shock wave beyond the front causes the contraction to stop and makes it expand—the phenomenon which is often observed after the onset of flares. The calculation shows that the collision of two shock-fronts at neutral plane can heat the plasma impulsively up to 10^7 °K in a small region ($\simeq 10^5$ cm), sets up powerful macroscopic motions with velocities more than 100 km/sec, and leads to the destruction (diffusion) of the initial magnetic field, which correspond to the observed phenomena of moustaches and of the destruction of magnetic fields by flares.

Two shock fronts approaching each other with velocity $\simeq 6.10^7$ can be considered as two magnetic mirrors, because $w_e \tau_e \gg 1$ in the fronts as well as in space between them. The gain of energy by electrons trapped in this space increases like $1/a^2$ (a being the distance between the fronts) and the leading term in the energy losses will increase as $1/a$ (ionization losses). X-rays and γ-radiation, as the result of Bremsstrahlung of accelerated particles and impulsive heating, should accompany the streams of electrons. This is in agreement with rocket measurements. It is of interest to note that it is possible to bring into quantitative agreement the data about the continuous emission of flares in the visible part of the spectrum with these rocket measurements when we assume that this visible continuous emission is the 'long wave-length tail' of Bremsstrahlung of particles with initial energies 10–100 m_0c^2. This shows that flares may be also considered as a source of γ-radiation [10].

REFERENCES

[1] Severny, A. B. *Trans. I.A.U.* **9**, 154, 1955; *Publ. Crim. astrophys. Obs.* **16**, 194, 1956.
[2] Severny, A. B. *Astr. J., Moscow*, **34**, 684, 1957.
[3] Severny, A. B. *Publ. Crim. astrophys. Obs.* **19**, 72, 1958.
[4] Severny, A. B. *Astr. J., Moscow*, **35**, 335, 1958.
[5] Severny, A. B. *Ibid.* **34**, 328, 1957.
[6] Friedman, H. *et al.* I.G.Y. Project, 1957.
[7] Nikulin, N. S., Severny, A. B. and Stepanov, V. E. *Publ. Crim. astrophys. Obs.* **19**, 3, 1958.
[8] Bumba, V. and Severny, A. B. *Observatory*, **78** (no. 902), 33, 1958.
[9] Severny, A. B. *Publ. Crim. astrophys. Obs.* **20**, 22, 1958.
[10] Severny, A. B. *C.R. Acad. Sci. U.R.S.S.* **121**, 819, 1958.

6. FLARE-ASSOCIATED PHENOMENA IN THE SOLAR CORONA

WALTER ORR ROBERTS

INTRODUCTION

The solar corona is markedly affected by the occurrence of flares. From a study of flare-corona interactions we may, thus, gain improved insight into the physical conditions responsible for flares and their terrestrial consequences. Only the beginnings of such researches have yet been made.

Observational studies of the associated coronal effects of flares, though less abundant and less detailed than we would like, do however indicate several salient facts:

(*a*) Pronounced apparent motions often occur in the emission-line corona at the times and locations of flares.

(*b*) When suitable observations of limb flares are available they seem to imply that tightly-curved prominences of looped character (type AS_1 in the Menzel and Evans classification [1]) are intimately connected with the flares, if indeed they are not the flares themselves. This tightly-looped character is also evident in the line-emission corona, though simultaneous prominence and coronal photographs show that the motions differ markedly.

https://doi.org/10.1017/S0251107X00021234 Published online by Cambridge University Press

(*c*) High-velocity 'spray' prominences, shooting outwards through the corona, along straight-line trajectories, are a frequent flare accompaniment [2].

(*d*) Flares usually produce distinctive radio-noise phenomena that originate in the corona.

(*e*) Flares tend to occur at the bases (or the centers of symmetry) of the outwardly directed streamers of the looped prominences and corona of an active region [3].

(*f*) There are some evidences of increases of X-ray emission below 15 Å, observed from rockets at times of solar flares [4], and such radiations most probably have their origin in the corona.

CORONAL MOTIONS ASSOCIATED WITH FLARES

Perhaps the most important observational advance since our last meeting has been the success of the Sacramento Peak Observatory staff in photographing the motions of gases emitting the green coronal line, using coronagraph and filter techniques earlier developed by Lyot. Ciné films of these motions by R. B. Dunn, H. Ramsey and other members of the Sacramento Peak Observatory staff reveal abundant examples of apparent coronal motion of a character very different from prominence motions. The association with flares of the specific features of the coronal movements is not yet on a secure basis, but the prime features of the motions appear as follows:

(*a*) Abrupt brightenings of specific regions well above the solar limb (20,000 km or more), earlier described by Waldmeier from spectroscopic data [5]. These sometimes appear with changes of the locus of brightening in the corona, a 'spotlight' effect, earlier hinted at in the films of Lyot.

(*b*) Gradual expansion of the regions of brightening, sometimes with the appearance of successively larger loops of well-defined character, described by Henry J. Smith as 'flashing loops' [6].

(*c*) Occasional development of monochromatic coronal spikes like the ones often visible in prominence spectrum lines.

