OBSERVATIONS OF THE SOLAR EMISSION
CORONA OUTSIDE ECLIPSE

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Observations of the emission lines of the solar corona outside eclipse have become thoroughly routine within the last decade at several observatories in both hemispheres, and the continuous record thus provided is highly significant in the study of solar activity. Useful as they are, however, the coronal spectrograms do not readily show structural details well, and the need for direct photographs has been evident from the first use of the coronagraph. Lyot first succeeded in photographing the corona with satisfactory detail and contrast, and made motion pictures of it in 1941. However, he did not institute a continuing program of such observations and little further was done until the recent still photography of Dollfus at the Pic du Midi, and the work reported in this paper.

Coronal photography without the benefit of an eclipse is difficult because of the faintness of the corona relative to the halo of atmospheric and instrumental scattered light through which it must be seen. Satisfactory results require a very clear sky, less than 25 millionths of the brightness of the sun, and a coronagraph combined with a birefringent filter transmitting one of the bright coronal lines.

During the summer and fall of 1955, Richard Dunn at the Sacramento Peak Observatory modified the small telescope that had been used for cine photography of prominences, converting it into a coronagraph suitable for cine observations of either prominences in the Hα line of hydrogen, or the emission corona in the λ 5303 line of [Fe xiv]. The critical features of the conversion were the use of a coronagraph objective, consisting of a specially polished simple lens, and the provision of appropriate auxiliary filters by means of which transmission bands of the birefringent filter either at λ 5303 or Hα could be isolated.

The optical system is shown in Figure 1. The objective, O,
Fig. 1.—Optical system of coronagraph for coronal photography.

has an aperture of 6 inches and a focal length of 100 inches. It forms an 0.93-inch image of the sun on the conical eclipsing disk, \( D \), mounted on the field lens, \( F \). The field lens forms an image of the entrance aperture, \( A \), on a slightly undersized diaphragm, \( S \), which intercepts diffracted light originating in the photosphere of the sun. The light of the corona and prominences is collimated by lens \( C \), and traverses a Dove prism, \( R \), by means of which the image can be rotated to any desired orientation. Lens \( I \) forms the final image, 1.9 inches in diameter, in the plane of the photographic film, \( P \), through the birefringent filter, \( B \). For visual observation, a reflex mirror, \( M \), can be inserted in the optical path to divert the light into an eyepiece, \( E \). The birefringent filter was constructed by Dunn, and has a band width of 2.0 Å at \( \lambda \) 5303, and 3.0 Å at H\( \alpha \). The two bands are centered accurately on the lines by a slight adjustment of the temperature of the filter. An Acme 35 mm motion picture camera takes single exposures on signal from a timer. Exposure times are typically 60 seconds for the corona on Kodak IV-J high contrast film, and \( \frac{1}{2} \) second for prominences on Kodak 103-H\( \alpha \) film. The instru-
ment is carried on an equatorially mounted rectangular spar along with three other simultaneously operating solar instruments. The whole assembly is photoelectrically guided on the sun with an accuracy of 1 to 2 seconds of arc, depending on the quality of the seeing.

After the first successful test photographs of the corona in August 1955, the equipment was put into permanent form, and a routine program of coronal cine photography was initiated in February 1956. Runs are made whenever the sky brightness 6' from the solar limb is less than 50 millionths of the brightness of the disk.

The result of the first 10 months of operation consists of 32 runs averaging several hours. The pictures show unexpectedly vigorous coronal activity with large and rapid variations in intensity, high apparent velocities, and continuously changing fine detail. This activity is very complex, and a meaningful quantitative analysis is not possible in a short time. However, its general nature can be described, and is sufficiently interesting to justify this preliminary report, in the form of some of the more striking photographs. Unfortunately they convey a rather meager impression of the vivid activity that is apparent in the motion pictures, but the principal features can be traced.

Whenever the coronagraph was in operation, the Sacramento Peak Observatory flare patrol was also running, photographing a 16 mm image of the disk of the sun every 5 minutes through an Hα filter of 0.5 Å band-pass. This series shows the solar disk correctly exposed, but only the brightest prominences, on every exposure. An occasional long exposure by hand was interspersed between regular exposures to show the fainter prominences. Thus good records of flare activity and somewhat less regular records of prominence activity during coronal runs are available. In several instances coronal spectra were also obtained during the coronal runs. In the discussion below I have tried to combine all the available information from the coronal photographs, flare patrol, and coronal spectrograms.

All the photographs show the corona over active regions centered on sunspot groups, because, with rare exceptions, these are the only regions where really bright corona occurs. The mate-
rial available is not sufficient to distinguish any but the most prominent characteristic formations in the corona. The most notable are relatively stable ray and arch structures. The rays are streamers, commonly 150,000 km long, often curved, which appear to radiate from a common broad center near the surface of the sun. No good example of this structure appears in the photographs presented here. Arches often occur in the form of several concentric parabolic or semicircular filaments, rather sharply outlined, usually decreasing in brightness from the inner to the outer filaments. They tend to expand gradually over periods of hours. An example of an arch is clearly shown in the first exposure of Plate IV, although the fainter outer filaments have been lost in reproduction. Both rays and arches are well known from eclipse observations.

