking pictures of the sun in the light of ionized calcium (K line) at intervals of three to five minutes. Another flare camera was later installed at Climax, but more were needed in order to record substantially all "detectable" flares, and Sac Peak was a logical place to put one.

As part of the Sac Peak instrumentation-development program, a breadboard model of a new flare-patrol camera was put in operation at the Boulder, Colorado, headquarters of HAO in the spring of 1950. An improved model, benefiting from the experience gained with the equipment at Boulder, was then put in continuous daily operation at Sac Peak starting in March 1951. This instrument took exposures in hydrogen-alpha light, at regular intervals whenever the sun was free of clouds. The flare camera and the six-inch telescope shared the same ten-foot spar, which was equatorially mounted and was guided on the sun photoelectrically. Thus mounted, the flare recorder pointed directly at the sun, and reflecting surfaces were unnecessary. By 1 September 1951, it had recorded 252 flares -- a "small but homogeneous sample," sufficient in itself to make some definite contributions to the understanding of flare phenomena.[17]

A related program of solar radio noise investigations began at Sac Peak, during 1950, under a contract with Cornell University. Two Cornell

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17. John W. Evans, "The Solar Flare Recorder of the Sacramento Peak Station," Science, 23 November 1951, pp. 539-544; "Solar Studies, Sacramento Peak," p.3.

engineers took up residence and began field testing in August of that year, with their test equipment located in mobile vans. These studies specifically concerned the 50- and 200-megacyle frequencies, and daily records were made starting 22 December 1950. The radio noise data were compared with simultaneous optical measurements of solar activity as observed from Sac Peak, and with data from other locations. Despite trouble with radio interference, the resulting analysis showed some significant correlations among optical measurements, radio noise levels, and ionospheric disturbances.[18]

Activities at Sac Peak further included the compilation of weather data; sky brightness measurements; daily sunspot drawings; and miscellaneous related observations. All this work represented in part a continuation of the early site-evaluation efforts, and it strengthened the belief that Sac Peak was the best possible choice for a general-purpose solar research station -- even better, in fact, than had been anticipated on the basis of the original findings.[19] At the same time, even the minor observational activities at Sac Peak had at least some intrinsic scientific value, over and above whatever usefulness they had as a guide in laying plans for the new observatory.[20]

Sac Peak likewise served intermittently as an instrumentation site in support of missile/rocket tracking on the adjacent Holloman and White Sands test ranges. And, little by little, a settled community was taking shape. Until the fall of 1948, a prefabricated garage and car trailer seem to have been the only living and working quarters -- other than tents -- available at the Peak. Then, in November 1948, work parties from Holloman began the erection of two larger prefabricated buildings,

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18. HAFB, Progress Summary Report, July-September and October-December 1950; History of Air Force Cambridge Research Laboratories, January-April 1951, p.47; History of Air Force Cambridge Research Center, July-December 1951, p.54.

19. Walter Orr Roberts, Supplement to Special Report 10 July 1948, 23 November 1948.

20. HAFB, Progress Summary Report, 1 February 1950; Historical Data, Air Force Cambridge Research Laboratories, July-December 1949, p. 49.

which were intended to serve as family housing for two of the observers stationed at the site. This work proceeded more or less concurrently with the construction of other needed buildings and facilities, including an electric generating plant; laying of water and sewer lines; maintenance and improvement of access roads; and creation of a radio communication link with Holloman (and later, for coordination of solar research activities, with Climax and Boulder). One major problem was maintaining access during the winter of 1948-1949, which brought some of the heaviest snowfalls in recent memory. Work parties were sometimes marooned en route to the Peak; transportation of materials was vastly complicated; and at one point it was necessary to air-drop heavy flying clothing to workers at Sac Peak who were in desperate need of warm apparel.[21]

The year 1950 saw the addition of a dormitory for single personnel, more semi-permanent family quarters, and various support facilities. A precision timing standard was completed and installed in the spring of 1951. And effective 6 April 1951 the Sac Peak operation was formally established as an outlying research activity of the Air Force's Geophysics Research Directorate at Cambridge. It received the official title of Upper Air Research Activity, which was possibly misleading in that the primary object of study was not the earth's atmosphere but the sun's.[22] Soon afterward an informal understanding was reached between Cambridge representatives and Holloman Air Force Base regarding the administrative and logistic support to be provided by the latter, on a continuing basis, in such matters as routine personnel administration, supply, and building maintenance.[23]

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21. Roberts, Special Report, 22 March 1948 (on contract W28-099 ac-364); HAFB, Progress Summary Report, 1 January 1949 through 1 November 1949.

22. HAFB, Progress Summary Report, October-December 1950; History of Air Force Cambridge Research Center 2 April 1951-30 June 1951, p. 60; "Solar Studies, Sacramento Peak," p.3.

23. Capt. Howard G. Bell, William F. Brooks, and Stanley E. Toye, memo to the Director, GRD, subj.: "Trip Report...Holloman AFB, 3-9 June 1951."

In December 1951, with the time for full-scale operation drawing near, a new contract was signed with Harvard University. Harvard undertook to operate the large coronagraph that was still under construction and other optical instruments at Sac Peak; conduct preliminary analysis of data at the Peak; and perform more detailed analysis and theoretical studies at the Harvard Observatory in Cambridge. In July 1952, the mechanical parts of the 26-foot-spar coronagraph were completed and erected at Sac Peak, although the optical system itself was not yet ready. By the end of August 1952 the original Sac Peak building program was substantially finished, with a total of 28 buildings accepted, not to mention cattle guards and utility lines. Sac Peak facilities now included a series of ten well-built, permanent-type family quarters set along the rim of the mountain and looking out upon a scenic panorama of breathtaking proportions. There were also excellent laboratory facilities, and a multipurpose community/administration building.[24]

On 4 September 1952, finally, Dr. John Wainwright Evans became Superintendent of the Upper Air Research Observatory, as the installation was now known. Dr. Evans was a Harvard-trained solar astronomer, previously associated with the Climax-Boulder research complex. As a staff member of HAO, he had been primarily responsible for directing the development of the large coronagraph and associated equipment, and he was therefore a logical choice for the job.[25] Operation of Sac Peak was to be managed in large part on a contract basis, with a Harvard team conducting optical studies of solar activity and Cornell University remaining in charge of the radio noise studies; support and housekeeping functions, on the other hand, plus a modest in-house research effort, were entrusted to a small Air Force military and civilian staff. Dr. Evans' role was to give a unified direction to all these activities and in fact

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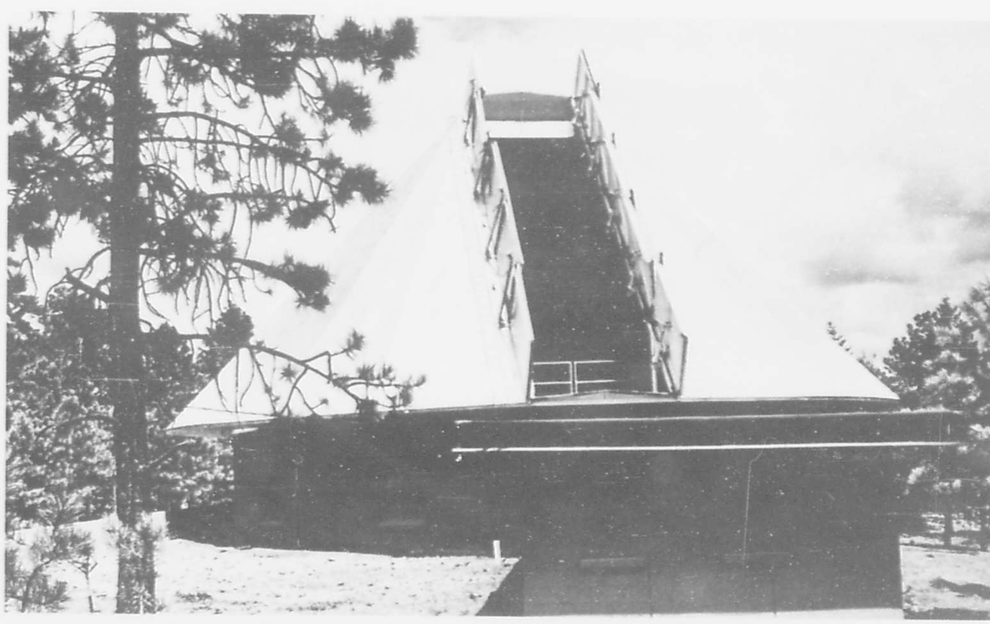
24. "Solar Studies, Sacramento Peak," p.4, and construction tables appended to same.

25. Moyer, Silver Domes, p. 154; Harvard University, Final Report for the Establishment of a Solar Observatory, p. 20.

to direct a broad Air Force program of solar research whose scope extended even beyond the model observatory in southern New Mexico.[26]

26. "Solar Studies, Sacramento Peak," p.4. The plan of operation was spelled out in a letter from Lt. Col. Frederic C. E. Oder, Director, GRD, to Donald H. Menzel, 8 May 1951.

Family Housing at SAC PEAK



Large Dome Housing The 16 inch Coronagraph
(Unusual Cloudiness in Background)

Chapter II

THE SACRAMENTO PEAK OBSERVATORY, 1952-1962: ADMINISTRATION AND RESOURCES

In September 1952, when Dr. John W. Evans was installed as superintendent, the Sacramento Peak research complex was not yet fully operational. However, it was already operational enough to rate as the Air Force's leading center of solar studies, and its organizational status was duly revised to reflect this fact. Since 1952, Sacramento Peak has gradually expanded its capabilities for research on solar phenomena and their terrestrial relationships. Although the refinement of observational equipment and allied instrumentation must be a never-ending process, the Air Force solar-research site has become without doubt one of the foremost installations of its kind in the United States and in the entire world.

Administrative Arrangements

Dr. Evans' arrival to assume direction of the Sac Peak station coincided with a change in both its official title and its place in the administrative hierarchy. Previously, Sac Peak had been a remote "activity" of the Upper Air Laboratory of the Geophysics Research Directorate (GRD) of the Air Force Cambridge Research Center--which in turn was a major component of the Air Research and Development Command (ARDC). It now became the Upper Air Research Observatory and was raised one echelon in the chain of command, to an equal plane with the Upper Air Laboratory and all the other laboratories that made up GRD.[1] Despite the distance from Sac Peak to GRD headquarters in Massachusetts, this working arrange-

1. "Solar Studies, Sacramento Peak," unsigned and undated manuscript dealing with the origins of the observatory, from the historical files of the former Air Force Cambridge Research Center (and now in the Historical Division, OAR), p. 4.

ment has continued in effect with only superficial changes ever since. The Air Force Cambridge Research Center went out of existence in the first half of 1960, but GRD did not; with its companion ERD (i.e., Electronics Research Directorate) it was set apart from other elements of the late Center to form the new (or more precisely: reconstituted) Air Force Cambridge Research Laboratories. In the general reorganization of Air Force research and development activities that took place on 1 April 1961, the Air Force Cambridge Research Laboratories ceased to belong to ARDC (or to ARDC's successor, the Air Force Systems Command); instead they were made a part of the Office of Aerospace Research, which itself received the status of a major command.[2] But all through these organizational changes business went on much as usual at Sac Peak. Daily operations were affected even less by the change in title from Upper Air Research Observatory to Sacramento Peak Observatory, which took effect on 1 May 1956.[3]

Although the vertical chain of command leads from Sac Peak to Cambridge and thence to Washington, D. C., the observatory also maintains a special relationship with the nearby Air Force Missile Development Center (AFMDC)[4] at Holloman Air Force Base, New Mexico. Holloman people, facilities, and equipment played an indispensable role in the construction of the solar research station; and in the spring of 1951, as mentioned in the previous chapter, an informal agreement was made for Holloman to provide Sac Peak with certain routine support on a continuing basis. Subsequently the Air Force Cambridge Research Center proposed

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2. Office of Information, OAR, <u>OAR Fact Sheet</u> (September 1961), pp. 3-4.

3. <u>History of the Air Force Cambridge Research Center 1 July - 31 December 1956</u>, p. 8. This series will hereafter be cited as <u>Hist AFCRC</u>.

4. Although the Air Force Missile Development Center was officially known until 1 September 1957 as Holloman Air Development Center, the current designation will be used throughout this discussion.

to locate a support detachment of its own at Sac Peak, which would have restricted the scope of assistance required from Holloman. However, this proposal was vetoed by Headquarters ARDC, in July 1952, on the ground that most support services could be obtained more efficiently and economically from the neighboring installation.[5] ARDC directed and the Cambridge Center and AFMDC agreed that the latter would take responsibility for vehicle and building maintenance; provide machine shop services "beyond the capacity of the [Sac Peak] model shop;" operate a mess at Sac Peak as a branch of the Holloman consolidated mess; process routine personnel actions and local purchases; and so forth. A small block of manpower spaces was made available to AFMDC expressly for support of Sac Peak. To carry out its responsibilities, AFMDC stationed a limited number of personnel permanently at the observatory, as well as performing other services for Sac Peak at Holloman and occasionally sending up special work parties for such purposes as cleaning out brush on a new fire lane.[6]

On the whole, these Cambridge-Holloman arrangements worked out successfully, but no one ever claimed that they offered an ideal solution. AFMDC has sometimes found the requirement to support Sac Peak slightly burdensome; and in 1958, for example, it proposed that many of the services it had been providing should henceforth be obtained commercially, by means of a service contract. This proposal was rejected at Headquarters ARDC for lack of funds,[7] but it was at least as attractive to Sac Peak as

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5. Ltr., Lt. Col. Peter J. Schenk, Deputy for Plans, AFCRC, to CG, ARDC, subj.: "Upper Air Research Observatory," 16 April 1952, with 1st ind. by Col. Ernest R. Manierre, Asst. Deputy for Operations, Hq. ARDC, to CO, AFCRC, 17 July 1952.

6. Ltr., Col. Manierre to CG, AFCRC, subj.: "Responsibilities for the Operation and Support of the Upper Air Research Observatory," 6 November 1952; identical ltr. to CO, HADC, with 1st ind. by Col. A. D. McEwen, DCS/M, HADC, to CG, ARDC, 5 December 1952; Hq.HADC, Staff Meeting Notes, 16 June 1953.

