II-3A-P1. Optical Evidence for Corpuscular Radiation of the Sun

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It is generally accepted that all magnetic storms result from clouds of ionized gases, mainly hydrogen, ejected from the sun and interacting with the field of the earth. Statistically the connection between sunspot activity and magnetic storms has been discovered in 1852. A direct connection had been found when Carrington on the 1st of September 1859 had for the first time observed a solar flare, followed the next day by a world wide magnetic storm. But even now after hundred years of optical solar observations the direct evidence supporting the view that ionized gas moves outward from the sun is rather meagre.

There have been recognised different types of solar corpuscular streams, distinguished by their velocities. The very fast streams may be characterized by a velocity of the order of 100,000 km/s, the fast streams by a velocity of about 2,000 km/s and the slow streams by a velocity of about 500 km/s. The fast and very fast streams are closely connected with solar flares, but the slow streams have quite a different origin. There are no sharp limits for the velocities. The slowest particles of the "very fast" component may have a velocity not very different from that of the "fast" component. The velocity-spectrum reaches from about 300 km/s to almost the velocity of light.

Much work has been done on the fast component; its travel time from the sun to the earth has been known already in the last century to be about one day, but it was not until Hale had demonstrated in 1931 the individual connection between great solar flares and severe magnetic disturbances. The very fast component consists of low energy cosmic ray particles of solar origin with proton energies ranging from 1 up to 1000 MeV. These solar cosmic rays have been detected in 1942 by Forbush. Both the fast and the very fast particles are produced by solar flares. The slow streams were detected by the author in 1946[1] when he found that the travel time of the particles producing a special type of magnetic storms that are not connected with flares amounts to several days corresponding to velocities between 300 and 600 km/s. Later on Biermann from the study of comets has deduced a similar corpuscular radiation of the same velocity of about 500 km/s. This radiation is almost independent of time and direction and now generally called the solar wind.

Small flares are not effective in producing magnetic storms. But even between the major flares and geomagnetic storms there exists no one-to-one correlation. A high percentage of large and bright flares are not followed by any significant disturbance of the earth's magnetic field. Even if each large flare is emitting a corpuscular cloud, in many cases it may be missing the earth. On the contrary very probably each large non-recurrent storm is produced by a flare. Much work has been done on a search for optical or radioastronomical properties of flares that will permit forecasters to distinguish storm-producing from non-disturbing flares. Barbara Bell[2] has studied the relations between geomagnetic activity and large flares, with primary attention to magnetic type and location of the flaring sunspot group. She has found that a major flare occurring in association with a magnetically complex sunspot group is much more likely to be followed by a major geomagnetic storm than is a similar flare in a unipolar or bipolar group. Great-storm flares show the expected concentration toward the central regions of the solar disc, and also an unexpected concentration in the northern solar hemisphere. In the 23 years studied northern spot groups produced 62% of all observed major flares, and 86% of those followed within 3 days by a great geomagnetic storm. This north predominance of great-storm flares appears about equally in each of the three sunspot maxima covered and is apparently not related to the 11-year solarcycle. Miss Bell also studied whether there is a difference in storm production when the flare is on the same, *i.e.* the favorable, or on the opposite, *i.e.* the unfavorable side of the solar equator as the earth. No significant geomagnetic difference was found between the favorable and the unfavorable flares of any given type. Thus it seems evident that the axial hypothesis is not an adequate explanation for the seasonal variation in frequency of great and lesser non-recurrent storms. At this meeting T. Gold will explain how a corpuscular ring cloud in the sun's equatorial plane may be produced, that prevents solar clouds to escape in the direction of the equator. Such a ring cloud is able to explain the seasonal variation of the magnetic storms.

The very fast component is a rare phenomenon and only observed in connection with flares of exceptional importance. The first high-energy particles of about 100 MeV arrive within 30 minutes to several hours following the flare. The particles are observed to arrive over the entire polar cap and down to latitudes limited only by the prevailing geomagnetic cut-off. At the same time the cosmic ray intensity is increased. At high altitudes this effect is always observed, at ground level only with the most important events. At ionospheric level the solar cosmic rays produce an additional ionisation in the D-region as was observed for the first time in connection with the exceptional flare of February 23, 1956.

It seems by now well established that flares producing fast and very fast particles are accompanied at the beginning by radio-outbursts of type III and II and, even more characteristically, at the end by noise storms of type IV. These storms are believed to consist of synchrotron radiation produced by relativistic electrons in the magnetic fields of the sunspots.

