OBSERVATION OF A CORONAL DISTURBANCE FROM 1 TO 9 $R_\odot$

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Abstract (*Solar Phys.*). On 1973 January 11, a flare near the west limb of the Sun caused a coronal disturbance which was observed with a unique variety of instruments. Radio observations of a type II and a moving type IV burst were obtained by the CSIRO Division of Radiophysics at Culgoora, Australia; white-light observations of a large, moving cloud were made by the U.S. Naval Research Laboratory coronagraph on OSO-7; *K*-corona observations of a decrease in coronal density were made by the High Altitude Observatory at Mauna Loa, Hawaii and Hα observations of a flare spray were made by the Institute for Astronomy, University of Hawaii at Haleakala (and also by H.A.O.).

The flare was observed with narrow-band – 0.5 Å and tunable 0.25 Å – Hα filter telescopes at Haleakala and the spray with broadband Hα coronagraphs at Haleakala and Mauna Loa, where the bandpasses were 7 Å and 10 Å respectively. The main features of the Hα events are outlined in Figures 1(a), (b), and (c). An importance IB flare began at 00^h36^m UT at N 12°, W 80° (*x* of Figure 1 (a)) in McMath region 12160, spreading to *y* at 00^h40^m, with further brightenings at 00^h47^m to 00^h49^m. The west limb spray began at 00^h37^m, with a minor ejection from position angle 286° (a of Figure 1(a)) followed by the major ejection at 00^h39^m from 289° (b of Figure 1(a)). The positions of various bright blobs were traced out to heights $\sim 2\ R_\odot$ (Figure 1(c)); they indicated that the spray material moved outwards with nearly constant (projected) velocities of 300 to 600 km s^{-1}. Minor surge activity was observed at c, d, and e of Figure 1(b) from 00^h50^m to 01^h12^m.

The radio spectrum recorded at Culgoora showed that the flare was accompanied – within one minute – by a group of type III bursts, a short-wave fadeout, and a

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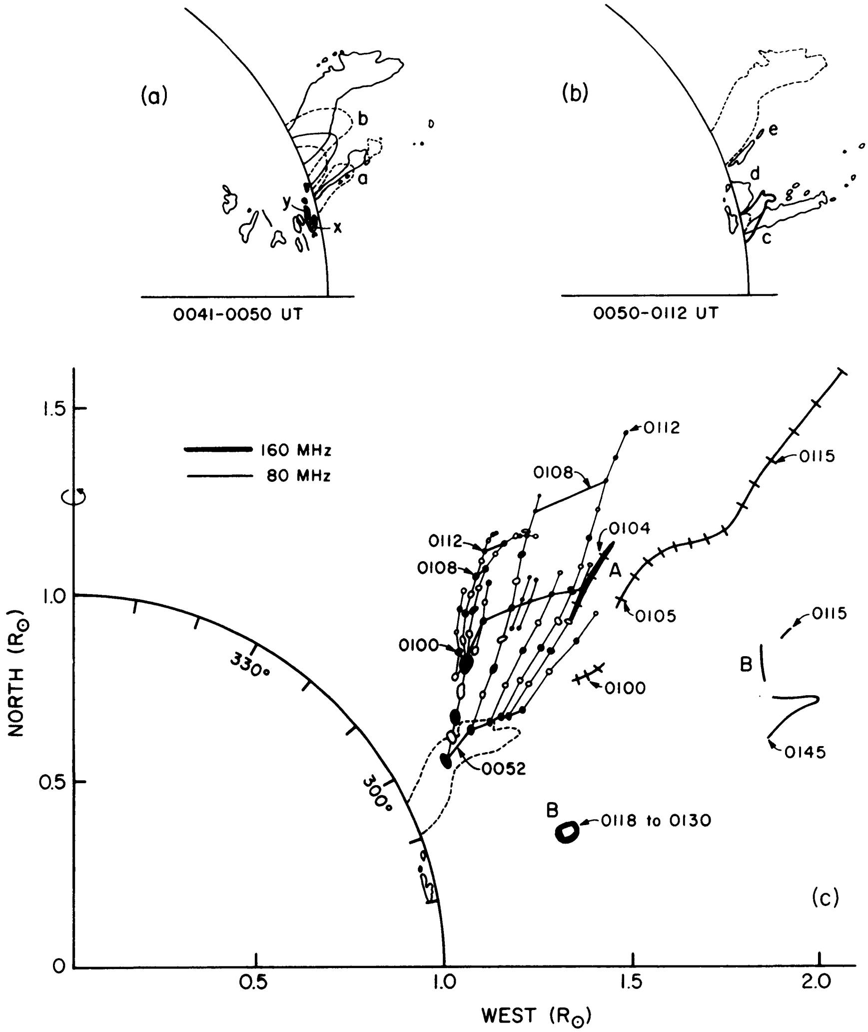