7. Ltr., Brig. Gen. Lee W. Fulton, Asst. Dep. Cmdr./Resources, ARDC, to Cmdr., AFMDC, subj.: "Study of Sacramento Peak Observatory Support Problems," 7 July 1958.

to AFMDC, and it was included as part of the "optimum program" for the observatory that Dr. Evans himself presented in June 1961.[8]

Meanwhile, in 1959, AFMDC had also suggested a much more radical change in its relationship with Sac Peak -- offering, in effect, to swallow the entire solar-research installation. On 3 April of that year (at the express invitation of Maj. Gen. Leighton I. Davis, ARDC's Deputy Commander for Research) AFMDC made a formal presentation to Headquarters ARDC for the "consolidation of solar energy research." This was to be accomplished by bringing together all Air Force research efforts related to solar energy under a new Directorate of Solar Energy Research, which would be established at Holloman as part of AFMDC. It was proposed that the Directorate should supervise an intensified Air Force research program in the field of solar energy conversion; build and operate the large solar furnace that was tentatively slated for construction as a Department of Defense facility outside Cloudcroft, New Mexico, in the Sacramento Mountains (but which in the end was never actually built); and, finally, assume full jurisdiction over the Sacramento Peak Observatory.

The one Air Force organization most closely affected by this proposal was the Air Force Cambridge Research Center, or more precisely GRD, which not only controlled the Sacramento Peak Observatory but also had charge of a major part of the existing Air Force research program on solar energy conversion. Understandably, GRD did not like the proposal. Indeed, less than two weeks after the AFMDC presentation GRD had already submitted a formal rebuttal. GRD held that the proposed consolidation would be in name only, since there was no "technical" relationship between the Sacramento Peak Observatory, the planned solar furnace, and the Air Force solar energy conversion studies currently underway at Cambridge or elsewhere. On the other hand, GRD noted that there was an intimate relationship between solar studies and atmospheric studies and

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8. John W. Evans, "Special Study, An Optimum Program for the Sacramento Peak Observatory" (13 June 1961), p. 8.

thus between the work at Sac Peak and the work of such other GRD elements as the Ionospheric Physics Laboratory -- not to mention the "less specific and less tangible benefits" derived by Sac Peak from its association with "the community of scientists at GRD." GRD likewise emphasized the close ties between solar energy conversion research and other Cambridge activities, while flatly disclaiming any requirement for use of the solar furnace facility. Undoubtedly GRD overstated its case in some respects; but neither had AFMDC managed to present a sufficiently conclusive case for disturbing what was, at least so far as Sac Peak w concerned, a generally satisfactory state of affairs. Thus in the end General Davis turned down the AFMDC consolidation proposal, in a letter of 25 May 1959 to the Commander of AFMDC. Nor has it been revived since that time.[9]

Money, Manpower, Facilities

Although Sacramento Peak Observatory is the largest research facility in the country that is exclusively devoted to solar studies, it naturally represents a rather small portion of the total Air Force research establishment. The annual level of expenditures since 1952 has been in the neighborhood of one to one and one-half million dollars, including construction work, AFMDC support costs, and all the research efforts performed under contract on behalf of the Sac Peak mission.[10] As for the value of Sac Peak's buildings, equipment, and so forth, it would be excessively complicated to work out a realistic figure of either original

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9. AFMDC, A Proposal for Consolidation of Solar Energy Research (n.d.); ltr., Mr. Alan M. Gerlach, Chief, Programs Division, GRD, to Mr. Raymond A. DeGraff, Scientific Advisor (to Dep. Cmdr./Research, ARDC), 14 April 1959, with attachment "Critique of AFMDC Proposal for Consolidation of Solar Energy Research;" Col. Frank J. Seiler, Asst. Dep. Cmdr./Research, memo to various addressees, subj.: "Proposal for Consolidation of Solar Energy Research," 19 May 1959; ltr., Maj. Gen. Leighton I. Davis, Dep. Cmdr./Research, to Cmdr., AFMDC, same subj., 25 May 1959.

10. Management Report (ARDC Form 111), Project 7649, 21 December 1960; interview with Dr. John W. Evans, Director, SPO, 27 March 1962.

or replacement cost because so many items have been completely built by and for the observatory itself or at least substantially modified after being acquired. A typical rough estimate, as of May 1957, was $5,000,000;[11] but new facilities and equipment of one sort or another have been added every year since then and are still being added.

Manpower totals at Sac Peak have fluctuated rather little. At such an isolated station, the availability of housing places a strict upper limit on the expansion of personnel strength at any given time, and the highly specialized nature of the work -- plus the small number of Air Force manpower spaces involved -- affords some protection against curtailment during the Air Force's periodic manpower crises. The overall trend has been one of very gradual expansion, reaching a total of 70 people assigned, for example, as of early 1962. This figure could be broken down into 10 military, 28 civil service, and 32 contractor personnel, which of course emphasizes Sac Peak's essentially civilian character. The combined military and civil service totals could be broken down again into a 13-man mission element belonging to GRD and a 25-man support element (including most of the military strength) provided by AFMDC. The contractor personnel stationed at Sac Peak are also a mission element, engaged in operating observational equipment, data reduction and analysis, and related activities. They were originally provided by Harvard University, except for a small staff from Cornell engaged in radio noise studies; but Cornell has since dropped out of the picture, while both the High Altitude Observatory and Geo-Science, Inc., now have personnel at Sac Peak in addition to the Harvard group. Last but not least, the Sacramento Peak Observatory has initiated a policy of playing host to visiting astronomers, usually from Europe, who come on temporary appointments for six months or longer. These visiting scholars are free to carry on research in their own special fields of interest, and they have made important contributions not only

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11. Alamogordo Daily News, 5 May 1957.

to solar astronomy but also to the intellectual climate of Sac Peak.[12]

The Sac Peak community further includes the wives and children of resident Air Force and contractor personnel. Some wives double as staff members, but even so the total population of Sac Peak -- which as a Post Office address is appropriately designated Sunspot, New Mexico -- is roughly twice the size of the observatory staff per se.[13] Yet the mere number of people living and working at Sac Peak is no doubt less important than their scientific and technical qualifications. And in this respect it is worth noting that the observatory director, Dr. Evans, is recognized in his own right as one of the nation's leading solar astronomers; this is clearly reflected in his presence on an array of scientific boards, panels, and committees that is always quite numerous and reached a total of 11 during the recent International Geophysical Year. His associates are also a select group, as indicated, for example, by the number of Sac Peak residents who hold the Ph.D. degree. There were nine of these as of March 1962, of whom seven were regular staff members, one was a European visitor on temporary appointment (Dr. E. Jensen from Norway) and one was another astronomer's astronomer wife who was just then working (in practice) on a part-time basis without pay.[14] In a community of slightly over 100 persons, this was a somewhat remarkable proportion, and at any given time there are still other competent astronomers at Sac Peak who have not yet obtained their final academic degrees. Indeed, to a certain extent Sac Peak serves as a graduate and postdoctoral training center in solar astronomy. It is particularly well suited for this role by virtue of the close association with Harvard University that has prevailed ever since the planning and construction of the observatory.

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12. USAF Project Justification Data (AF Form 161), Sacramento Peak Observatory Research Site, Family Housing Appropriated, 1 May 1962 (actually about March 1962; form postdated); interview with Dr. Evans, 27 March 1962.

13. Cf. John W. Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, p. 437, and ARDC Newsreview, August 1958.

14. Alamogordo Daily News, 5 May 1957; GRD, Annual Report, Twelfth Year (August 1959), pp. 112-117; interview with Dr. Evans, 27 March 1962.

To attract and hold a capable scientific staff -- whether its members are working for a contractor or directly for the Air Force -- Sac Peak can offer some truly outstanding mountain and forest scenery. Dr. Evans has been quoted as boasting that he possesses "the most beautiful office in the whole United States government."[15] Scenic attractions help to make up for the admitted isolation of the site, which is about an hour's drive (substantially more in the early days) from the nearest large community, Alamogordo, and roughly three hours distant from the closest metropolitan area, which consists of the twin border cities of El Paso, Texas, and Ciudad Juárez, Mexico. Sac Peak has even become something of a tourist attraction in its own right for residents of the surrounding areas, who each summer drive up to tour its facilities and admire its natural setting. At one time tourist activity was mainly limited to an annual outing sponsored by the Alamogordo Chamber of Commerce. Subsequently, Sac Peak began holding open house each Sunday afternoon during the months from May through October.[16]

Sac Peak also has excellent television reception, thanks to its high elevation. No less than five channels are available for viewing[17] -- a greater number than at either Alamogordo or El Paso. However, it takes more than scenery and television to create a livable scientific community on an isolated mountain top. A whole complex of facilities is also needed; and in this respect Sac Peak has by and large fared quite well. It was once described (in 1953) as the brightest spot in all of GRD, as far as facilities were concerned.[18] To be sure, facilities have not always been adequate in all respects. Family housing, to take one example, must be provided at Sac Peak both for military personnel and for civilians (including contractors) because of the

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15. ARDC Newsreview, August 1958.

16. Cf. Alamogordo News, 10 June 1954, and Alamogordo Daily News, 11 June 1959.

17. Alamogordo Daily News, 5 May 1957.

18. Hist AFCRC, January-June 1953, p. 68.

isolation of the site and the difficulty of regular commuting from any nearby town. And since 1952 this housing has included both well-built permanent quarters (originally sufficient for ten families) and quonsets and other prefabricated units officially listed as "substandard" but in practice never replaced. Moreover, once the observatory became fully operational there was simply not enough housing to meet the demand, which meant that what was billed as "the most complete and powerful solar observatory in existence" had to function at less than its full potential for lack of staff members. Specifically, only nine scientists could be accommodated as against the full team of fifteen (plus technicians, secretaries, firemen, et al.) for which the observatory had been designed.[19] However, money for the construction of six additional permanent-type units was finally released in the spring of 1957, and the units were completed in 1958.[20] This alleviated but did not wholly solve Sac Peak's housing problems.

Still other facilities and miscellaneous conveniences have been added from time to time. With respect to communications, to take a further example, the original radio link with the outside world was supplemented early in 1953 by a radio-telephone system,[21] and later on conventional telephone service was extended to Sac Peak. The Peak's isolation was diminished in still another way during 1955, with the construction of a helicopter landing strip. This fulfilled a requirement for helicopter service to Sac Peak which GRD had underscored as far back as May 1951 and provided much faster access to the installation from Holloman Air Force Base both as a matter of convenience and as a safety measure in case of snowstorms that might block road travel (or other possible

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19. GRD, Pre-Briefing Book (for the meeting of the Geophysical Research Panel, Scientific Advisory Board, 27-28 June 1955), p. C-6.

20. Alamogordo Daily News, 15 April 1957; interview with Dr. Evans, 27 March 1962.

21. Holloman Air Development Center, Daily Bulletin, 20 February 1953.

emergencies).[22] And in 1960, at long last, the road to Sac Peak was hard-surfaced all the way, resulting in an appreciable reduction both in travel time and in the danger of occasional interruption of road travel.[23]

The Instrument Complex

From the standpoint of the observatory mission, however, the main thing at Sac Peak is the complex of observing instruments and related equipment. Many of these instruments were already in operation by the end of 1952, but others have been installed since then, and all have undergone intermittent modification and improvement. The largest are either clustered upon or associated with the main coronagraph spar, a "rectangular box" which is 26 feet long, weighs 9¼ tons, is photo-electrically guided on the sun, and is so delicately mounted that one of the motors in its driving mechanism is rated at 2½ mousepower (with one mousepower equal 1/10,000 horsepower). The spar itself was installed in July 1952, but at that time the work of grinding and polishing the optical parts of the coronagraph system was still proceeding slowly and painstakingly at the High Altitude Observatory in Boulder, Colorado. In September 1953 the coronagraph's 16-inch objective lens was put in place, and a few weeks later the instrument was in operation -- with the help of a certain amount of temporary equipment. The first photographs of the sun's chromosphere were taken with the new system (in the light of hydrogen alpha) on 14 November. That was not a particularly good day for observations, but according to Dr. Evans the resulting pictures were still better than any he had seen before, excluding those taken during natural eclipses.[24]

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22. Ltr., Capt. Howard G. Ball, Chief, Research Service Office, GRD, to CO, HAFB, subj.: "Aircraft Assignment," 18 May 1951; Hq.HADC, Staff Meeting Notes, 20 January 1955; Hq.6580th Air Base Group, HAFB, Staff Meeting Notes, 29 April 1955.