(*d*) Rare coronal 'whips', which are sudden disruptions of the large-scale pattern of the quasi-static forms surrounding an active region. These sometimes seem to exhibit a damped oscillatory character, after the initial disturbance.

Newkirk has shown [7] that for highly active regions emitting the yellow lines of Ca XV, there are often distinct Doppler motions evident, which he has studied in detail for twenty-four active regions. Such regions, other workers have shown [8], appear to be closely associated with flares. Hence the results of Newkirk can probably safely be imputed to coronal gases associated with flares, though the detailed time-scale of the coronal developments following a specific flare is still uncertain and merits careful attention. His work showed that for such regions there was a good probability of detecting Doppler displacements in coronal lines ($\lambda 5303$ and $\lambda 6374$) at the positions of strongly curved prominence loops. Moreover, the coronal Doppler motions were most pronounced in the middles of the loops, rather than at their bases or their tops, and did not over-reach the upper limits of the prominences. Newkirk concluded, thus, that the coronal gases, unlike the associated prominence gases, do not move rapidly along the direction of the loop elements, but that their motions derive solely from the bodily displacement of the loop elements as a whole—with the attendant dragging along of coronal and prominence gases.

This work suggests the speculation that prominence gases ride freely along the magnetic lines of force above the active region, but that the coronal gases simply outline the locus of motion of the prominence material, save when a flare or other violent solar event produces a disruption of the general pattern of the atmospheric magnetic field, at which times the coronal gases, dragged bodily along with the field 'tubes', do reveal gross motions.

Evans' recent preliminary results [9] of mapping a sunspot magnetic field pattern during a flare seem consistent with this suggestion. Evans found a sudden change in the map of the longitudinal magnetic field component in a sunspot group, just at the time of a flare, in spite of finding a reasonably steady pattern before the flare. The change was

https://doi.org/10.1017/S0251107X00021234 Published online by Cambridge University Press

apparently everywhere a decrease, which reached a drop of 300–500 gauss in a spot field that reached 1500 gauss. It is probable that the magnetic field patterns in the atmosphere above underwent simultaneous bodily distortions.

If the above speculative descriptive picture can be confirmed and found to be general, its theoretical implications will be highly important.

PHYSICAL CONDITIONS ABOVE FLARES

Physical conditions in regions overlying flares are not yet well understood, and will not be reviewed in detail here. There is reasonably general agreement: (*a*) that coronal temperatures above flares are greatly elevated, sometimes to temperatures of 4×10^6 °K [10], as indicated by the presence of lines of high ionization atoms and by the great breadths of these lines, and (*b*) that coronal condensations around flares correspond to greater than average coronal electron densities, reaching values perhaps over 10^{11} electrons/cc.

It seems likely, moreover, that flares are generally elevated from the disk, sometimes by substantial amounts [11], which carry them into the regions of high coronal temperature, even though their H-alpha emissions probably come from temperatures of less than 25,000° K. The variations of the source function with depth in flares is still unknown, as are many of the related particulars of the energy input and output of solar flares and their associated coronal regions.

Kleczek [12] has suggested, for example, that the simultaneous emission of the high ionization lines and the low temperature emissions in active flare regions is to be expected in terms of processes involving a sudden adiabatic compression of the coronal gas, with abrupt heating to higher than normal coronal temperatures, followed by rapid radiative cooling to temperatures appropriate to the hydrogen emissions.

In any event, it seems highly likely that substantial advances will be made if it is possible to obtain good quality sequences of spectrograms showing the simultaneous development of flare and coronal spectrum lines in a limb flare. Adequate high resolution coronographic spectra of limb events, at rapid sequence, under good observing conditions, at a range of wave-lengths, have assumed a high priority in determining the fundamental physical characteristics of these most important of solar phenomena, the solar flares.

REFERENCES

[1] Menzel, D. H. and Evans, J. W. *Convegno Volta, Nat. Accad. d. Lincei*, **11**, 119, 1953.
[2] Warwick, J. W. *Ap. J.* **125**, 811, 1957.
[3] Warwick, C. Unpublished, 1958.
[4] Chubb, T. A., Friedman, H., Kreplin, R. W. and Kupperian, J. E., Jr. *J. Geophys. Res.* **62**, 389, 1957 and elsewhere.
[5] Waldmeier, M. *Z. Ap.* **27**, 73, 1950 and elsewhere.
[6] Smith, H. J. Unpublished communication, 1958.
[7] Newkirk, G. *Ann. Astrophys.* **20**, 127, 1957.
[8] Dolder, F., Roberts, W. O. and Billings, D. E. *Ap. J.* **120**, 112, 1954; Roberts, W. O. *Ap. J.* **115**, 488, 1952; Waldmeier, M. *Z. Ap.* **27**, 73, 1950 and elsewhere.
[9] Evans, J. W. Unpublished preliminary results of work in progress at Sacramento Peak.
[10] Billings, D. E. *Ap. J.* **125**, 817, 1957.
[11] Warwick, J. W. *Ap. J.* **121**, 376, 1955.
[12] Kleczek, J. *Bull. astr. Insts. Csl.* **9**, 115, 1958.