There are two kinds of polar blackouts: such with a sudden commencement and such with a gradual onset. The time interval between flare and onset is from half an hour to 5 hours for the sudden commencement type and from 1 to 50 hours for the events with a gradual onset. Both these events are more often observed in connection with flares on the sun's western than on the eastern side[3),4)]

The characteristics of the three types of solar corpuscular radiation and its terrestrial effects are given in the following table.

Many attempts have been made to detect the ejection of high speed clouds from the sun. All these optical observations have yielded very little success. To my personal belief none of these observations is conclusive. I must confess that the corpuscular radiation of the fast and very fast type has not yet been detected by optical methods.

The flare itself does not show large scale motions. It is an almost stationary brightening of the chromosphere. The flare starts in the chromosphere, expands slowly, rises up to about 50,000 km and is transformed into a sunspot-type prominence and then it fades away. The rising speed is not more than a few km/s. Therefore it is clear that the flare material is not the corpuscular cloud. In many cases surges are rising out of the flare with velocities up to several

Table I. The three types of solar corpuscular radiation.

Type	Characteristic velocity	Time delay	Solar origin	Radio events	Terrestrial effects
Very fast	75 000 km/s	0.5–5^h for sudden commencement, blackouts. 1–50^h for blackouts with gradual onset.	Very important flares especially on the western hemisphere.	Type II, III, IV	Low energy cosmic rays. Polar blackouts.
Fast	2 000 km/s	17–50^h	Large flares especially near the central region.	Type II, III, IV	Great non-recurrent sudden commencement. Storms.
Slow	500 km/s	3–6^d	M-regions. Coronal rays. Old centres of activity. UM-regions. C-regions.	R-centres?	Recurrent storms of moderate importance with gradual onset.

hundred km/s. It may be that in some cases the surge is leaving the sun, but mostly the material falls back to the chromosphere. Therefore it is unlikely that surges represent the high speed cloud we are looking for. If this were so, one could expect that flares with surges are capable of producing a magnetic storm, but that flares without a surge are not. This is not observed. Flare with surges are not necessarily followed by magnetic storms, whereas flares without surges may be magnetically active.

An exceptional flare appeared just at the sun's limb on February 21, 1942[5]. It was for the first time that the vertical development of a large flare could be studied. On both sides of the bright flare, small surge-like filaments have been observed, the details of which could not be identified on pictures at 2 minutes-intervals. It may be that these were high speed features. To change completely position and shape of these features within 2 minutes the velocity must be several hundred km/s. Such high speed features are now called spray-prominences. Quite recently at the Sacramento Peak Observatory such sprays have been observed up to several 100,000 km from the sun's limb.

Spectroscopically the flare shows at its very beginning an asymmetrical $H\alpha$-profile, the blue wing being weaker than the red one[6]. This is observed whether there is a surge or not; it is a pure flare phenomenon. A surge may produce a similar effect. The asymmetry of the $H\alpha$-line can be accounted for by a cloud moving away from the sun. The velocities involved as deduced from the Doppler shifts amount up to 50 km/s. This observation does not rule out that even higher velocities may occur.

Recently Moreton has observed a phenomenon in connection with flares that looks like a rapidly expanding cloud[7]. The velocities involved range from 500 to 2000 km/s. As the observations were made in the centre of $H\alpha$ the cited velocities do not mean an outward motion, but a propagation along the surface, by which otherwise stable filaments may be activated. Whether the velocity of about 1000 km/s corresponds to a corpuscular stream or a wave disturbance is not yet clear. This observation refers to a travelling disturbance along the sun's surface, but it may be that the same disturbance is spreading out into the corona.

Now we turn to the slow corpuscular streams. These are distinguished from fast and very fast clouds not only by their velocity but by the fact that they are emitted continuously over weeks or even many months, whereas the emission of the faster clouds is confined to a few hours or perhaps to the duration of the flare only. The long persistence of the slow emissions gives rise to the well known 27 day recurrence of the moderate storms. There is obviously no clear connection between the slow corpuscular radiation and the activity centres of the sun. Therefore Bartels has introduced the term M-region to designate the location from which the slow streams take their origin.

A first attempt to identify the M-regions was made by the author in 1939 and 1942[8]. He introduced the term C-region; this is a region of the inner corona which shows the emission line 5303 relatively strong, in absence of larger photospheric disturbances. C-regions are always in or near the sunspot zone, but within this zone they are in spot-free areas. C-regions have statistical properties similar to those of M-regions, and therefore both may be identical.