23. Interview with Mr. Tito Martinez, Real Property Branch, Deputy for Civil Engineering, AFMDC, 28 March 1962.

24. Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, pp. 437-438; AF Supplementary Progress Report Card (ARDC Form

Over the following months -- and years -- the large coronagraph and its associated equipment were repeatedly modified, rearranged, and added to, until by the latter part of 1955 a fairly complete system was in regular use. The operation of the coronagraph system has been described in the following terms:

> ...The single-lens objective of about 25 feet focal length images the sun on an occulting disk of variable diameter at the lower end of the spar. This disk is supported on a two-foot stem extending from the center of the field lens behind it, so there are no shadows from supporting members. Following the field lens is a pair of 6-inch prisms, which reflect light back inside the spar up to a flat quartz mirror, at the intersection of the polar and declination axes.
>
> This mirror sends the light down the hollow polar axle through a secondary lens system into the observing laboratory....The 16-inch coronagraph can be used both for limb objects and the solar disk itself. For the latter work, the field lens carrying the occulting disk is replaced by an unobstructed field lens.
>
> In the observing laboratory, the image from the 16-inch coronagraph can be adjusted to any desired diameter by choosing an appropriate final lens for the secondary optical system, and the light can be directed into any one of a number of accessory instruments....[25]

Among the accessory instruments used with the coronagraph, one of the most important is the large Littrow spectrograph installed in mid-1955. This high-accuracy research tool has a focal length of 13 meters, a slit four inches long, and a variety of gratings that offer dispersions from 0.3 to 15 millimeters per angstrom.[26] Another accessory instrument, added in 1959, is a

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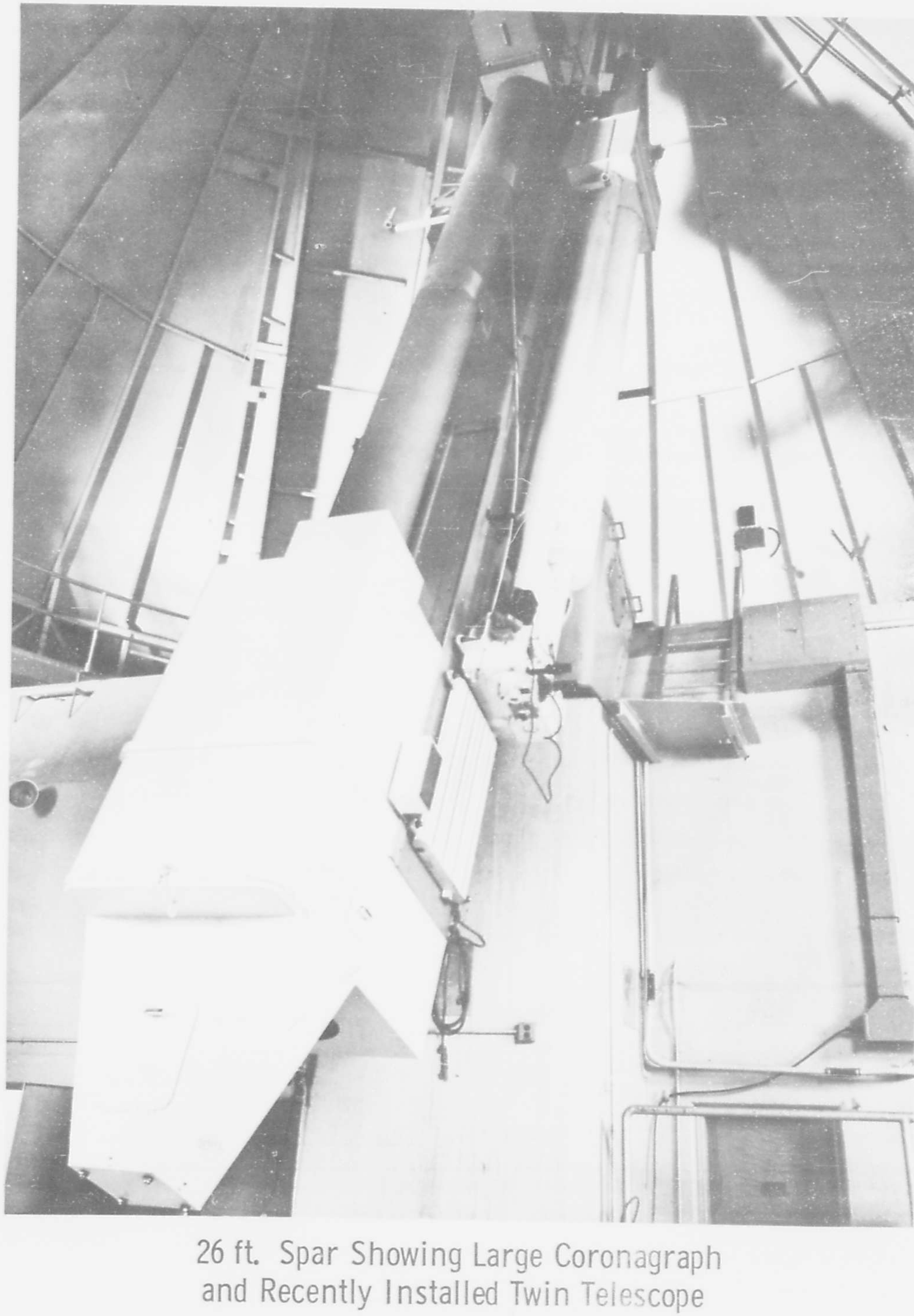
82), Atmospheric Radiation, 11 April 1953; Hist AFCRC, July-December 1953, p. 121; GRD Spectrum, 4 December 1953.

25. Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, pp. 438-439.

26. Ibid., p. 439: Harvard University, Final Report under ARDC Contract AF19(604)-146 for the Operation of a Solar Observatory at Sacramento Peak, New Mexico (22 December 1958), p. 8.



26 ft. Spar Showing Large Coronagraph
and Recently Installed Twin Telescope

> ...spectroheliograph (SHG) built around a specially designed optical system.... The transmission band is adjustable to any desired wavelength and any band width from 3 A to 0.1 A. The purpose of this instrument is to photograph the sun in the light of a single line of the spectrum.... The new SHG is unconventional in that it is a zero dispersion double monochromator, quite free of scattered light, giving a much sharper image with broad band widths than any previous spectroheliograph. Its speed is low, but its virtues far outweigh this disadvantage.[27]

This does not, of course, exhaust the list of accessory instruments, of which others, such as the universal spectrograph, will be mentioned later in connection with specific research efforts.

Sharing the main spar with the 16-inch coronagraph is a 15-inch chromosphere telescope which was put in operation in July 1955. It is tubeless, has its own occulting disk and birefringent filter, and is used for taking "large-scale motion pictures of the chromosphere and prominences.[28] Still later, in 1960, the observatory staff assembled a fixed horizontal telescope which features a two-mirror coelostat and a 12-inch objective lens. The coelostat telescope differs from the other large observing instruments (with the exception of the new 16-inch telescope mentioned below) in that it is designed primarily for studies of the solar disk rather than of phenomena at the limb. Even though it is not mounted on the 26-foot spar, light can be fed from it to any of the accessory instruments normally used with the large coronagraph; indeed, the coronagraph and coelostat telescope can be used simultaneously with any two of the accessories.[29]

Another noteworthy event in the development of the Sac Peak instrument complex was the completion, in December 1961, of a new "twin" telescope consisting of a 9-inch coronagraph and 16-inch telescope. The new coronagraph is intended especially for use in photoelectric observations of coronal brightness, while the 16-inch telescope is for studies of

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27. GRD, Annual Report 1960 (AFCRL 637), p. 181.

28. Hist AFCRC, July-December 1955, p. 58; Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, pp. 437-438.

29. GRD, Annual Report 1960, p. 181.

magnetic fields and velocities in solar active centers. Apart from fulfilling these objectives, the new coronagraph and telescope will relieve some of the pressure on other instruments at Sac Peak which are at present considerably overloaded. They have been mounted together on the 26-foot spar, but their use will be limited until their associated accessory instruments (e.g., photometer, spectrograph, magnetic/velocity recorder) are also completed and installed.[30]

In addition to the large observational instruments at Sac Peak, there are a number of smaller instruments which also require mention. Size is not, of course, the only distinguishing characteristic, since the larger instruments are mainly used in special-project research, while the smaller ones have as their primary mission to support the patrol program of routine daily observations.

The original patrol instrument was a 4¼-inch coronagraph mounted on an eight-foot equatorial spar, which was installed in 1949 and remained in service "essentially unchanged" until mid-1957. Its primary function was the daily recording of coronal spectrum intensities, in association with a six-inch spectrograph. In 1957 this patrol coronagraph and the associated spectrograph were replaced by completely new instruments especially designed and built at Sac Peak. These instruments brought an appreciable increase in both quantity and quality of routine coronal spectra, while at the same time they greatly facilitated spectral surveys of "bright, transient limb phenomena."[31]

The new patrol spectrocoronagraph was mounted on Sac Peak's ten-foot equatorial spar, which closely resembles the main 26-foot spar and now carries the entire group of patrol instruments. Two of these instruments -- a six-inch coronagraph and a 2½-inch flare-patrol camera -- date from 1950, when the ten-foot spar itself was installed. The

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30. SPO, "AFCRL Status Report, Sacramento Peak Observatory" (draft manuscript, March 1962, for inclusion in 1962 AFCRL annual report), p. 15; John W. Evans, "Memorandum on High Energy Proton Showers in Space and their Avoidance" (April 1961), p. 6; interview with Dr. Evans, 27 March 1962.

31. Harvard University, <u>Final Report</u>, p. 7; "The Sacramento Peak Observatory," <u>Sky and Telescope</u>, August 1956, p. 440.

six-inch coronagraph was originally an ordinary telescope but has been greatly modified and improved and is an instrument of exceptional quality. It is used for patrolling the east and west edges of the solar disk and for taking motion pictures (in a choice of spectral lines) of either solar prominences or the corona. The flare-patrol camera serves to take hydrogen-alpha pictures of the entire sun at regular intervals (originally every five minutes but now every two) during clear daylight hours and thus to record automatically any except the very briefest of solar flares. Finally, this same ten-foot spar carries a six-inch telescope which was obtained about 1952 and is used for making daily records of sunspots and faculae.[32]

Like the larger instruments, all of the present patrol instruments have, of course, undergone repeated modification and improvement since they began operation. Some of them will be transferred, with minor alterations, to a new patrol mounting of about double the present capacity that was recently installed in a small dome situated at the highest point of the observatory site. However, this new patrol arrangement, which is also to include certain entirely new observing equipment, probably will not be completed until late in 1963.[33]

The Sac Peak patrol program also seeks to monitor variations in solar radio activity. The main radio observing equipment is at present located at an off-site contractor installation near Fort Davis, Texas, and will be described in the following chapter. However, both radio data from Fort Davis and optical patrol observations from Sac Peak are reported daily to a central clearing point at Boulder, Colorado, for use by other solar scientists and government agencies. The data go first to the Boulder offices of the High Altitude Observatory (HAO), where they are combined with similar data from the HAO Climax station; they go then to the Boulder Laboratories of the National Bureau of Standards,

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32. Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, pp. 439-440; SPO, "AFCRL Status Report," pp. 2-3; interview with Dr. Evans, 27 March 1962.

33. SPO, "AFCRL Status Report," p. 17.

for use in forecasting of radio conditions.[34] By one means or another, the data are further

> ...distributed to all interested agencies, and are published in various forms in the weekly and quarterly bulletins of solar activity at the High Altitude Observatory, the monthly F-series of the National Bureau of Standards, daily charts of solar activity of the Fraunhofer Institute, and the Quarterly Bulletin of the International Astronomical Union.[35]

As already indicated, more will be said later about scientific equipment in connection with specific research accomplishments. However, it is also necessary to observe here that the sheer quantity of data collected at Sac Peak poses a severe problem of data reduction, principally involving the conversion of photographic observations into numerical form. Hand methods of reduction are sufficient at best to "sparsely sample" the data involved. For example, six man-months of effort were devoted to hand reduction of eight spectrograms, each of two seconds' exposure, taken of a single major flare on 18 September 1956; and even then a large part of the useable information in these films simply was not touched.[36]

Hence the observatory staff -- especially Dr. Edwin W. Dennison -- have devoted a significant portion of their time and effort to the task of improving and where possible automating data-reduction techniques. In this effort they have adapted commercially-available equipment to their special needs, designed and built new data-reduction equipment in the observatory shops, and had special equipment made to order by instrument contractors. They have also worked to make the output of Sac Peak data-processing devices compatible with the nearby digital-computer complex of AFMDC. Yet the mass of data to be processed grows so steadily that almost as fast as one bottleneck has been overcome still another has appeared.[37]

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34. Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, p. 440.

35. R & D Project Card, Project 7649, 1 March 1960, p. 12.

36. Harvard University, Final Report, p. 10.

37. GRD, Annual Report, Eleventh Year (April 1958), p. 93, and Annual Report, Twelfth Year, pp. 76-77.

An innovation which promises to by-pass at least some of the tedious work of photographic data reduction as well as to provide other important advantages is the greater use of electronic techniques in observational activity. About 1958 Sac Peak launched a major effort to develop electronic image tubes of high quantum efficiency for astronomical use, although the interest of the observatory staff in the possible use of such devices goes back several years earlier. The effort has culminated in the development of a field photometer under the direction of Dr. Dennison and with rather extensive contractual participation by the Eberline Instrument Company of Santa Fe, New Mexico.[38] Without any doubt, this work represents a significant achievement:

> Contrary to the usual impression, the solar physicist is hampered by not enough light, or to be more pertinent, not enough signal from his observing equipment. The classical astronomical response to this situation is to gather more light (with a bigger telescope). However, the recent development of several types of photoelectric image tubes with a sensitivity from 10 to 100 times that of the fastest photographic plates offers a very much neater avenue for advance, namely, to utilize the light delivered by the telescope more efficiently. The requirement at Sacramento Peak Observatory is somewhat beyond the usual need to secure a presentable picture of the object under study. Quantitative data on the light distribution over a field are required. Toward this objective, Dennison has developed a black box which accepts a signal from an orthicon-type image tube and produces either a picture or an isophote chart of the image projected on the tube.... In its present state, the system is between 50 and 100 times as sensitive as the fastest photographic plates, and operated at this speed it has comparable photometric accuracy. In spite of an inconveniently small field, the gain in speed is revolutionary.[39]

This equipment has been undergoing final adjustment, checkout, and calibration for some time and is still capable of considerable improvement. But it is expected to go into regular operational use in the summer of 1962.

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38. GRD, Annual Report, Eleventh Year, pp. 93-94, Annual Report, Twelfth Year, pp. 76-77, and Annual Report 1960, p. 181.

