8. CONTINUOUS SOLAR SURVEY, CINEMATOGRAPHY,
AND ELECTRONIC SUN-FOLLOWER

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8.1. Continuous Solar Survey

Automatically timed observations of solar activity conducted on a routine minute-to-minute basis are currently undertaken by a relatively small, though increasing, number of observatories. A substantial number of additional stations possess instruments that would be suitable for such work as well. The recording of the data is usually made on 35-mm motion-picture film. Larger pictures are too costly and too cumbersome to process, examine, and store in large numbers. Either spectroheliographs or birefringent filters are used for surveys of the solar disk or the limb, isolating $H\alpha$ or the K line of $Ca\,\Pi$. A larger number of stations take frequent limb and disk observations but no continuous series.

The need for continuous solar surveys grows as new aspects are discovered of solar activity and of solar-terrestrial relationships (cf. chaps. 5 and 6). Except for some experiments made at Pic du Midi, McMath-Hulbert Observatory, and elsewhere, no cinematographic survey of the sun in integrated light or in the coronal lines has been made. While such surveys would probably reveal fewer changing phenomena than conventional $H\alpha$ or $Ca\,\Pi$ surveys, they would nevertheless be of great interest.

For continuous solar surveys the interval between exposures must be short compared to the development or decline time of the observable solar events. Also, observations must include the entire solar limb or disk, as the case may be. This means that 2–3 minutes is the maximum allowable time between exposures encompassing the whole sun, though a 5-minute interval will include nearly all events. (Some solar flares develop to maximum in 0.5 min.) Few solar programs in present operation attain the above goals entirely, though some approach them.
a) Mount Wilson Observatory, California.—K₂ spectroheliograms are taken during suitable weather with a 7-foot-focus solar telescope at 3–5-minute intervals. The photographs, taken on 35-mm motion-picture film encompass the full solar disk and are of excellent quality. They are supplemented by disk photographs in white light, Hα spectroheliograms of 60-foot focus, Hα spectroheliograms of 18-foot focus, K₂ spectroheliograms of 18-foot focus, and K-line observations of limb prominences with 18-foot focus. The “continuous” program has been in effect since June, 1936, and provides an impressive volume of material on solar flares and other solar phenomena.

b) The McMath-Hulbert Observatory of the University of Michigan, Lake Angelus, Pontiac, Michigan.—A similar survey program has been in operation since 1937 with emphasis on specific regions of activity, rather than on comprehensive tabulation of all significant events. Since 1939 the 50-foot tower of the observatory has been used for this work, which includes automatic photography in Hα and K of disk and limb at a rate of two or more pictures per minute, as the activity demands. Here 35-mm films are used, and three image sizes (18, 53, and 110 mm) are available.

In addition, the Stone radial-velocity spectroheliograph has been used on features exhibiting substantial activity to give rapid-sequence measures of line-of-sight velocities. The radial-velocity camera records small segments of spectrum centered on Hα for successive strips of the solar image. The technique used is similar to that of Deslandres’s “spectro-enregistrateur des vitesses”; but 35-mm film is used for recording, and a complete series of strip spectra can be taken every 170 seconds. These observations are supplemented by observations with the spectrographs of the McGregor Tower and with the small visual spectrohelioscope, with which a check is maintained of continuing solar activity.

c) Meudon Observatory, Seine et Oise, France.—A new instrument for continuous survey work has recently been installed at Meudon. It consists of a Lyot birefringent filter transmitting 0.75 A centered at Hα. It is designed for photography of the solar disk or limb and is equipped with an automatic sequence-controller that operates it at a rate of several pictures per minute. In addition, it is fitted with photoelectric devices that arrest the picture-taking unit when the brilliance of the solar image drops below a predetermined value, that compensate the camera exposures for variations in atmospheric transparency, and that guide the telescope with great accuracy so that cinematographic observations are possible during suitable sky conditions. The image is recorded on 35-mm film.