Fig. 1. Sketches of moving Hα material and positions of radio sources for the coronal disturbance of 1973 January 11. (a) Early development of the Hα spray events a and b; successive profiles are shown by full and dashed lines alternately. The flare area is hatched, with the main flare centres indicated by *x* and *y*. Plage regions are outlined and the dark points nearby are sunspots. (b) Outline of surges c, d, e at later times. For c a thick line shows its initial outline. The dashed profile outlines the spray event b at 00^h50^m. (c) Observed positions of bright blobs of the Hα spray at 2-min intervals; the light lines show the trajectories, while the heavy lines indicate the leading edge at specified times. The observed path of the moving type IV is also shown (at A) with cross marks indicating 1-min intervals, while the scatter in positions of the stationary type IV source is shown (at B) with the initial and final positions indicated by the corresponding times. In both (A) and (B) thin lines indicate 80 MHz observations, thick lines 160 MHz observations.

broadband type IV burst in the decimetre and metre wavelength ranges commencing at 00^h40^m and 01^h00^m, respectively. An intense complex type II burst started at $\sim 00^h48^m$, its beginning time being uncertain on account of the simultaneous type III bursts which accompanied a second phase of flare brightening. The frequency drifts of the various bands in the type II burst indicate that multiple shock waves travelled outwards through the corona with speeds ~800 to 1200 km s^{-1}.

From 00^{h}54^m to 01^{h}45^m, heliograph pictures were recorded once every second at either 80 or 160 MHz. At 80 MHz the type II source was multiple and located at 1.6 to 1.7 $R_\odot$ extending in position angle from 280° to 310°. The moving type IV source had a fairly constant (projected) velocity ~600 to 700 km s^{-1} at both 80 and 160 MHz (thin and thick lines at A in Figure 1(c)). The radio source and the leading parts of the Hα spray were at similar heights between 01^{h}00^m and 01^{h}12^m.

As the moving type IV source faded, a stationary type IV or 'storm continuum' source (B of Figure 1(c)) appeared above the flare region at ~1.4 $R_\odot$ (160 MHz) and ~2.0 $R_\odot$ (80 MHz). Both the moving and stationary sources were unpolarized.

K-corona intensities above the flare-spray region (out to 1.6 $R_\odot$) were measured by the coronal activity monitor at Mauna Loa. This instrument scans at a fixed height for several minutes before moving to a new height. Several fixedheight scans taken