39. SPO, "AFCRL Status Report," p. 18.

Chapter III

OBJECTIVES AND ACCOMPLISHMENTS IN SOLAR RESEARCH

The work performed at Sacramento Peak is above all else observational, seeking to collect the largest possible amount of accurate and detailed data on solar activity. However, the observational function forms part of a broader effort of solar research which is officially documented as Air Force Project 7649, Solar Terrestrial Effects. This research effort seeks not merely to gather solar data for their own sake but also to determine correlations between solar and terrestrial events; to interpret the basic solar data and solar-terrestrial correlations in terms of solar physical processes; and, as the long-range objective, to devise "methods for predicting sun-induced geo-astrophysical disturbances on the basis of knowledge of the physical processes involved." An intermediate objective is to make empirical predictions on the basis of statistical correlations established between solar and geophysical events, until such time as the more scientific approach based on fundamental understanding of solar processes becomes generally applicable.[1]

The director of Project 7649 is Dr. John W. Evans, who also heads the Sacramento Peak Observatory (SPO). But the work itself is not limited to that performed either by Air Force scientists or by contractor personnel at the Sac Peak site. Other observational work, in support of the project mission, is performed under contract at different locations; at the present time this includes the entire effort in radio observation of solar activity, although in the past such studies have been conducted at Sac Peak as well. A large part of the analytical and theoretical work under Project 7649 is also performed by off-site contractors. And, of

1. R & D Project Card (DD Form 613), Project 7649, 1 March 1960, p. 2.

course, the entire project effort is coordinated as closely as possible with non-Air Force solar research as well as with those Air Force research efforts that do not fall within the project framework yet are directly concerned with solar phenomena of one sort or another.

Project 7649 with its present title and a comparable (though not identical) format dates back to 1954; its objectives and approach have not changed fundamentally since that time, despite certain shifts in emphasis and despite a large increase in the scale of accomplishment made possible by the expansion of research capabilities both at Sac Peak and elsewhere. However, the same project in somewhat embryonic form was officially approved as far back as October 1949.[2] In fact, it is in

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2. See the document cited in the preceding footnote and all other versions of the DD Form 613 for Project 7649, including the draft of the latest revision dated 1 January 1962.
   The original task subdivisions of Project 7649 were:
   - Task 76490, Observation and Interpretation of Optical Phenomena
   - Task 76491, Observation and Study of Solar Energy
   - Task 76492, Audio and Radio Frequency Solar Noise
   - Task 76493, Eclipse Observation of the Sun

   In 1956 a Task 76494, Terrestrial Responses to Solar Activity was added to the project structure; and in 1962 the task structure was reorganized as follows:
   - Task 764901, Solar Phenomena (formerly Task 76490)
   - Task 764902, Space and Earth Responses to Solar Emissions (formerly Task 76494)
   - Task 764903, Solar Energy (formerly Task 76491)
   - Task 764904, Solar Noise (formerly Task 76492)
   - Task 764905, Solar Eclipses (formerly Task 76493)

   Although these task subdivisions are used in official documentation of the project effort, no attempt will be made to follow them strictly in this chapter in the discussion of research activities.
   It should be noted as a matter of record that proposals have occasionally been made to establish a second project as a vehicle for Air Force documentation and funding of certain portions of the Sac Peak mission; but this has never actually been done. During fiscal year 1962, two research contracts under Project 7649 were transferred to Project 8635, Research on Physical Processes, which is a project assigned to another unit of the Geophysics Research Directorate of Air Force Cambridge Research Laboratories. However, this was a move designed to meet some short-run funding difficulties; it left Sac Peak personnel in charge of monitoring the contracts in question, and it was not destined to be permanent. (Management Report [ARDC Form 111],

considerable part an outgrowth of the exploratory studies of key problems in solar research and ways of attacking them that such Harvard astronomers as Donald H. Menzel carried out during the period 1947-1952, under the terms of the same Air Force contracts that provided for design and development of the Sacramento Peak Observatory. From the specific types of data sought by observation to the over-all "philosophy" of solar-terrestrial research, there is little in the subsequent history of Sacramento Peak Observatory and related off-site efforts that is not spelled out or at least clearly foreshadowed in the Harvard exploratory studies.[3]

The Impact on Solar Studies

That much-overworked term "coordination" is a poor way of expressing the special relationship which has developed between Sacramento Peak Observatory and three other leading centers of solar astrophysical research: the Harvard College Observatory, the High Altitude Observatory (HAO), and the Boulder Laboratories of the National Bureau of Standards. These four organizations have established their own informal steering committee[4] and in fact constitute a team, three of whose members have derived partial support from contracts awarded by the fourth -- i.e., by Sac Peak. However, the non-Air Force members of this team do more work that bears directly upon the Sac Peak mission than what is expressly supported by Sac Peak contracts. Thus it is often slightly arbitrary -- at least from the standpoint of solar astrophysics -- to make distinctions between the work that is supported in one way and related work that

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Project 8635, 30 June 1961; interview with Major Joseph X. Brennan, Chief, Geophysics Division, Directorate of Research Programs, DCS/ Plans and Programs, Hq. OAR, 12 April 1962)

3. See, for example, Donald H. Menzel and Barbara Bell, Scientific Report No. 1, Survey of Problems for Solar Observatories, 20 June 1952 (prepared under contract AF 19(604)-146). Of course, neither this study nor any other could accurately foresee the present importance of solar flare predictions for space experimentation.

4. R & D Project Card, Project 7649, 1 March 1960, p. 11.

is supported in another. Suffice it to say that all four team members are engaged in a well-rounded, nonduplicating program of solar observations, analysis, and theoretical study.

As defined by Dr. Evans, this combined effort amounts to a "second-generation revision of the theories of solar physics and the structure of the solar atmosphere," resulting in "a number of quite fundamental changes in our picture of the sun, some of which are now generally accepted as established fact, and some of which are still the subjects of considerable controversy, to be settled by further observational evidence." But the development of scientific understanding in a field such as this cannot be adequately described in terms of sudden breakthroughs or discoveries. To quote again from Dr. Evans, "The development has been gradual, and does not usually consist of isolated notable events so much as a slow evolution of ideas constantly checked and stimulated by observational data already in the archives at [Sac Peak], or special observations taken for the purpose."[5]

One facet of the "slow evolution" mentioned by Dr. Evans has been a steadily increasing emphasis upon magnetic activity for the explanation of solar phenomena. The matter was well expressed in the Geophysics Research Directorate Annual Report 1960:

> The magnetic fields of solar active centers around sunspot groups are strong enough to dominate completely all other forces and sources of energy in controlling the active phenomena of the centers. It is almost inevitable, therefore, that the flares, active region prominences, coronal "hot spots," radio bursts, and x-ray and corpuscular emissions must result from magnetic activity. The magnetic field should be the unifying underlying force which powers all of the more visible activities. Thus, a study of the field and its changes during the development of an active center is presumably a most fundamental approach to an understanding of solar activity.[6]

Another recurrent theme, which appears with almost monotonous regularity, is growing recognition of the extreme complexity of solar structure and

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5. GRD, Monthly Bulletin, May 1960, p. 7.

6. GRD, Annual Report 1960 (AFCRL 637), p. 178.

behavior. Thus the joint attack by Sac Peak scientists and their team associates on the problems of solar astrophysics has among other things completed the work of undermining the "classical approach, which assumed at the outset that the solar atmosphere is everywhere in local thermodynamic equilibrium and homogeneous except for height gradients."[7] However, the achievements of the Sac Peak program can be appreciated better by examining contributions made in specific research areas. A nonexhaustive (and partly random) sampling is presented in the remainder of this chapter and in the following chapter.

Research on the Photosphere

The solar photosphere -- conventionally defined as the region which constitutes the visible surface of the sun and in which the "normal" absorption lines and continuous background of the solar spectrum originate -- is an important research topic at Sac Peak even though the observatory is better known for its unique chromospheric and coronal research capabilities. One noteworthy accomplishment in this connection, due in considerable measure to the efforts of Dr. John Waddell of Geo-Science, Inc., was to devise a system capable of defining the profiles of the absorption lines with an accuracy exceeding that of more conventional techniques by a factor of four or five. The system made use of the observatory's 16-inch coronagraph, a high-resolution spectrophotometer, and the 13-meter spectrograph, with the latter serving as a "double pass" instrument (i.e., the light going through the grating two times). A dark absorption line, surrounded by a continuum ten or fifteen times as bright, is inherently hard to measure; but the "double pass" technique largely eliminated scattered light from neighboring parts of the spectrum and thus made possible the unusual accuracy.[8]

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7. GRD, GRD Annual Report, Eleventh Year: A Technical Memorandum to the Director, GRD (April 1958), p. 86.

8. GRD, Annual Report 1960, p. 175; GRD, Monthly Bulletin, May 1960, p. 7, and July 1960, p. 8. Dr. Waddell, who worked as a contractor scientist at Sac Peak, attributes the design of the "double pass" system to Dr. Evans, who in turn gives the main credit to Waddell. Cf. Waddell, Solar Research at Sacramento Peak Observatory (AFCRL 247, January 1961), p. 4.

These and other observations of the photosphere, analyzed both at Sac Peak and by off-site contractor scientists, have amply demonstrated the inaccuracy of the older assumption that the photosphere was "approximately in thermodynamic equilibrium." Moreover, the data now available have been found to require "a very substantial revision of the accepted table of atomic abundances in the sun" -- and thus too, presumably, in the universe at large.[9]

One of the most interesting studies carried out at Sac Peak during 1961 had to do with vertical and horizontal motions in the line-forming ("reversing") layer as indicated by Doppler line shifts. The results showed that the horizontal motions were characterized not by regular oscillations but rather by "a tendency for long-enduring large velocities, on which are superposed smaller random velocities," whereas the vertical motions revealed definite oscillation periods. The latter gave "clear evidence of a resonance effect." The findings from this investigation, which was conducted by Dr. Evans together with the visiting French astronomer, R. Michard, came frankly as something of a surprise; and the study has since been extended to the hydrogen-alpha line that originates much higher in the solar atmosphere.[10]

Perhaps the most publicized single achievement to date by a Sac Peak contractor consisted of a series of photospheric observations. This was an instance of special-project research, directed by Dr. Martin Schwarzschild of Princeton University Observatory, and involved a pioneering attempt to photograph the solar surface from an unmanned balloon floating above 90% of the earth's atmosphere. The objective was "to obtain the sharpest possible image of small detail, by getting above the atmospheric turbulence responsible for bad seeing." The project was chiefly supported by the Office of Naval Research (ONR), but both the National Science Foundation and the Sacramento Peak Observatory acted

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9. GRD, Monthly Bulletin, May 1960, p. 7.

10. SPO, "AFCRL Status Report, Sacramento Peak Observatory" (draft manuscript, March 1962, for inclusion in 1962 AFCRL annual report), pp. 8-10.

as co-sponsors. The latter gave partial financial assistance through a transfer of funds to ONR; in addition, Dr. Evans helped design the optical system of the balloon-borne telescope.[11]

Two separate flights were made, in the fall of 1957, yielding about 2000 feet of exposed film. As noted by Schwarzschild himself,

> All told, about 10 frames have the superior resolution for which we had hoped. These 10 frames exceeded the minimum goal of the entire undertaking....[12]

Schwarzschild brought the films to Sac Peak for analysis with the help of the observatory's computing microphotometer and contour densitometer. The analysis was a time-consuming process, but it supplied important new information concerning the granulation pattern of the solar surface. Three main characteristics stood out on the basis of these observations: the wide variation in size of the surface granules; the fact that most of them had "complicated shapes of irregular polygons;" and, rather surprisingly, the presence of an over-all pattern of nonstationary convection among the surface granules. All this forced a revision of several previously accepted ideas in solar astronomy.[13] Moreover, for their contribution to the success of the experiments, Schwarzschild, Evans, and Dr. John B. Rogerson, Jr., of the Princeton Observatory jointly shared the 30th Newcomb Cleveland Prize awarded by the American Association for the Advancement of Science in December 1957.[14] (Sac Peak is not, however, a participant in Project Stratoscope II, which is the present continuation of Schwarzschild's balloon-astronomy program.)

Chromospheric Research and Eclipse Expeditions

Other significant studies in the Sac Peak program have concerned the nature of the solar chromosphere, the transparent layer 10,000 to 20,000 kilometers thick that rests upon the photosphere. These studies had as

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11. GRD, Annual Report, Eleventh Year, pp. 90-91; interview with Dr. Evans, 27 March 1962.

12. Martin and Barbara Schwarzschild, "Balloon Astronomy," Scientific American, May 1959, p. 57.

13. GRD Annual Report, Eleventh Year, p. 91; Schwarzschild, "Balloon Astronomy," Scientific American, May 1959, pp. 57-58.

14. Science, 17 January 1958, p. 139.

their point of departure the careful analysis of eclipse observations obtained by a team under the leadership of Dr. Evans in February 1952 (before he became Director of Sacramento Peak Observatory).[15] The analysis was conducted over the following months and years both at Sac Peak and by scientists working under contract at the Harvard College Observatory and at HAO; and it

> ...showed that, contrary to the prevailing belief, the chromosphere is a region of positive temperature gradient, considerably hotter than the underlying photosphere. Since all other chromospheric characteristics depend upon the temperature gradient, this finding was fundamentally important.[16]

The 1952 eclipse data were not adequate to establish the exact dependence of temperature on height, but they did provide the basis for a series of theoretical models of the chromosphere. And they have, naturally, been greatly extended and checked by subsequent and continuing observations of the chromosphere and its spectrum which have been made at Sac Peak principally with the 15-inch chromosphere telescope and 16-inch coronagraph. In the course of these observations, astronomers at Sac Peak have scored some quite notable achievements: for example, the first motion picture records anywhere showing fine details of spicule structure in the chromosphere, which were taken by Dr. Richard B. Dunn of the observatory's small civil service research staff.[17]

Nevertheless, there are certain types of chromospheric data -- in particular, spectroscopic variation with height -- that can be obtained in the required detail only under eclipse conditions. Hence one distinct subdivision of Sac Peak's Project 7649 is Task 764905 (formerly 76493),

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15. GRD, Monthly Bulletin, May 1960, p. 8.

16. GRD, Annual Report 1960, p. 175.

17. GRD, Program Notes: Meeting of the Geophysical Research Panel of the Scientific Advisory Board, 15 and 16 June 1956, p. A-28; GRD, list of "major accomplishments" submitted to Historical Office of the Air Force Research Division (now OAR), May 1960; Harvard University, Final Report under ARDC Contract AF19(604)-146 for the Operation of a Solar Observatory at Sacramento Peak, New Mexico (AFCRC TR-58-288, 22 December 1958), passim.