Most of the more dynamic activity observed appears to consist of rapid changes in brightness rather than motion of material. Strong filaments or broad areas brighten and fade in place. A common feature is the sudden development of a sharply outlined very dark area, which may be a roughly circular spot, perhaps 30,000 km in diameter, high in the mass of coronal material, or a complete gap in the corona along the limb.

Although it is rather exceptional, instances of the actual motion of material are occasionally observed. The expansion of arches may be an example, and the motions of the knots visible in Plates IV and V quite certainly are, since Doppler shifts are unmistakably present in the green coronal line.

In the photographs the position angle $\theta$, indicated at the bottom of each plate, is measured eastward from the projection of the solar axis of rotation on the north limb to the center of the frame. The lower 30,000 km of the corona is eclipsed by an oversized occulting disk. The apparent limb in the H$\alpha$ prominence pictures is the top of the chromosphere approximately 7000 km above the photosphere.

Plates I, II, and III show the activity over an active center as it crossed the east limb of the sun.

Plate I shows the development of two brilliant surge-like coronal knots. The motion pictures give the impression of rapid
Solar corona Sept. 9, 1956
\[ \theta = 113^\circ \]
PLATE II

Solar corona and prominences Sept. 10, 1956

$\theta = 112^\circ$
changes in brightness without mass motion. No detectable Hα activity occurred during this run, although one very small (importance 1⁻) flare preceded and two followed it, directly under the coronal surge. A coronal spectrogram taken at 15:54 UT showed a strong yellow line (λ 5694 of [Ca xv]) and coronal continuum in the surge.

Plate II shows a somewhat similar but more complex activity in very nearly the same location. Again the yellow line was strong. A small Hα surge, accompanying a small slow flare, apparently coincided with the rapidly changing filament in its later stages. This surge may well have been present in the earlier stages, and missed in the flare patrol camera because of large line of sight velocity, which would shift the Hα line out of the 0.5 Å transmission band of the filter.

Plate III shows one of the most spectacular events observed so far. The feature of interest is the high streamer above the mass of the corona. Unfortunately it was quite faint and difficult to reproduce. All the frames on this plate have been "dodged" to bring out the high filament without grossly overexposing the lower corona. The times indicated are for the coronal exposure, and the disk pictures coincide within one minute. The streamer first appears rooted in the corona near the center of the frame and strongly curved over into a horizontal position toward the right, about 10⁵ km above the arc of the occulting disk. At 19:05 UT a small flare appeared under the horizontal section, and within 5 minutes the streamer had whipped up into a vertical position. The velocity of the end of the "whip" was of the order of 600 km/sec, suggesting a shower of auroral particles. In the motion picture, the static vertical streamer appears to form a barrier against which the whipping streamer seems to impinge and bounce back quite perceptibly. The photograph at the bottom of the plate, for 19:27 UT, shows the position of static prominences throughout the phenomenon. The black spot inside the limb near the center indicates the position angle of the root of the vertical streamer. This is the only instance of such activity so far observed at Sacramento Peak. It is interesting that the yellow line appeared weakly only at the northern end of this active region, far to the left of the streamers, at 15:02 UT. However,
the active region was well on the disk and the yellow line may have been present here also but too low for observation. Also, it may have been present at the time of the flare.

Plates IV and V show another quite remarkable activity, in which many details of the corona appear to coincide exactly with details in a vigorous \( \text{H}\alpha \) loop prominence. The correspondence is obvious if it is remembered that the edge of the occulting disk in the coronal pictures is about 23,000 km above the limb in the \( \text{H}\alpha \) pictures. Very strong yellow coronal lines of \([\text{Ca} \text{ xv}]\) at \( \lambda 5694 \) and \( \lambda 5446 \), accompanied by a strong coronal continuum, were evident in the loops. Both the prominence lines and the green and red coronal lines exhibited marked line of sight velocities in the loops, with differences that suggest that the coronal material forms a sheath through which prominence material moves. The relation between the two has been studied in detail by Newkirk at the High Altitude Observatory. His results are now in press. A small (importance 1") flare occurred in the region at 20:31 UT, but did not appear to be associated with any abrupt coronal response.

The \( \text{H}\alpha \) frames at 16:34, 16:40, and 16:45 UT were taken with a large-scale 15-inch telescope on 35 mm film. The telescope had been operating since sunrise on November 22, and unfortunately ran out of film at 16:46. The remaining \( \text{H}\alpha \) pictures are from the flare patrol.

In presenting this material, the author’s contribution is principally that of a scribe. The photographs are the result of the efforts of Richard Dunn in designing and building the equipment, and of the careful work of the observers, Harry Ramsey, George Schnable, and Howard DeMastus. The prints were mounted and labeled for reproduction by Robert Mitchell.


PLATE III

Solar corona and Hα disk features Sept. 12, 1956
\( \theta = 113^\circ \)

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PLATE IV

Solar corona and loop prominence Nov. 22, 1956

$\theta = 251^\circ$
Solar corona and loop prominence Nov. 22, 1956
\[ \theta = 251^\circ \]