This instrument is supplemented by the Meudon spectroheliograph and
the automatic limb-prominence apparatus; the latter was used by Lyot prior to 1940 at the Pic du Midi, in conjunction with his 20-cm coronograph. The Pic du Midi itself is not now engaged in a "continuous" program.

d) High Altitude Observatory, Climax, Colorado.—A continuous program of prominence observations in Hα of a 70° arc of the solar limb has been carried out since 1942 with a 5-inch Lyot-type coronagraph. A birefringent filter of 4 A transmission at Hα is used, and part of the image of about 50 mm diameter is recorded on 35-mm film at rates up to six pictures per minute. The entire circumference of the sun is therefore not under constant observation, but only a visually selected 70° arc. The coronagraph at Climax is accurately aimed toward the sun by a photoelectric guiding device.

e) Crimean Astrophysical Observatory, Simeis, Crimea, U.S.S.R.—In 1948 regular cinematographic records of prominences at the limb were instituted, and in 1950 regions of the solar disk came under similar systematic observation. Birefringent filters are used, providing a range of band widths for several spectral lines, including Hε λ 10830 A.

Photographs are taken with three different solar instruments on a minute-to-minute basis, with special attention to flares, dark filaments, facular regions, and chromospheric activity.

f) Sacramento Peak Station, Harvard College Observatory, Sacramento Peak, New Mexico.—Since February, 1950, a continuous program of solar disk observations has been carried out, first at the High Altitude Observatory laboratory at Boulder, Colorado, and since early in 1951 at Sacramento Peak. The entire solar disk is photographed with a birefringent filter centered at Hα. The band pass of the filter first used was 0.5 A and later it was 1.0 A. The rate is one picture per minute.

In addition, a continuous limb program is conducted with a 4 A birefringent Hα filter. The camera photographs either a 17-mm image of the full solar limb or a 50-mm image of a 70° arc. The records are on 35-mm motion-picture film. Both disk and limb films are taken with telescopes that are photoelectrically aimed at the sun, and the films are suitable for being viewed in motion.

A number of other observatories are engaged in occasional rapid-sequence disk or limb photography but do not conduct "continuous" programs regularly. Among these are the following: Swiss Federal Observatory at Arosa, Switzerland; Wendelstein and Schauinsland Observatories in Germany; Kanzelhöhe Observatory in Austria; Kodaikanal Observatory...
in India; and the United States Naval Observatory. Still other observatories, such as the Royal Observatory at Edinburgh and the Astrophysical Observatory at Arcetri, have made extensive visual and photographic observations of solar flares and other disk and limb phenomena.

Automatically operated continuous programs of solar observation are scheduled by Stockholm Observatory, Sweden; Uccle, Belgium; San Michel (Haute Provence), France; Tortosa, Spain; Coimbra, Portugal; National Observatory (Ondrejov), Czechoslovakia, and two observing stations in southern Italy, operated from Germany and Sweden. For further information reference is made to the list of solar equipment by Coutrez (p. 728).

The completion by Lyot of 12 high-quality Hα filters with a band width of 0.8 A will permit the inauguration of additional automatic solar surveys. These filters have been distributed throughout the world, and it now seems feasible that a really world-wide network of Hα survey telescopes can be established, with I.A.U. co-ordination.

The need is clear for such a network to provide homogeneous solar data. It could be filled by the use of a series of automatic solar cameras of relatively modest design but capable of routine operation on a uniform basis at all hours U.T. It would be necessary to provide a central laboratory to handle the data, capable of assembling a truly continuous record, suitable for reduction by cinematographic techniques. All other methods would be too laborious. Cinematographic examination of the records and photoelectric detection of disturbances, either from the film or in the survey equipment itself, would be desirable as detection aids.

8.2. CINEMATOGRAPHY

The list of observatories engaged in cinema studies of solar features is nearly the same as that given above, which is not surprising, since similar techniques are involved.

McMath was the first to apply motion-picture techniques to solar research, while Lyot developed it independently soon afterward. Special mention is made here of Lyot's chromospheric films in Hα and his corona films in λ 5303 and λ 6374 A. The requirements of motion-picture projection are more stringent than those for the continuous survey. Not only must the photographs be taken at a rapid rate, but also the guiding must be accurate, or the projection will be too jerky to be useful.