Solar Eclipses, which is concerned with making observations of the chromosphere (and to a lesser extent the corona) at times of total solar eclipse. This effort has been consistently supported by HAO under a series of special contracts.[18]

As far back as 1955 the Sac Peak and HAO staffs began preparations for the total eclipse of 12 October 1958, which they hoped to study not only for the immediate purposes of Project 7649 but also as a United States contribution to the International Geophysical Year. A joint crew headed by Dr. Evans set forth to the South Pacific atoll of Pukapuka (located on the path of totality) to view the eclipse, arriving far enough in advance to make sure that all was in readiness for the exciting four-minute interval of darkness. The United States Navy provided "magnificent logistical support," while back in New Mexico the usual Sunday afternoon public tour of Sac Peak was cancelled for 12 October so that personnel who stayed behind could make observations of their own for correlation with the data expected from Pukapuka. Unfortunately, the effort came to nought, so far as ground-based optical observations were concerned, since the sky at Pukapuka was completely overcast at the time of the eclipse. (Research rocket firings and radio investigations at the time of the eclipse were naturally a different story.)[19]

There was some consolation in the fact that another favorable opportunity was due almost exactly one year later. Once again, a joint Sac Peak-HAO expedition set forth, this time to the Canary Islands under the leadership of Dr. Dunn. But again cloudy weather on the day of the eclipse -- 2 October 1959 -- interfered with the observations. During totality "the clouds did thin for a precious few seconds, giving...a faint view of the corona and some bright prominences;" but the chromosphere itself was not observed even for an instant.[20] This time there

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18. R & D Project Card, Project 7649, 1 March 1960, pp. 8-9.

19. GRD, GRD Annual Report, Twelfth Year: A Technical Memorandum to the Director, GRD (August 1959), pp. 76, 78; Alamogordo Daily News, 10 and 13 October 1958; Walter Sullivan, Assault on the Unknown (New York: McGraw-Hill, 1961), pp. 182-188, 427.

20. R & D Project Card, Project 7649, 1 March 1960, p. 9; R. Grant Athay, "The Solar Chromosphere," Scientific American, February 1962, p. 50, from which the quoted phrases are taken.

was a longer wait until the next try on 5 February 1962. Even then, in view of the low probability of good weather at the proposed observation site -- Lae on the northeast coast of New Guinea -- and the failure of project personnel to give sufficient advance notice of their desire to go, it was not certain until almost the last minute that higher headquarters would approve the investment of Air Force funds in an expedition. But a Sac Peak-HAO crew did go, headed by Dr. Dunn, and for a change the weather proved favorable. Thus the expedition was extremely successful, although no discussion of detailed results will be possible until much time-consuming effort has been spent on data reduction and analysis.[21]

Meanwhile, thanks partly to the failure of the 1958 and 1959 expeditions, Sac Peak and contractor scientists have continued to rely to a significant extent upon the 1952 eclipse data for analysis of chromospheric conditions. But those data have been supplemented, as mentioned, by a large fund of critical observations made at Sac Peak. The result, notes Dr. Evans,

> ... has been a decisive overturn of the previous model of the chromosphere, which now turns out to be a region of increasing temperature (with height) composed of an intricate "fur" of tiny spikes known as spicules, surrounded by a hotter homogeneous atmosphere. In fact we now consider the chromosphere as the transition zone between the low temperature at the top of the photosphere (4400° K) and the high temperature of the higher corona (2,000,000°K)....[A] revision of the whole picture of this layer...is now going forward at SPO and in the rest of the group [i.e., Harvard, HAO, and National Bureau of Standards] to construct a new model of the chromosphere and determine the process by which energy traverses the relatively low temperature region to heat the overlying corona.[22]

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21. Ltr., Mr. Stanley E. Toye, Chief, Management Requirements Division, GRD, to Director of Administrative Services, Hq. OAR, subj.: "Request for Project Clearance (P-7649, Solar Terrestrial Effects)," 11 September 1961, and 1st ind. to same by Col. Kenneth W. Gallup, Chief of Staff, OAR, 10 October 1961; SPO, "AFCRL Status Report," pp. 10-11; Washington Daily News, 5 February 1962; interview with Major Brennan, 26 April 1962.

22. GRD, Monthly Bulletin, May 1960, p. 8.

Prominence Studies

Solar prominences -- great atmospheric protuberances with the appearance of enormous flames -- are in most respects another chromospheric phenomenon,[23] but they still constitute an important topic of study in their own right. Prominence observations have been conducted at Sac Peak both as part of the daily patrol program and in connection with more specialized research. One tool obtained expressly for prominence studies happens to bear the longest name of any Sac Peak accessory; the motion stereospectroheliokinematograph, which was developed under contract by DePauw University and was first installed in July 1958 on the six-inch coronagraph. The device was intended to help in the mapping of motions of prominence material in three dimensions, but it still requires more working over before it can become truly operational.[24] However, other instruments at Sac Peak have contributed a large supply of prominence data; and the analysis of such data has demonstrated, not surprisingly, that the former assumption of homogeneity throughout large volumes of a prominence "is grossly in error, leading to calculated characteristics that have little to do with the actual physical state of a prominence...."[25]

Research at Sac Peak has likewise helped to establish 10,000 to 22,000°K as the approximate temperature range for prominences, as against the 100,000°K or more previously deduced in some instances from measurements of spectroscopic line broadening. It has now been made clear that such measurements are not a reliable index of prominence temperatures. This very fruitful investigation was carried out by Dr. Frank Q. Orrall of Sac Peak, who obtained some exceptionally fine ultraviolet and infrared spectra of prominences at the limb of the sun, in collaboration with

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23. So, too, are solar flares -- which will be dealt with in a separate chapter.

24. Management Report, Project 7649, 31 July 1958; GRD Annual Report, Eleventh Year, p. 92; Harvard University, Final Report, p. 7; interview with Dr. Evans, 27 March 1962.

25. GRD, GRD's Tenth Year, An Annual Report (1 May 1957), p. 88.

Dr. J. T. Jefferies, who began this work at Sac Peak and continued it after transferring to the Boulder Laboratories of the National Bureau of Standards.[26]

Studies of the Corona

One aspect of the daily patrol program at Sac Peak, going back to the start of observational activity, is the recording of the distribution of coronal brightness in several different emission lines. These observations are made by means of a specialized spectrocoronagraph and form an important part of the growing accumulation of optical data on solar activity. For example, they figured largely in the intricate studies of correlations between geomagnetism and the intensity of coronal lines performed under contract for Sac Peak by astronomers of the Harvard College Observatory. These studies suggested, among other things, that there is a definite correlation between the "long-mysterious M-regions, the hypothetical solar source of recurrent geomagnetic storms," and "a characteristic weakness" of the green (5303) coronal-emission line.[27]

Then too, starting in October 1955, Sac Peak has produced direct time-lapse motion pictures of the corona -- something that has been termed "an observational feat of the first magnitude." The difficulty of this achievement can be inferred from the fact that the corona is only one-hundredth to one-thousandth as bright as the solar prominences. The only previous non-eclipse coronal photographs (as distinct from coronal spectrum observations) had been taken by Bernard Lyot in France, and they were not of the same quality as those obtained at Sac Peak. These coronal photographs are taken with a special system built around the observatory's six-inch coronagraph and a birefringent filter by Dr. Richard B. Dunn. The filter transmits a band of light which is centered on the

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26. F. Q. Orrall and J. T. Jefferies, "On the Interpretation of Prominence Spectra. V. The Emission Lines in Quiescent Prominences," Astrophysical Journal, January 1962, pp. 109-121 (and previous articles cited therein); GRD, Annual Report 1960, p. 173; SPO, "AFCRL Status Report," p. 7.

27. Harvard University, Final Report, pp. 7, 11, 20, 27, 30.

green coronal-emission line. In conjunction with other instrumentation at Sac Peak, the complete system has been used for making simultaneous motion pictures of the corona and prominences and spectra of both at varying heights from the solar surface; and in such cases the analysis of a single day's observations has been known to take several months.[28]

Whereas Lyot's coronal photographs had not revealed any "marked motion or dynamic activity,"[29] those taken at Sac Peak since 1955 suggest a very different interpretation of the corona:

> The results of these unique movies were a complete surprise. The corona turns out to be a region of explosive activity instead of the static halo it had been supposed to be. One aspect of this activity is the sudden development of small regions of very high temperature, between 4 and 6 million degrees [coronal "hot spots"], which are in all probability the source of charged particles that shower the earth and induce geomagnetic disturbances. On the whole, the coronal activity shown on the SPO films is so complex and varied that only a bare beginning in its classification and interpretation has been possible. . . .[30]

Radio Observation of Solar Activity

The original plans for Sacramento Peak Observatory specifically called for radio as well as optical observations of solar activity;[31] and the first chapter of this study has already mentioned that radio noise investigations were started at Sac Peak, by a contractor team from Cornell University, as far back as 1950. Ultimately this Cornell program was using four small radio telescopes, covering a frequency range from 55 to 3200 megacycles, to study solar radio emission from

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28. History of the Air Force Cambridge Research Center (hereafter cited as Hist AFCRC), July-December 1955, p. 59; GRD, Program Notes...15 and 16 June 1956, p. A-28.

29. Harvard University, Final Report, p. 6.

30. GRD, Monthly Bulletin, May 1960, p. 8.

31. Cf. Donald H. Menzel and Walter O. Roberts, Proposal for the Establishment of a Solar Observatory Near Sacramento Peak (December 1947), p. 55.

the chromosphere to the outer corona. The program provided useful observational data, even though Dr. Evans himself felt that the Cornell staff put too much emphasis on the instrumental aspects as against solar research per se. Also, the program continued to be hampered by radio interference -- both from nearby test activities on what is now the interservice White Sands Missile Range and from Sac Peak's own electrical system.[32]

The Cornell research effort expired in 1954. But radio studies still had a place in the over-all Sac Peak research program, as indicated by the inclusion of a Task 764904 (formerly Task 76492), Solar Noise, in the formal structure of Project 7649. The task objective is "to determine the radio frequency energy distribution of solar active regions; to identify the sources of radio radiation with optically observable features of activity;and to discover and explain any correlation with geophysical effects."[33]

Before any large-scale efforts could be undertaken, with high-sensitivity equipment, it was necessary to select the most suitable site for radio investigations. In August 1955, therefore, a special study was launched to determine the amount and strength of radio interference around Sac Peak as well as in the vicinity of the Lowell Observatory, Flagstaff, Arizona, and the McDonald Observatory, near Fort Davis in western Texas.[34]

The results of this investigation showed conclusively that the Sac Peak area was not suitable for solar radio astronomy, largely because of the missile-range activities, which had increased substantially since 1950. The Fort Davis area, however, appeared highly satisfactory. Ac-

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32. Hist AFCRC, January-July 1953, p. 85; AF Supplementary Progress Report Card (ARDC Form 82), Atmospheric Radiation, 11 April 1953; Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, p. 440; interview with Dr. Evans, 27 March 1962. See also above, pp. 9-10.

33. R & D Project Card, Project 7649, 1 March 1960, p. 8.

34. Hist AFCRC, July-December 1955, p. 59.

cordingly, the Air Force awarded a contract to Harvard University for the installation and operation near Fort Davis of a radio spectrometer (or dynamic spectrum analyzer). The exact spot chosen was a radio-quiet bowl in the Davis Mountains, where 1500-foot mountain walls screened out man-made radio interference. A 28-foot paraboloid antenna was erected, which followed the sun across the sky each day from sunrise to sunset and fed three sensitive receivers. The receivers were jointly capable of scanning the frequency range from 100 to 580 megacycles.[35] Preliminary operations began on 22 August 1956, regular operations about six weeks later; and two years after that a pair of "home-made fixed antennae" was added so that the Fort Davis installation could also record the band from 25 to 100 megacycles. (For lack of a steerable antenna, the latter range could be studied only for three or four hours daily around noon.) Early in 1960 still other equipment extended the available coverage to the 2100-3900 megacycle range. In February 1962, finally, the Fort Davis radio observatory completed the installation of a new 85-foot antenna which offers even greater sensitivity -- sufficient to follow radio activity through the approaching sunspot minimum.[36]

The director of the radio observatory from the beginning has been Dr. Alan Maxwell, who supervised the design and construction of the original equipment and who formerly was associated with the Jodrell Bank radio telescope in Great Britain. At the start of 1962 the Fort Davis site had a total staff of about a half dozen.[37] It has remained under contractual operation, as a radio-astronomy field station of the Harvard

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35. GRD's Tenth Year, p. 30; A. Maxwell, G. Swarup, and A. R. Thompson, "The Radio Spectrum of Solar Activity," Proceedings of the IRE, January 1958, pp. 142-148.

36. Harvard University, The Development and Operation of a Dynamic Spectrum Analyzer (AFCRL 625, April 1961), pp. 2, 4; R & D Project Card, Project 7649, 1 March 1960, pp. 7, 8; Evans, "Special Study, An Optimum Program for the Sacramento Peak Observatory," p. 4; interview with Dr. Evans, 27 March 1962.

37. Sky and Telescope, September 1955, p. 460; interview with Dr. Evans, 27 March 1962.

College Observatory. However the Fort Davis contract has been monitored from Sac Peak, as part of the research effort of Project 7649.[38] Originally a direct radio-communication link existed between the two installations, not only for routine daily reporting of data from Fort Davis but also to give scientists at Sac Peak immediate notification of the onset of electromagnetic disturbances of the type that precedes a solar flare.[39] This link has since been replaced by ordinary telephone service, but the same close coordination continues.

The Fort Davis program has been principally concerned with the observation over a large section of the radio band of "non-thermal transient disturbances, sometimes of great intensity, which originate in localized active areas," and with the interpretation of these emissions "in terms of dynamic processes occurring in the solar atmosphere."[40] Fort Davis data have of course served as a basis for correlations between solar radio-spectrum activity and various indices of optical activity as observed mainly from Sac Peak. Moreover, they played an important part in the identification of two major varieties of solar radio-noise phenomena: U-bursts, whose existence was revealed by observations at the Fort Davis site in late 1956, and Type IV bursts whose special characteristics were first recognized by the Fort Davis staff. The Type IV bursts accompany some large solar flares and are the only known indicators of high-speed protons which reach the earth about one and one-half hours later; apparently, they constitute radiation emitted by the protons as they leave the sun.[41]

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38. To be sure, the Fort Davis contract was one of the two transferred briefly to Project 8635 during fiscal year 1962 - but even then it continued to be monitored from Sac Peak. See above, p. 33, note 2.