In a second attempt it was possible to correlate closely the M-regions with long-lived filaments (stable prominences)[1]. In a third investigation the nature and development of M-regions have been studied. These regions from which the continuous corpuscular radiation of the sun originates are those which were at first covered by spots but afterwards remained spot-free for a considerable length of time. This view was able to explain the remarkable property of the *M*-regions, that they appear only in those years which immediately precede the sunspot minimum[9].

These various attempts to identify the M-regions have been considered by a number of astronomers as representing a change in the views of the author, in the belief that each later communication was a correction of the previous one. This, however, is not the case; the various papers do not represent different views, but only different aspects of one and the same view. Both the large filaments of the main zone, as well as the C-regions, are the successors of spots, but survive long after the disappearance of the entire spot groups. Regions which are covered by filaments, C-regions and dead spot areas are different aspects of one and the same event.

More recently Babcock has found a similar connection between M-regions and the magnetic unipolar regions on the sun. This confirms very well the proposed nature of the M-regions, as the magnetic unipolar regions are always very old centres of activity[10].

Some authors have confirmed these results, some others did not. The latter have used the intensity of the corona without making any distinction between cases where the bright coronal regions occur in conjunction with spots and where they appear without spots. Since, however, the coronal brightness is always greater near spots, and since the greatest observed brightnesses have always been associated with spots, we must expect the statistics of coronal intensities to be very similar to those of the spots, while they will differ essentially from the statistics of the C-regions as I have defined them.

Neither the C-regions nor the stationary filaments nor the unipolar regions represent the solar corpuscular radiation, but are only indicators of it. From eclipse photographs it is well known that the base of a long streamer is usually occupied by a stationary prominence. Therefore the long coronal rays are believed to represent the corpuscular streams we have looked for for such a long time. Unfortunately the coronal rays can only be observed at a total eclipse. Therefore our knowledge of the nature of these streamers is meagre and especially nothing is known of their motions. Sometimes old and stable filaments begin to rise, are accelerated upwards and escape from the sun with velocities of at least 500 km/s. As these filaments and the coronal streamers are intimately connected, it is believed that the coronal rays represent the solar streamers and that the prominences are floating in them. Such an ascending prominence has been observed on March 18, 1961 reaching a height of 733,000 km (Fig. 1). The trajectory was very similar to the shape of a coronal streamer observed during the total eclipse of the sun on February 15, 1961 at the same latitude as the prominence was observed. Accepting that the material in the coronal streamer was subject to the same motion as the prominence, then the equation of continuity is fulfilled: $r^2v\rho=$const. ($r=$distance to the centre of the sun, $v=$velocity, $\rho=$density in the coronal streamer). This observation gives strong support to the idea that the long, stable rays of the corona represent corpuscular streamers. If this is so, then this observation is the first optical evidence for corpuscular radiation of the sun.

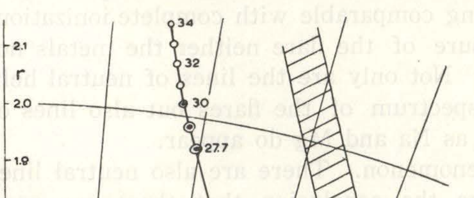

Fig. 1.

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Discussion

Sarabhai, V.A.: In many of the regions which show flare activity, one see the repeated flaring within a short period. Many experiments are dealing with the particle emission from the sun. You emphasized the time delay of the optical event to the arrival on the earth. In the light of the comment which you made, flare has perhaps little to do with the actual emission of particles. Could you give us your view as to how valid these arguments are regarding the time of delay. Particularly, what do you think that these optical phenomena are at least triggering mechanism?

Waldmeier, M.: I do not think that optical flare produces high energy particles. High energy particles are produced at the same moment as we see the flare certainly not before. Before the flare, nothing is seen optically in the corona that is extraordinary. After the flare we can see some disturbances in the corona for several hours which are probably closely correlated with type IV radio outburst.

Carmichael, H.: Can you estimate the duration of time required for the acceleration of the very high energy particles by the flare? Is it a process that goes on for seconds only, or minutes, or perhaps hours.

Waldmeier: Most probably the acceleration of the very high energy particles takes place during the flash-phase at the beginning of the flare. The duration of the flash is of the order of ten minutes.