For optimum results with pictures on 35-mm film and solar-image sizes between 17 and 100 mm, two to three pictures per minute are indicated. Guiding should be so good that the image does not jump by amounts
greater than the uncertainties introduced by resolution and seeing. In a 5-inch instrument guiding errors up to 2"–3" can usually be tolerated, and occasional errors of 3"–4". A drift in guiding, slow compared to the apparent motion of the image in the film, will not impair the projection quality, even though it may somewhat complicate measurement and analysis.

Telescopic guiding of suitable quality is attainable either from equatorial drives with rate-controlling and rate-changing devices, as done at the McMath-Hulbert Observatory, or by photoelectric servo mechanisms, as done at the High Altitude Observatory. Data on changes of form, motions, and brightness in prominences, flares, filaments, and in the corona are most readily derived from cinematic studies, while some phenomena may thus be detected that would go unnoticed upon frame-by-frame examination.

8.3. Electronic Sun-Follower

For an observer equipped with an ordinary telescope and finder it is most difficult to correct both co-ordinates with sufficient accuracy to maintain an unbroken sequence of pictures of motion-picture quality. Thus various automatic devices have been developed.

At the McMath-Hulbert Observatory the problem was solved by providing the coelostat with an accurate equatorial mounting and a computing device, controlled by the observer who monitors the image at the start of a solar "run." The computing device adjusts the right ascension and declination rates, as demanded by the guide-run period (McMath, 1937).

Another approach was made by the High Altitude Observatory, where a fully automatic photoelectric guider was developed (Roberts, 1946; Fowler and Johnson, 1951). In principle it consists of two pairs of photoelectric tubes located behind an occulting disk on which a solar image is formed by a long-focus lens mounted in fixed relationship with the solar telescope. The right-ascension tubes are so located that a centering of the solar image decreases the light to one cell and increases that to the other. The impulses to a suitable bridge circuit containing the tubes are utilized, after amplification, to provide the necessary change of rate. The declination pair is similarly connected.

The telescope drive uses a synchronous motor, and all guiding, automatic or manual, is accomplished by varying the frequency driving the motor. This procedure, originated at the McMath-Hulbert Observatory, eliminates the need for a differential drive, lowers the cost of construction, and eliminates backlash. Also, the drive mechanism can be simplified from
a large worm-and-gear drive to a friction-roller drive built to provide approximately the correct solar rate with the normal drive-motor speed.

The Climax guider is a continuously variable servo mechanism. However, satisfactory off-on servos may be used also (Whitford and Kron, 1937; Babcock, 1948). The extent to which photoelectric finders are now in use may be seen in the table (p. 728) compiled by Dr. Coutrez.

REFERENCES

Fowler, E., and Johnson, S. 1951 Electronics, 24, 118.
Roberts, W. O. 1946 Electronics, 19, 100.

9. SOLAR WORK AT HIGH ALTITUDES FROM ROCKETS

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The study of the portion of the solar spectrum from the ultraviolet to X-rays became possible in 1946 through the use of rockets, which are able to carry radiation-measuring equipment to altitudes where the atmosphere remaining overhead causes negligible attenuation. Rockets employed have been the German V-2, and the U.S. Aerobee and Viking. The V-2 is capable of carrying a 2000-pound payload to an altitude of about 170 km; the Aerobee carries 150 pounds to 110 km; Vikings flown to date have carried 400 pounds to 220 km or 900 pounds to 170 km. The V-2 is stabilized until fuel burn-out at about 37 km; thereafter, it rolls about its principal axis at 2 r.p.m. or less, and frequently yaws slowly and unpredictably. The Aerobee rolls at about 1 r.p.s. and also yaws unpredictably. The Viking, however, is a stabilized rocket that eventually will be stable in roll and yaw to within 5°.

The most difficult problem in recording the solar ultraviolet spectrum from rockets has lain in designing a spectrograph that will give intense spectra in spite of the roll and yaw of the rocket, which prevent the instrument from remaining pointed at the sun. This problem has been partially solved by designing spectrographs and other devices with extremely wide useful fields of view. Nevertheless, instability of the rockets places a severe limitation on all solar experiments, reducing by a factor of 10–100 the amount of data that might conceivably be obtained on a flight and