39. Hist AFCRC, July-December 1955, p. 59; GRD Annual Report, Eleventh Year, p. 87.

40. Harvard University, Development and Operation of a Dynamic Spectrum Analyzer, pp. 2-3.

41. Ibid., pp. 7, 16; GRD Annual Report, Eleventh Year, p. 87; Maxwell, Swarup and Thompson, "The Radio Spectrum of Solar Activity," Proceedings of the IRE, January 1958, p. 147; A. Maxwell and G. Swarup, "A

Regular radio observations of solar activity at Sac Peak have not been resumed since the activation of the Fort Davis site. During the International Geophysical Year, the observatory did install and operate equipment to measure fluctuations in cosmic and tropical-thunderstorm radio noise due to sun-induced changes in the ionosphere, but this was not the same as direct observation of solar radio emissions.[42] However, since 1955 Sac Peak has also given contractual support to one other program in solar radio astronomy, conducted by the Institute for Theoretical Astrophysics of Oslo, Norway, which continuously monitors a portion of the solar radio spectrum as part of an international patrol network.[43]

Other Research Studies

The research program of Project 7649 includes a great many other significant studies, some broadly theoretical and some quite specific. The Harvard College Observatory has conducted studies under contract for Sac Peak on magnetohydrodynamic theory, on ionospheric problems -- and on theories of the origin of the solar system.[44] Studies such as these naturally make use of data provided by other research activities of Project 7649, while at the same time they also help to guide future research. HAO, the Boulder Laboratories of the National Bureau of Standards, Geo-Science, Inc., and still other domestic contractors have likewise performed theoretical and other work for Sac Peak in addition to the specific contributions mentioned elsewhere in this history. Then, too, three European institutions -- the Institute for Theoretical Astrophysics

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New Spectral Characteristic in Solar Radio Emission," Nature, 4 January 1958, pp. 36-38; ltr., Dr. Evans to Lt. Col. James A. Fava, Chief, Geophysics Division, Directorate of Sciences, Hq. OAR, subj.: "Sacramento Peak Observatory Requirements in FY 62," 18 April 1961.

42. GRD Annual Report, Eleventh Year, p. 93; GRD Annual Report, Twelfth Year, p. 78.

43. Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, p. 440; interview with Dr. Evans, 27 March 1962.

44. Harvard University, Final Report, pp. 12-13, 19, 27, and passim, and Development and Operation of a Dynamic Spectrum Analyzer, pp. 11-13.

in Norway, as already mentioned; France's Centre National de la Récherche Scientifique; and the Arcetri Observatory near Florence, Italy--have received support, in most cases at a rather modest level, for observational activity, interpretative studies, and other work related to the Sac Peak mission.[45]

A research activity that requires more special mention is a study of variations in solar energy conducted under contract by the Lowell Observatory. In this investigation, which began in 1953, the brightness of the planets Uranus and Neptune was

> ...carefully compared with the fixed stars photoelectrically, in order to detect changes in solar luminosity freed from the uncertainties of atmospheric absorption (since both source and photometric standards are outside the atmosphere). The reductions clearly indicate an increase of 2.5 ± 0.3% in solar brightness in the blue end of the spectrum in phase with the rise of the sunspot cycle.[46]

This result was reported in 1959 and caused surprise in that it contradicted previous findings made both at the Lowell Observatory and elsewhere. Nevertheless, the observations appeared to command some degree of confidence.[47] They have been continued and expanded, as the main activity of Project 7649's Task 764903 (formerly 76491), Solar Energy. Indeed, as a further check on the reported results, the Lowell Observatory has now constructed equipment to accomplish the far more difficult job of comparing the sun with fixed stars during daytime.[48]

Despite its primary concern with ground-based optical observations, the Sacramento Peak Observatory has been keenly aware of the importance

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45. It should be noted that the Institute for Theoretical Astrophysics has done more for Sac Peak than simply to operate a radio patrol (cf. Management Report, Project 7649, 20 October 1959). A complete listing of research performed under contract for Sac Peak can be found in the various Project Cards (DD Form 613s) for Project 7649.

46. GRD Annual Report, Twelfth Year, p. 77.

47. Ibid. Cf. Donald H. Menzel, Our Sun (Cambridge: Harvard University Press, 1959), p. 81.

48. R & D Project Card, Project 7649, 1 March 1960, p. 8; RDT & E Project Card, Project 7649, 1 January 1962 (draft), p. 20; Management Reports, Project 7649, 12 November 1959 and 1 November 1960.

of rocket and satellite observations, particularly for data on the far ultraviolet and x-ray regions of the solar spectrum. Rocket experiments for the study of solar radiation have been conducted by Dr. Herbert Friedman and other scientists of the Naval Research Laboratory (which has made the greatest single contribution to this type of experimentation) as well as by other units of the Geophysics Research Directorate (GRD) to which Sac Peak belongs. Dr. Hans Hinteregger of GRD's Photochemistry Laboratory is the leading Air Force experimenter in this special field.[49] Rocket experiments have not been conducted by the Sacramento Peak Observatory itself, but Sac Peak has supported some work on instrumentation for rocket research through contracts awarded both to HAO and to the Institute of Optics of the University of Rochester. The observatory's present contract with the Centre National de la Récherche Scientifique is also related to rocket research on problems of solar radiation.[50]

With the advent of the first artificial satellites, Sac Peak gave special consideration to the possible use of satellite vehicles to gather solar research data, and its contract program further provided some support for the design of equipment (at the University of Rochester) for this purpose.[51] However, a proposal by the observatory to conduct its own solar satellite program was turned down at higher headquarters in the spring of 1960. The decision specifically left open the possibility that Sac Peak might contribute experiments to solar-research satellites to be launched by the National Aeronautics and Space Administration; but the observatory has no immediate plans to do so.[52]

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49. Cf. "The Ultraviolet Light Brigade," Saturday Review 6 January 1952, p. 79.

50. Management Reports, Project 7649, 17 June 1958 and 17 November 1959; RDT & E Project Card, Project 7649, 1 January 1962 (draft), p. 7.

51. GRD Annual Report, Eleventh Year, p. 95; GRD Annual Report, Twelfth Year, p. 77.

52. Lt. Col. James A. Fava, Director of Operations, DCS/Plans and Operations, Hq. OAR, memo to record, subj.: "Equipment at Sac Peak," 12 May 1960; interview with Dr. Evans, 27 March 1962. The National

What is currently the most active of all research areas in the Sac Peak program still remains to be considered. This is the broad topic of solar flares, including their geophysical effects and the art -- not yet really a science -- of their prediction. If only because the topic has become unusually timely, it deserves treatment in a chapter by itself. First, however, it is well to note here that Sac Peak has played host from time to time to various research and test activities lying outside the scope of Project 7649 and of the observatory's own research program. The intermittent use of Sac Peak as an instrumentation site for tests conducted on the nearby missile-firing ranges has already been pointed out in a previous chapter. But Sac Peak has also served as a regular observation site for a number of miscellaneous research programs in the geophysics area. For example, for several years starting in the mid-1950s the Photochemistry Laboratory of GRD maintained an optical meteor-observing station at Sac Peak, operated by a Harvard crew under Air Force contract. This meteor station worked in conjunction with a similar station at Mayhill, New Mexico, 22 miles distant, and it cooperated further with a meteor radar station operated at Sac Peak by a Stanford University team. In addition to its original assignment, the Harvard meteor station at Sac Peak performed important service in the field of satellite tracking in the weeks immediately following the launching of the first Soviet satellites.[53] (Dr. Edwin W. Dennison and other members of the regular Sac Peak staff also did some work in satellite tracking at that time, by use of radio techniques.[54])

Aeronautics and Space Administration launched its first Orbiting Solar Observatory in March 1962 (New York Times, 8 March 1962). The Naval Research Laboratory has also launched several smaller satellites especially for the study of solar radiation.

53. Evans, "The Sacramento Peak Observatory," Sky and Telescope, August 1956, p. 441; Alamogordo Daily News, 4 November 1957; interview with Dr. Evans, 29 March 1962.

54. GRD Annual Report, Eleventh Year, p. 91.

Similarly, GRD has supported a night-sky airglow observing station at Sac Peak since 1955. This activity is currently operated under contract by Geo-Science, Inc.[55] And still other examples could be given. All of them, whether in some way complementary to the observatory mission or quite unrelated to it, add to the role of Sacramento Peak as a scientific observation site.

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55. E. R. Manring and H. B. Pettit, "A Study of the Airglow Emissions at 5577, 5890, and 6300 A with a Photometer of High Spectral Purity," in M. Zelikoff, ed., The Threshold of Space (New York and London: Pergamon Press, 1957), pp. 58-64; interview with Dr. Evans, 29 March 1962.

Chapter IV

FLARE PATROL AND FLARE PREDICTION

Solar flares have not yet supplanted sunspots as the best-known variety of solar disturbance, but for the past year or so they have been rapidly catching up. Many persons who would be hard put to explain what a flare is, even in the most general terms, have at least the vague impression that flare effects are somehow troublesome from the standpoint of man's conquest of space. That impression is perfectly correct. Fortunately, however, solar astronomers were interested in flares even before they became a featured topic in the missiles-and-space trade journals. Indeed, flares were one of the main topics of investigation in the original research program of Sacramento Peak Observatory, at a time when knowledge of solar phenomena was recognized as having direct practical importance chiefly for the understanding of effects upon terrestrial weather and radio propagation.

The primary source of daily flare data at Sac Peak is a patrol camera mounted on the ten-foot spar, which photographs the sun in the red light of hydrogen (hydrogen alpha) at brief fixed intervals.[1] Basically, this is the same equipment that began regular operation in March 1951. It and a comparable flare-patrol camera used at Climax by the High Altitude Observatory serve as back-up to one another: if on a given day there is bad weather at one location, there is a good chance that the sky will be clear at the other observatory. However, both Climax and Sac Peak are located on about the same longitude. In order to extend daily coverage to flare events occurring after sundown in the continental United States -- and at the same time fill a last remaining gap in an international network of flare-patrol stations -- the Air Force estab-

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1. Above, pp. 28-29.

lished another flare-patrol station during 1956 in the Hawaiian Islands. The latter is operated by the University of Hawaii under contract with the Sacramento Peak Observatory.[2] Yet Sac Peak itself has consistently provided the fullest coverage. During one 12-month period that was by no means the best on record as far as weather is concerned -- fiscal year 1958 -- there were 216 days (59%) when the Sac Peak flare-patrol camera was able to make observations during more than half the daylight hours; at the other extreme, on only 49 days (13%) were no observations made at all because of cloudy weather, equipment maintenance, or other reasons.[3]

By and large, the number of days per year when atmospheric conditions are favorable for flare-patrol operations has not varied greatly. On the other hand, the quality of coverage obtainable with the equipment has improved substantially since the present flare-patrol camera began to operate in the spring of 1951. Originally it used

> ...a 1A birefringent filter constructed of ammonium dihydrogen phosphate crystals. This filter produced inferior images of the solar disk, and its operation was erratic. Marked improvement resulted when, in June 1955, a ½A quartz-calcite filter was substituted. The new filter greatly increased the sensitivity of the flare patrol, permitting for the first time a continuing patrol of "sub-flares," a frequent and geophysically important phenomenon differing from classical chromospheric eruptions only in magnitude.[4]

The filter was changed again in January 1958, when a ½A Halle filter was substituted;[5] but this change and all later modifications of the equipment gave relatively modest improvement in performance, as compared with that achieved in mid-1955.

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2. GRD, GRD Annual Report, Eleventh Year: A Technical Memorandum to the Director, GRD (April 1958), p. 92; interview with Dr. John W. Evans, Director, SPO, 27 March 1962.

3. Harvard University, Final Report under ARDC Contract AF19(604)-146 for the Operation of a Solar Observatory at Sacramento Peak, New Mexico (AFCRC TR-58-288, 22 December 1958), p. 4.

4. Ibid.

5. Ibid.

The basic flare-patrol camera has not been used exclusively for taking brief exposures at set intervals; nor are the regular flare-patrol films helpful only for compiling daily flare data. By the same token, important information on flares -- and on solar phenomena commonly associated with flares -- is obtained from other patrol-type instruments at Sac Peak and from such special-research equipment as the 16-inch coronagraph. In a broad sense, in fact, the Sac Peak flare patrol might be said to consist of the entire complex of optical and radio observing equipment operated either at the Peak itself or by off-site contractors. The end product is a continuous record of flares and related phenomena that for quality as well as for sheer quantity is unequalled at least within the Free World. In addition to the routine daily coverage, this record includes pictorial coverage of some of the most interesting solar events of recent times -- such as the giant flare-prominence of 10 February 1956 which exploded at its most active stage and shot forth fragments at 1200 kilometers a second, as against a previous maximum observed for solar objects of about 715 kilometers a second.[6] Another notable event was the flare that occurred on 10 May 1959, attaining a length of 100,000 miles and width of 50,000 miles according to what seemed a conservative estimate; this was probably the largest single flare observed from Sac Peak up to that point.[7]

Flare studies at Sac Peak have further included certain special investigations which in themselves constituted noteworthy advances in solar research. For example, astronomers had long felt the inadequacy of available spectroscopic data on flares but were unable to do better because flares change continually and rapidly, while most spectrographs could record only a small portion of the visible spectrum in each exposure. This problem was attacked by Drs. Henry and Elske Smith, a

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6. GRD, Program Notes: Meeting of the Geophysical Research Panel of the Scientific Advisory Board, 15 and 16 June 1956, p. A-28.