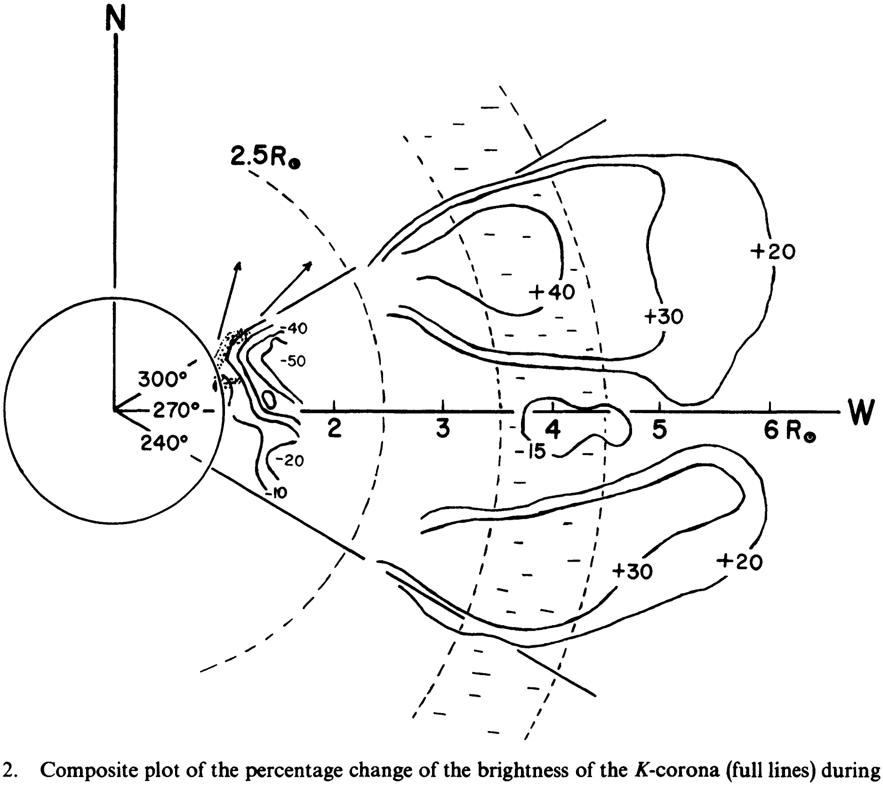

Fig. 2. Composite plot of the percentage change of the brightness of the *K*-corona (full lines) during the coronal disturbance of 1973 January 11. The isophotes below 1.6 $R_\odot$ were obtained by subtracting fixed-height scans taken by the coronal activity monitor at different times before and after the transient event. The isophotes between 2.5 and 6.0 $R_\odot$ were obtained by subtracting the OSO-7 coronagraph picture at 00^{h}14^m taken before the event from the one at 02^{h}28^m. The stippled region and the arrows indicate the Hα spray and ejection cone. The dashed arc at 2.5 $R_\odot$ indicates the outer edge of the OSO-7 coronagraph occulting disk. The polarization of the OSO-7 picture is tangential everywhere except in the hatched region between 3.5 and 4.5 $R_\odot$, where it is radial.

before and after the transient event showed that a major decrease in intensity had occurred, indicative of a depletion in the number of electrons along the observer's line of sight. The projected area of the *K*-corona depletion was extensive, ranging in height between 1.1 to 1.6 $R_{\odot}$ at position angles 240° to 300° (see the isophotes below 2 $R_{\odot}$ in Figure 2). We estimate from our limited coverage of the transient event a starting time – at 1.5 $R_{\odot}$ – of 00^h50^m, similar to the time of arrival of the fastest Hα spray material at that height. The depletion at 1.5 $R_{\odot}$ lasted until about 01^h08^m.

Instantaneous, two-dimensional pictures of the white-light corona between 3 and 9 $R_{\odot}$ were recorded at 00^h14^m, 01^h47^m, 02^h28^m, and 03^h30^m by the OSO-7 coronagraph. The first picture, obtained before the flare event, was subtracted from the remaining pictures to enhance their contrast. The high-contrast pictures clearly show that a cloud of enhanced electron density moved outwards from ~3 to ~9 $R_{\odot}$.