Athay, R.G.: I think it is also fair to say that most of the activites occur during the time of rise to maximum of the flare and the later state is apparently decay phenomena.

Swann, W.F.G.: I should like to ask as to the degree of ionization at the temperature of the flare. Does it amount to anything comparable with complete ionization?

Waldmeier: At the temperature and pressure of the flare neither the metals nor hydrogen and helium are completely ionized. Not only are the lines of neutral helium and hydrogen extremely strong in the spectrum of the flares but also lines of neutral metals of such low ionization energy as Na and Mg do appear.

Athay: So, the flare is a very complex phenomenon. There are also neutral lines present in a flare and we just have to arrive the conclusion that there are very sharp temperature gradients within the flare.

Sarabhai: I am wondering if the form of the corona changes with short duration, and which indicates that the matter is coming out through the corona.

Waldmeier: As I already talked there is a condensation in the corona, all with observing connection with the flare. We have limb flare. After one hour, intensity of the flare very much decreases. Then there remains only the coronal condensation, which has life time of several hours and shows always a very small rising velocity of only about a few km/s so that it arise $5\times10^4\sim10^5$ km after a few hours.

Athay: If I could comment furthermore, an observer at Sacramento Peak has successfuly photographed a green line corona through filters. They observed loop like structures which at time do break by a rip like action with velocity of the order of a few hundred to thousands of km/s, which certainly suggest a sort of thing which you suggested.

Carmichael: You discussed the very interesting connection between coronal streamers, filaments, M-region, and unipolar regions on the sun. It is known that filaments slowly migrate to the polar regions on the sun. Doesit follow that there may be a close connection between these phenomena and the general magnetic field of the sun? In other words, is the general field to be attributed to an accumulation of these streamers towards the poles of the sun?

Waldmeier: There is indeed a very close connection between the sun's general magnetic field and the polar zone of prominences [M. Waldmeier, ZS. f. Astrophys. **49** (1960) 176]. This zone is a separation between magnetic fields of opposite polarities. As this zone is migrating towards the pole, the polar field vanishes and becomes replaced by the opposite field on the low-latitude side of the zone. As the long coronal streamers originate from regions occupied by prominences, these streamers indicate the boundary of the general magnetic field rather than the field itself.

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II-3A-P2. Solar Radio Outbursts and Acceleration of Electrons

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Wide-band spectra of intense long-duration outbursts are studied. In a course of such an outburst there occur three distinctive components of outburst. One is long-duration outburst on cm-waves and the other is believed to be original type IV burst on m-waves. These groups occur with a clear gap in the frequency range or are mixed in some frequency ranges by accompanying another group on dm-waves.

In order to account for the above characteristics, acceleration of electrons due to hydromagnetic waves is discussed. In order that the accelerations proceed to relativistic energies, redistribution of the velocity of accelerated electrons must be made. This redistribution may be made by Coulomb collisions with thermal electrons before their energies are lost by the collisions.

The accelerated electrons tend to accumulate to the places where the magnetic field is greater to radiate synchrotron radiations. At intense eruption, a few magnetic bulges would be made to be separate radio sources for m-IV, dm-IV and cm-IV outbursts.

It is also shown that hard X-ray bursts and microwave bursts with short durations are consistently explained by the same electrons accelerated at moderate eruptions.

§1. Wide-Band Spectra of Intense Outbursts with Long Durations.

Dynamic spectra of intense outbursts have been studied in Japan in a wide frequency range, from 9400 Mc to 67 Mc, at about ten point frequencies and partly using swept frequency records[1),2)]. Number of the outbursts studied from 1958 through the end of 1960 is about twenty.

Generally, the spectra show complex patterns. However, in the course of such an outburst, there appears at least three distinctive components of long-duration outbursts. One is outburst in centimeter-wave range (tentatively named cm-IV), the other is in decimeter-wave range (dm-IV) and another is in meter-wave range (m-IV) which seems to be original type IV named by A. Boischot. At large eruptions, all of three components occur and they are mixed in some frequency ranges, but sometimes have clear frequency gap. In some moderate events only two of them occur.

Examples of intense outbursts are shown in Fig. 1. These spectra show clear frequency-gap between dm-IV (above about 200 Mc) and m-IV (below 200 Mc).

Sometimes, dm-IV and m-IV show slow frequency drift with time towards lower frequencies (see, Fig. 1). It should be noted that outbursts at 200 Mc are generally an *extension of dm-IV* except during 10−20