7. Alamogordo Daily News, 13 and 31 May 1959.

husband-wife team assigned to the Harvard contractor staff at Sac Peak, who set out to obtain a series of complete spectra throughout a flare's brief existence. They used the 16-inch coronagraph and a universal spectrograph (designed and constructed at Sac Peak) that covered the entire region from 3900 to 6800 angstroms on each exposure with a dispersion of 2.5 millimeters per angstrom. They observed several flares, with indifferent results.[8] Then, as described in a later report:

> After months of waiting for the coincidence of good weather, a good flare, and availability of telescope time, they obtained a fine series on the large flare of 18 September 1957. The observations are unique in that the whole visible spectrum is shown, with sufficient dispersion for line profile studies, for all stages of flare development including the crucial pre-maximum phase.[9]

Another special investigation, directed by Dr. Evans, provided the first known detailed observations of magnetic field strength over the entire area of an active center on the solar disk before, during, and after a sizeable flare. These observations were accomplished on 30 April 1958 with the 16-inch coronagraph and 13-meter Littrow spectrograph. They indicated that the flare was associated with a dramatic drop in magnetic energy in the surrounding area and that, if this one example proved typical, solar flares actually represent "very minor by-products of a far more energetic magnetic cataclysm."[10] In this experiment the process of photographic data reduction required an "unreasonable" amount of effort, but Evans and his associates subsequently worked to devise -- and so far have partially implemented -- more effi-

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8. Harvard University, Final Report, pp. 8-9; GRD Annual Report, Eleventh Year, p. 89; John T. Jefferies, Elske v. P. Smith, and Henry J. Smith, "The Flare of September 18, 1957," Astrophysical Journal, January 1959, pp. 146-163. The universal spectrograph did not equal the observatory's large Littrow spectrograph in accuracy; but for the purpose at hand this was offset by its other advantages.

9. GRD Annual Report, Eleventh Year, p. 89.

10. GRD, GRD Annual Report, Twelfth Year: A Technical Memorandum to the Director, GRD (August 1959), p. 75.

cient techniques both for "mapping" the magnetic fields of solar active centers and for reduction of the data obtained.[11]

Sac Peak's Project 7649, Solar Terrestrial Effects (which as indicated before comprises the entire research program of the observatory), has also supported one series of balloon-borne flare-research experiments, conducted in the latter part of 1957. The experiments were designed to look for certain gamma rays that would be expected if nuclear reactions occur in connection with solar flares. Five balloons were launched, carrying special detection equipment developed under contract by the Armour Research Foundation. However, the investigation entailed some rather difficult requirements as to balloon performance, and four out of five flights were unsuccessful because of balloon problems. In the one other case, while the balloon performed successfully, the scientific results were negative but inconclusive.[12]

Fortunately, the outcome of these balloon experiments is not entirely typical. As already mentioned, the Sac Peak research program has produced a vast amount of information on solar flares; and that information has been very widely used. Almost from the beginning, Sac Peak reported routine flare data along with other patrol-type observations on a daily basis to the High Altitude Observatory and to the National Bureau of Standards, for use by other interested scientists. And in 1957 it began routine reporting of the occurrence of large solar flares to the North American Radio Warning Service at Engleside, Virginia.[13] Sac Peak's flare-reporting activities were in fact expanded considerably as a contribution to the International Geophysical Year (IGY), which despite its title lasted 18 months from 1 July 1957 to

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11. GRD Annual Report, Eleventh Year, p. 89; GRD, Annual Report 1960 (AFCRL 637), p. 178. On the new 16-inch telescope for observations of the magnetic fields of active centers, see above, pp. 27-28, and below, p. 63.

12. GRD Annual Report, Eleventh Year, p. 92; Management Report (ARDC Form 111), Project 7649, 6 November 1957; interview with Dr. Evans, 27 March 1962.

13. Harvard University, Final Report, p. 4; interview with Dr. Evans, 27 March 1962; above, pp. 29-30.

31 December 1958. Sac Peak was one of 44 stations around the world that made a concerted effort to monitor solar flares throughout the duration of the IGY, and the 1/2A Halle filter was supplied to the observatory by the U. S. National Committee for the International Geophysical Year, so that it could better fulfill its role in the IGY program. What is more, Sac Peak's basic flare-patrol system was formally recommended as a model to other IGY participants by the International Astronomical Union.

Sac Peak also supported the IGY by flashing immediate notice of any major solar flare to Navy research-rocket crews at San Nicolas Island off the California coast. Actually, Sac Peak shared responsibility for alerting San Nicolas with two other observatories: Mount Wilson in California and Climax in Colorado. When notice of a major flare was received, the Navy sought to fire a Deacon rocket to gather data on flare radiation emitted at the far ultraviolet and x-ray end of the spectrum, which could not be satisfactorily monitored even at a mountain-top observatory because of the screening effect of upper atmospheric layers. Similar flare alerts were sometimes provided to research-rocket-launching ships at sea and to Navy and Air Force rocket crews on the nearby White Sands Missile Range. Such assistance to other research groups has continued, as required, even after the IGY; but flare notification should not be confused with flare prediction, which is a more recent development.[14]

Sac Peak's in-house and contractual research program has made use of the data obtained in both routine and special flare observations, for a continuing effort to classify and interpret solar flares in terms of their intrinsic characteristics and their observed associations with

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14. GRD Annual Report, Twelfth Year, p. 78; Harvard University, Final Report, p. 4; Walter Sullivan, Assault on the Unknown (New York: McGraw Hill, 1961), pp. 178-180. Sac Peak's Hawaii flare-patrol station was established, at least in part, for IGY purposes; but it has become an integral and continuing part of the observatory program.

other solar or geophysical phenomena.[15] In the course of this effort, Dr. Henry Smith "has listed on punched cards the important characteristics of the 11,000 flares observed by the [Sac Peak] flare patrol." Together with his wife, Dr. Elske Smith, he has also completed a book on flares for a leading commercial publisher; the authors originally planned to turn out a semipopular account, but in fact they produced what has been described as "the definitive work on the subject to date."[16]

By the close of the 1956-1960 solar maximum, furthermore, Sac Peak scientists were in a position to compile a set of "flare indicators." These could be defined as necessary preconditions, either singly or jointly, for the appearance of major solar flares, although they by no means guarantee that such activity will occur:

a) A large complex sunspot group.
b) Complex magnetic field, with many poles of opposite sign.
c) Unusually bright plages in the light of hydrogen or calcium lines.
d) Frequent outbursts and a high background level of radio emission.
e) Hot spots in the overlying corona, indicated by the limb appearance of the yellow line of Ca XV in the coronal spectrum.
f) High level of minor activity, including numerous small flares, loop prominences (generally visible only at the limb) and surges.[17]

So far, flare analysis has consisted mainly of statistical correlations among flare indicators, the flares themselves, and flare-induced effects in the terrestrial atmosphere and near space. Fundamental scientific understanding of flare phenomena still has not progressed beyond a somewhat primitive stage. Nevertheless, simply on the basis of empirical and statistical data it has become possible to make rough predictions

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15. Cf. GRD, Program Notes: 15 and 16 June 1956, p. A-29; Harvard University, Final Report, pp. 12, 19, 21-22.

16. SPO, "AFCRL Status Report, Sacramento Peak Observatory" (draft manuscript, March 1962, for inclusion in 1962 AFCRL annual report), p. 11.

17. John W. Evans, "Special Study, An Optimum Program for the Sacramento Peak Observatory," (13 June 1961), p. 3.

of solar flare activity; and Dr. Evans frankly admits that the job of predicting flares has recently become "rather more important" than he had anticipated.[18]

This increasing interest in solar flares is directly related to the advent of the space and satellite era. One problem concerns the effect of ultraviolet radiation and x-rays (principally x-rays) from flares upon the ionosphere, leading to disturbance of radio communications; this effect had been known and studied for some time but could become unusually critical as regards communication with a satellite vehicle.[19] Even more serious is the problem of corpuscular radiation from solar flares, consisting of energetic protons and some heavier particles. The existence of such radiation was fairly well established before the launching of the first man-made satellite, but its intensity and potential significance became apparent only as a result of United States and Soviet satellite experiments. Among radiobiologists, concern over the hazard of solar flare radiation has tended to overshadow the older preoccupation with galactic cosmic radiation and at the very least to rival the problem posed by the Van Allen radiation belts (which are themselves largely of solar origin for that matter).[20] In addition, the burst of radiation particles from a solar flare can have adverse effects on various types of sensitive equipment, such as photographic emulsions and some electronic devices. Thus, quite apart from the more obvious threat to manned space flight, flare radiation has the potential to nullify or sharply reduce the usefulness of other extremely expensive space shots. And it was damage incurred by a specific unmanned satel-

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18. Ltr., Dr. Evans to Maj. Gen. Daniel E. Hooks, Cmdr., OAR, subj.: "SPO Prediction Program," 27 April 1961.

19. Missiles and Rockets, 14 August 1961, citing Dr. Knox Millsaps, Chief Scientist, OAR.

20. Cf. Hermann J. Schaefer, "Current Problems in Astroradiobiology," Aerospace Medicine, May 1961, pp. 435-441, and the collection of papers from a Symposium on Aerospace Radiobiology, Aerospace Medicine, October 1961, pp. 893-946.

lite payload, more than any other immediate factor, that led to the establishment of a regular flare-prediction service at Sacramento Peak.

The satellite in question was the Air Force's Discoverer XVII, launched from Vandenberg Air Force Base, Calif., on 12 November 1960, and successfully recovered after 31 orbits around the earth. One item in the Discoverer payload was a batch of special nuclear emulsion provided by Dr. Herman Yagoda of the Air Force Cambridge Research Laboratories, primarily for the measurement of galactic cosmic radiation; but the satellite grazed the lower fringes of the Van Allen radiation, and it was launched shortly after the eruption of a large solar flare which caused the radiation level above the atmosphere to become (temporarily) several thousand times greater than the normal cosmic-ray background. The density of tracks left by these other radiations made it extremely difficult to "unravel" those made by old-style galactic cosmic rays, thus nearly spoiling Yagoda's original experiment. Indeed, the emulsion was later described as "completely fogged" by the radiation dose it had received, although special development techniques did permit the extraction of some data on galactic cosmic rays.[21]

This incident was duly noted by space-systems project personnel at the Air Force Ballistic Missile Division (AFBMD) in Los Angeles. As solar flare radiation might also damage other satellite payloads, there was need for some expert advice on how to avoid the problem; and the officials who were most directly interested turned first to the Lockheed Aircraft Corporation, which had the closest solar-research facility, at Burbank, California. However, the growth of interest in flare radiation was also brought to the attention of Col. George Jones, the Cambridge

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21. Herman Yagoda, Radiation Studies from Nuclear Emulsions and Metallic Components Recovered from Polar Satellite Orbits (GRD Research Notes No. 54, March 1961); Maj. Currie S. Downie, Chief, Geophysics Division, Directorate of Plans, DCS/O, Hq. OAR, memo to record, subj.: "How AFBMD Happened to Contact Sac Peak Observatory About Solar Flare Prediction," 3 May 1961; Lt. James F. Allison, R & D staff assistant, Geophysics Division, Directorate of Programs, DCS/Plans and Programs, Hq. OAR, staff study, subj.: "Solar Prediction Program," April 1962 (draft version).

Laboratories' liaison officer at AFBMD, and Col. Jones then arranged for an AFBMD representative to meet with Dr. Evans at Sac Peak. The meeting took place about the middle of March 1961, and before the end of that month Sacramento Peak Observatory inaugurated a regular prediction service consisting of (1) a daily phone call to AFBMD giving an estimate of flare probabilities over the next several days and (2) immediate notification of the occurrence of any large and potentially damaging solar flare. In return, AFBMD at once made available $100,000 in fiscal year 1961 funds and indicated that more financial support might be forthcoming in the future. This assistance was not given as a contribution to the over-all Sac Peak research program: rather, it was intended to cover certain immediate requirements for improving the prediction service. On 1 April 1961, when AFBMD was divided into a Ballistic Systems Division and a Space Systems Division, the latter inherited the primary interest in flare prediction -- which has been expanded since March 1961 both in frequency (to at least twice daily) and in the number of "customers" served.[22]

Nevertheless, the prediction service has its limitations. As explained in September 1961 by Major General Daniel E. Hooks, Commander of the Office of Aerospace Research:

> To date, we have a poor batting average forecasting unsafe periods, but our record in forecasting safe periods is 100%. In other words, when we say it's safe, it is safe. The rest of the time we just don't know. It may be safe -- and it may not.[23]

There must inevitably be false alarms, when an experiment is postponed because of possible flare danger that does not materialize. This is not too serious a difficulty at the moment, but it promises to become

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22. Ltr., Evans to Hooks, subj.: "SPO Prediction Program;" Downie, memo to record, subj.: "How AFBMD Happened to Contact Sac Peak;" unsigned memo from SPO, subj.: "Solar Proton Showers, " 14 April 1961; Missiles and Rockets, 14 August 1961; interview with Dr. Evans, 27 March 1962.

23. Maj. Gen. Daniel E. Hooks, address to SAFOI Worldwide Information Conference, Philadelphia, 19 September 1961.

downright critical in the near future. During 1967-1971 the solar cycle will again reach a period of maximum activity. Even then there will be sufficient safe periods for conducting flare-sensitive experiments, but with the forecasting methods originally used it would be almost impossible to pick them out in advance -- for there will be scarcely any periods when no flare indicators at all are present. At the same time, current prospects are for a steady increase in the number of space missions, some of which -- especially manned missions -- will be highly sensitive to flare damage. Hence the prediction service must undergo substantial refinement over the next few years, directed toward an ever more discriminating treatment of flare indicators.[24]

Fortunately, some progress is being made already. The time wasted in false alarms decreased significantly during the first year of the Sac Peak prediction service: whereas in March 1961 well over half of the time had to be designated as unsafe, by March 1962 the figure was down to around 30%. Among other things, the age of an active center and its location on the solar disk have been taken into account along with the flare indicators, in order to narrow down the number of active centers regarded as likely to produce dangerous flares. Further improvement can be expected to result from the use of Sac Peak's newly installed 16-inch telescope. With its special accessories (not yet fully operational), this instrument is chiefly intended for studying the magnetic fields of active centers -- one of the most crucial of the flare indicators, and one of the most difficult to observe. Even so, much will remain to be done, both in fundamental analysis of flare phenomena and in the continuing augmentation and perfection of the instrument complex.[25]

Naturally, other organizations besides the Air Force have studied the problem of solar flare prediction. The Lockheed solar-research facility is one of these.[26] Another is the National Aeronautics and Space

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24. Evans, "Special Study, An Optimum Program for the Sacramento Peak Observatory," p. 2 and passim.