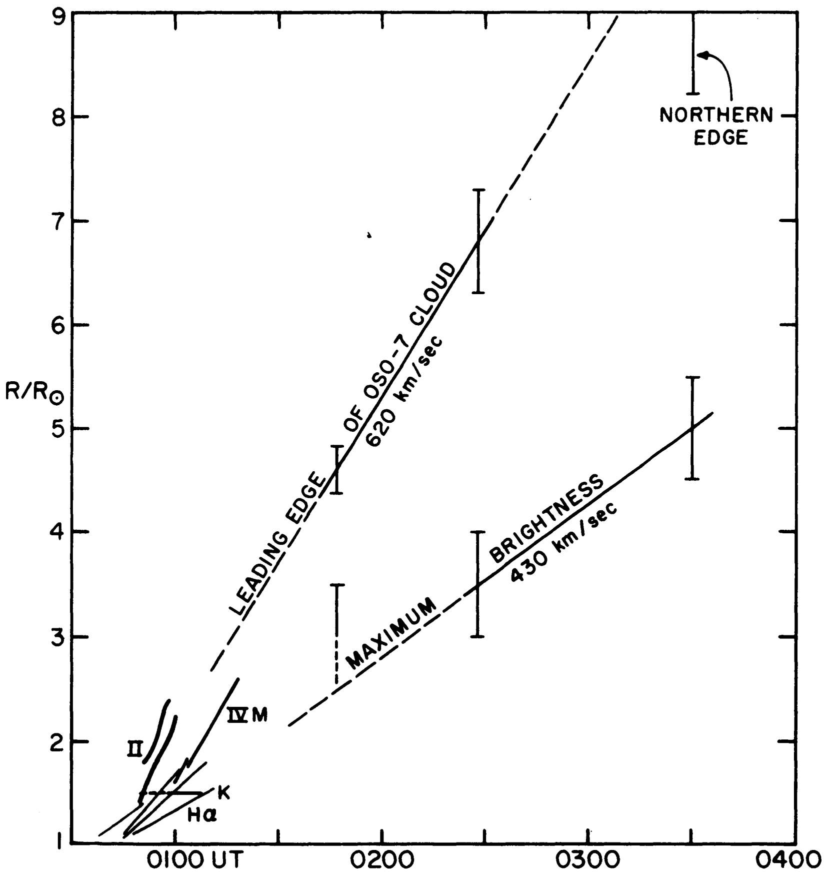

Fig. 3. Combined height-time plots of the observed ejecta in the coronal disturbance of 1973 January 11. Apart from the type II burst the projected radial velocities range from 430 km s^{-1} (the speed of the region of maximum brightness in the OSO-7 white light cloud) to 620 km s^{-1} (the speed of the leading edge of the OSO-7 cloud). The times and errors of measurement for the OSO-7 cloud are indicated. At 03^h30^m only the northern edge of the cloud was in the field of view of the coronagraph. See text for further details.

Isophotes of the percentage increase in K-corona brightness over heights 2.5 to 6 $R_\odot$ at 02^h28^m are plotted in Figure 2. The enhanced regions at position angles 250° and 300° correspond well with the two depleted regions at lower heights ($<2\ R_\odot$) observed with the coronal activity monitor.

The height of the leading edge of the white-light cloud as well as the height of the maximum excess brightness of the cloud is plotted against time in Figure 3. Also shown on this figure are the trajectories of the Hα spray (light lines) and of the type II and moving type IV bursts (labelled II and IVM, respectively). In addition, the duration of the K-corona transient at 1.5 $R_\odot$ is indicated (labelled K). We note that all the observed velocities, with the exception of that of the type II burst, lie within a velocity range of 400 to 600 km s^{-1}. Furthermore, the temporal and height agreement shown in Figure 3 suggests that a common disturbance moved outwards from the chromosphere and was manifested in various types of activity. We suggest that at the time of the flare and spray, a rearrangement of the coronal magnetic field allowed the trapped coronal gas above the flare region to expand and move outward, causing the decrease in electron density at $\lesssim 2\ R_\odot$. This material acted as a piston, driving the shock wave which caused the type II burst. The driver gas continued moving outward, producing a white-light enhancement at heights of 3 to 9 $R_\odot$. We estimate that $\sim 10^{39}$ to 10^{40} electrons (and protons) were expelled outwards to form the white-light cloud. The total energy in the expelled gas, Hα material, and radio bursts (excluding the shock wave) was $\sim 10^{31}$ erg, i.e. about one order of magnitude less than the total energy in a moderately sized flare. It will be interesting to see if an interplanetary shock wave occurred after this event.

DISCUSSION

Newkirk: The last two papers have discussed the mass content of expelled material as both cool spray material and coronal plasma. We should be very cautious in our identification of either of these with the shock material observed in interplanetary space on the basis of a mass comparison alone.

Stewart: I agree. The material in the spray is less than 10% of that in the K-corona transient or the OSO-7 clouds.

Giovanelli: Is it possible to determine whether the material is pushed out from below or pulled out from above?

Sturrock: Barnes and I have recently noticed that force-free fields may become unstable against eruption. The resulting behavior may be related to sprays. It is hard to say whether the gas should be said to be 'pulled out' or 'pushed out'.