25. SPO, "AFCRL Status Report," pp. 4-6, and above, pp. 27-29.

26. Missiles and Rockets, 7 August 1961.

Administration (NASA), which has financed study contracts related to flare prediction as well as conducting some in-house research on the problem; but NASA has no effort in the area of flare patrol and flare prediction comparable to what the Air Force has been doing at Sac Peak. NASA at one point considered the possibility of establishing its own flare-patrol system. However, NASA and Air Force representatives met in May 1961 to coordinate their respective programs of solar research and in particular to discuss flare prediction. The sense of this meeting was that there existed room for closer cooperation between the two agencies, and also that a NASA flare-patrol system would represent duplication of Air Force effort unless it were established in some other part of the world -- i.e., to function when night had fallen at Sac Peak (and at its Hawaiian flare-patrol substation).[27]

It is interesting to note that this NASA-Air Force coordination meeting occurred just after the first American astronaut, Commander Alan Shepard, had made his memorable flight from Cape Canaveral under the auspices of NASA's Project Mercury (5 May 1961). That was not one of the experiments for which Sac Peak provided a special flare-prediction service; indeed, the observatory's forecast for 5 May was "unsafe," and a fairly large (class 3) flare did occur later that day at 1900 hours eastern time.[28] Of course, the flare problem in Shepard's flight was distinctly limited in any event because of the moderate altitude and brief duration of the experiment, and the same can be said regarding the later Mercury suborbital flight by Captain Virgil I. Grissom. However, the initial orbital flights by Soviet astronauts were a somewhat different matter. The Russians did not consult Sac Peak, but they consulted

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27. Downie, memos to record, subj.: "Information from Sac Peak Observatory," 10 May 1961, and subj.: "Coordination with NASA on Solar Research and the Prediction of Solar Proton Events," 15 May 1961; Kinsey A. Anderson and Carl E. Fichtel, Discussions of Solar Proton Events and Manned Space Flight (NASA TN D-671, March 1961).

28. Downie, memo to record, subj.: "Information from Sac Peak Observatory," 10 May 1961.

their own solar scientists, who obviously came up with the right answers. General Hooks pointed out that Sac Peak's predictions in April 1961 were

> ...consistently for unsafe conditions except for the 11th, 12th, 13th and 14th. On April 12th, the Russians seem to have agreed with us, for it was on that day that Major Gagarin was launched into orbit.
>
> When Major Titov went up on his longer flight [6 August], we were forecasting "Double Green" or super-safe conditions. In point of fact, the actual day the Russians chose for this epochal flight was the safest we [had] on record since 1955. This is a point worth remembering if anyone should ever ask you why the Air Force spends money to investigate flares on the surface of the sun, some 93 million miles away. The Russians obviously know when it is safe to send a man aloft. We, too, must know, and since solar disturbances will become more frequent and more intense in the next few years, we must increasingly refine our forecasting techniques if we are to isolate and make use of safe periods for travel in space.[29]

When Lieutenant Colonel John H. Glenn made the first orbital flight in Project Mercury on 20 February 1962, the solar flare problem was more important than it had been for the Shepard and Grissom experiments. The particular orbital trajectory chosen for Colonel Glenn was not such as to pose a critical radiobiological hazard even if a fairly large flare had occurred; but it would have been obviously unfortunate if communications had been affected during the flight by flare-induced disturbances. Therefore Sac Peak was called upon to make flare predictions specifically in preparation for the Glenn flight. The predictions were made two or three times daily, for a period of approximately two weeks prior to the experiment; they were telephoned directly to the radio warning station of the National Bureau of Standards at Fort Belvoir, Virginia; and a "safe" solar forecast was, of course, one of the prerequisites for the final scheduling and launch of the flight.[30]

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29. Hooks, address to SAFOI Worldwide Information Conference, 19 September 1961.

30. Lt. Allison, memo for record, subj.: "NASA Request for Solar Prediction," 5 April 1962; interview with Dr. Evans, 27 March 1962; information obtained from the Office of Manned Space Flight, Hq. NASA, May 1962.

Chapter V

PLANS AND PROSPECTS

The critical importance of flare prediction, as discussed in the preceding chapter, has been cited in support of current recommendations for a major increase in the "firepower" of Sacramento Peak Observatory. These recommendations call principally for the construction of a solar tower telescope and must be distinguished from the continuing modification and improvement of the instrument complex that has been almost a routine activity at Sac Peak. Nor is the interest in Sac Peak expansion based exclusively on the flare problem. Indeed, the requirement for a tower telescope was inserted in the Project 7649 development plan as far back as March 1958,[1] before flares had become quite so lively an issue.

In September 1959, furthermore, the observatory submitted a detailed, formal proposal that can fairly be taken as the point of departure for all subsequent efforts to obtain a thoroughgoing increase in the Sac Peak research capability. This proposal called attention to certain developments which, it was claimed, had become increasingly evident over the past two years:

> (a) Solar research is now poised on the verge of a spectacular series of breakthroughs which are held back by a dam of ignorance about the ultraviolet nonmetallic resonance spectrum of the sun and an absence of laboratory information on collisional cross-sections, F-numbers and plasma physics, etc. These data are generally subsidiary to more basic observations but they are critical. Although the methods of interpretation of observations at the SPO are very advanced by classical standards, they are basically developments of horse and buggy classical methods and exploit only a fraction of the information inherent in the data. The full potential of the growing body of superb observational data can be released only by a laboratory and satellite attack on the outstanding subsidiary problems which are of tremendous importance in all fields of Astrophysics and a broad range of Physics and Space Technology.

1. R & D Project Card (DD Form 613), Project 7649, 7 March 1958.

(b) The technological and theoretical tools to break this bottleneck are at hand.

(c) The necessary investigations are not being undertaken anywhere else in the world on an adequate scale except possibly in the USSR.[2]

There followed a statement of an improvement program whose estimated cost was almost six million dollars -- covering new scientific instruments, laboratory space, and support facilities. The program included several items, such as a special laboratory for satellite instrumentation, that have been deleted from more recent requests. But the key ingredient has remained always the same: a solar tower telescope.

The tower telescope was originally requested not only for its greater observing power but also because its installation would permit greater economy in the use of the 16-inch coronagraph, which would ultimately wear out with repeated cleaning. Dr. Richard B. Dunn of the observatory staff assumed primary responsibility for design of the instrument, but in addition a contract was awarded in 1959 to Joseph Nunn and Associates of Pasadena for engineering studies related to the design of the tower structure.[3] As presently envisaged,

> The [30-inch] tower telescope consists of a vertical fixed reflecting optical system extending from 180 feet below ground level to 125 feet above ground in a solid concrete tower. The system is fed by a pair of flat mirrors at the top. The whole optical system will be enclosed in a vacuum tube with the pressure reduced to about 1 mm of mercury, and light will be admitted to the first mirror through a quartz window at the top of the tower. This arrangement avoids the shortcomings of the present fixed telescope. The aperture is adequate to take advantage of the best seeing (freedom from refractive errors in the thermally inhomogeneous atmosphere). The internal optical path is evacuated, and hence free of convection. And the light is received by the instrument above the levels of the most serious ground convection.[4]

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2. SPO, "Solar Research Proposal," 23 September 1959.

3. GRD, GRD Annual Report, Twelfth Year: A Technical Memorandum to the Director, GRD (August 1959), p. 76; Management Report (ARDC Form 111), Project 7649, 12 January 1959.

4. John W. Evans, "Special Study, An Optimum Program for the Sacramento Peak Observatory" (13 June 1961), p. 6.

Such a telescope has been described by Dr. Evans as "the best possible for observation of details on the solar disk." It offers exceptionally high resolution and is thus extremely important for research on solar active centers, a field of study "where further significant advances depend primarily upon the ability to analyze still finer details, beyond the reach of the 12 inch [fixed] telescope [and other existing instrumentation]."[5]

The tower telescope, by itself, can be expected to cost in the neighborhood of three million dollars (including utility extensions, laboratory area, etc.) and to take about four years to construct. But the time might be reduced to two and one-half or three years if another $500,000 in "expediting funds" were made available. This would be obviously helpful in preparing for the next sunspot maximum, when, as mentioned in the previous chapter, flare prediction will require much more sophisticated interpretation of the flare indicators. Moreover, if the flare problem and other key problems are to be dealt with successfully, there is a requirement to improve and/or supplement other existing equipment, as is already being done to a certain extent; and to assign additional personnel at Sac Peak not only to operate the tower telescope but also to expand the present patrol activities and prediction service and to carry out an accelerated program of fundamental solar studies. The increase in staff would consist mainly of contractor personnel, but it would still be necessary to construct more housing units at Sac Peak, not to mention other support facilities and (ideally) further community and recreational facilities. The required increase in scientific staff is about 50%. The required expenditure is now set at around four million dollars for facilities and equipment plus a substantial increase in yearly operating funds.[6]

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5. Ibid.

6. Ibid., pp. 4, 7-8; John W. Evans, "Memorandum on High Energy Proton Showers in Space and their Avoidance" (April 1961), pp. 5-7; ltr., Dr. Evans to Brig. Gen. Ralph W. Wassell, Dir./Research and Technology, DCS/D, Hq. USAF, subj.: [Sac Peak Expansion Program], 8 May 1961.

At first glance, it might appear that the plans for Sac Peak expansion represent at least partial duplication of developments planned or in progress elsewhere -- notably at the Kitt Peak Observatory in Arizona, where a solar tower telescope is now under construction with support from the National Science Foundation. However, not even the Kitt Peak tower telescope is exactly like the one proposed for Sac Peak; nor could any other major observatory be directed to devote its full research potential to those topics of primary and urgent importance to the Air Force. Hence the proposed major increase in Sac Peak capabilities has obtained widespread support within the Air Force, not only at Headquarters Office of Aerospace Research (OAR) but also from such elements as the Geophysics Research Panel of the Air Force's Scientific Advisory Board.[7] The main difficulty, of course, is one of funding, since Sac Peak expansion happens to be one of many worthwhile projects competing for a share of Air Force research and development dollars.

The search for a way to fund the Sac Peak expansion program is a long and complicated story in itself, most of which is not truly germane to the present history. Indeed, it overlaps with the still more complicated story of the earlier effort to build a large solar furnace outside Cloudcroft, New Mexico, not far from Sac Peak; when the observatory submitted its formal proposal of September 1959, it was hoped that most of the funding might come from an appropriation originally passed by Congress for solar furnace construction. The solar furnace was not built, but the money was specifically earmarked for solar-research facilities in the Cloudcroft area, and needed additions to the Sac Peak complex seemed to offer an acceptable alternative use. No action was taken at that time, but the same method of financing received careful consideration when, in 1961, the growing importance of flare prediction gave renewed impetus to the drive for Sac Peak expansion. By the end of 1961,

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7. Ltr., Rear Adm.(ret.) Paul A. Smith, Chairman, Geophysics Panel, SAB, to Lt. Gen.(ret.) Donald L. Putt, Chairman, SAB, subj.: "Sacramento Peak Solar Observatory," 18 August 1961.

however, the Department of the Air Force had decided against any attempt to use the solar furnace money for this purpose. Thus OAR had to fall back on more normal procedures to seek the necessary funds, and as of this writing (April 1962) the outcome is not yet clear.[8]

Despite its present inconclusive status, the expansion program still forms a necessary part of this history. This is true simply because in recent months it has dominated all planning and administrative activities with respect to the Sacramento Peak Observatory. In the last analysis, however, that program is not an end in itself but rather a means to promote the long-range research objectives of the observatory -- objectives that will remain substantially the same no matter what is finally decided either on the expansion program as a whole or on any one of the individual recommendations of which it is comprised.

8. Lt. James F. Allison, R & D staff assistant, Geophysics Division, Directorate of Programs, DCS/Plans and Programs, Hq. OAR, staff study, subj.: "Solar Prediction Program," April 1962 (draft version). This study contains specific references to all the key items of documentation relating to Sac Peak expansion efforts.

GLOSSARY

AF	Air Force
AFB	Air Force Base
AFBMD	Air Force Ballistic Missile Division
AFCRC	Air Force Cambridge Research Center
AFCRL	Air Force Cambridge Research Laboratories
AFMDC	Air Force Missile Development Center
AFSC	Air Force Systems Command
AMC	Air Materiel Command
ARDC	Air Research and Development Command
CG	Commanding General
Cmdr.	Commander
CO	Commanding Officer
DCS	Deputy Chief of Staff
DCS/D	Deputy Chief of Staff/Development
DCS/M	Deputy Chief of Staff/Materiel
DCS/O	Deputy Chief of Staff/Operations
DD	Defense Department
Dep.	Deputy
Dir.	Director, Directorate
ERD	Electronics Research Directorate, AFCRL
FY	Fiscal Year
GRD	Geophysics Research Directorate, AFCRL
HADC	Holloman Air Development Center
HAFB	Holloman Air Force Base
HAO	High Altitude Observatory
<u>Hist AFCRC</u>	<u>History of the Air Force Cambridge Research Center</u>
Hq.	Headquarters
Ind.	Indorsement
Ltr.	Letter
NASA	National Aeronautics and Space Administration

n.d.	no date
NBS	National Bureau of Standards
OAR	Office of Aerospace Research
ONR	Office of Naval Research
R & D	Research and Development
RDT & E	Research Development Test and Evaluation
SAB	Scientific Advisory Board
SAFOI	Secretary of the Air Force, Office of Information
SHG	Spectroheliograph
SPO	Sacramento Peak Observatory
Subj.	Subject
TN	Technical Note
TR	Technical Report
USAF	United States Air Force

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