CORONAL STRUCTURE AND SOLAR WIND

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ABSTRACT

Recent observations of large scale coronal structures and solar wind have been studied. The intercorrelation of the two have been qualitatively explained through the focussing of solar-ion streams taking account of the local and general solar magnetic fields. This explains the association of coronal holes with weak, diverging open magnetic field lines and envisages the transfer of hydromagnetic wave energy from nearby active centers to account for the enhanced outflow of solar wind associated with coronal holes.

1. CORONAL STRUCTURES AND SOLAR WIND

During the past one decade, we gained some new information regarding the solar wind and their association with coronal structure. The coronal structures are primarily responsible for filling the entire interplanetary space with fast and slow solar wind. Variation of solar wind speed by several hundred kilometer over its mean value of 450 km/s have been observed (Gosling et al., 1976). In addition, Feldman et al. (1976) have revealed several instances of high speed streams of velocity $\geq$ 650 km/s during March 1971 through July 1974. None of the existing theory predicts speeds in excess of 650 km/s at 1 A.U. with proton flux of $(3.3 \pm 0.5) \times 10^{8}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}$. These streams have different characteristics than the usual solar wind; eg. $T_p^{\perp}/T_p^{\parallel} = 2.4$ instead of normal 0.5; also $T_p > T_e$ instead of $T_e > T_p$. Thus there is a significant gap between theory and observation and input of some additional energy source is required.

Further, information collected through X-ray and EUV measurements by OSO-7 and Skylab ATM mission and by 1.5 $R_{\odot}$ K-corona observations have revealed the existence of two prominent coronal structural features; vis.

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(i) The Active Centres: They constitute large bright areas of high density and temperature in corona similar to coronal condensations overlying strong bipolar or more complex magnetic field regions of the photosphere. Many loop-like structures are seen invariably connecting regions of opposite magnetic polarity in the photosphere. Hansen et al. (1976) showed that the bright coronal regions of 1.5 $R_{\odot}$ K-corona, being identical to active centres, inhibit geomagnetic activity on +3 day of its CMP-consistent with the "cone of avoidance" model of Allen (1944).

(ii) The Coronal Holes: The large coronal structures of greatly reduced X-ray, EUV and metric radio emission are usually referred to as coronal holes (CH). The density and temperature above CH are respectively lower by a factor of 3 and 2 than the average quiet sun, while the thickness of the chromospheric-coronal transition zone increased by a factor of 3 in holes over that in quiet sun. K-corona observations also reveal similar properties of the holes. Most important and striking aspect of these holes is their apparent occurrance in weak open diverging unipolar magnetic regions. These holes are seen to occur both at the centre and the pole. The polar holes, though similar to equatorial ones, are somewhat larger and long lived structures.

CMP of CH are now known to be followed by increase in geomagnetic activity (K_p maximum at +3 day). In general near equatorial CH($\leq |40^{\circ}|$) are associated with enhanced solar wind speed at 1 A.U. in the ecliptic plane with the interplanetary magnetic polarity in stream agreeing with solar polarity beneath the CH and that they are responsible for M-storms. (Altschuler et al., 1972; Munro and Withbroe, 1972; Bell and Noci, 1973, 1976; Krieger et al., 1973; Vaiana et al., 1973; Neupert and Pizzo, 1974; Timothy et al., 1975; Hansen et al., 1976; Nolte et al., 1976; Rickett et al., 1976; Sheeley et al., 1976). In fact both equatorial CH and M-regions are known to develop in areas empty of spots.

Earlier, Tandon (1958, 1963, 1966) proposed that M-regions have coronal origin and can be placed in two groups; vis. (i) the disturbed M-region and (ii) the quiet M-region. The basic properties of these M-regions, as envisaged through various possible identification of M-regions with variety of solar features, are respectively identical with the active centres and the CH.

2. FOCUSSING OF SOLAR-ION STREAMS

Considering the effect of "frozen in" magnetic feild on the focussing of solar plasma streams, especially in the neighborhood of the solar atmosphere, Tandon (1958, 1963, 1966) has obtained the following conditions for the focussing of streams:

$$i_c \geq i_c = (2N\Psi + q^2 + 2M)^{\frac{1}{2}} \qquad (1)$$

that is, the stream will get focussed if the total current in the stream of unit length exceeds the critical value i_c. Here N, Ψ, q, and M are respectively the total number of particles per unit length of the stream, the mean kinetic energy of the particles due to transverse component of velocity, the total charge per unit length of the stream and the polarized electric field energy per unit length of the stream. Further, M involves a vector product of frozen-in field H and the velocity V and hence will be zero when the condition (1) may be satisfied and hence the stream may get focussed. Further it is evident from the condition (1) that in the neighbourhood of the active centre of the sun, M will be relatively large and hence the magnetic field will disperse the solar plasma particles from the stream and the stream may not get focussed, i.e., there will be an increase in the non-radial dispersion of the stream, referred to as "magnetic dispersion". However, there is a likelihood for the stream to get focussed in the neighbourhood of coronal regions where the magnetic field of the active centres decreases considerably.

Let us now consider the bearing of condition (1) on coronal structures. The magnetic field associated with active centre will give rise to large magnetic dispersion which may continue to a distance of about one solar radius or so. Afterwards the focussing is likely to set in since the magnitude of the magnetic feild at such large distances decreases considerably on account of low density. Such a process of magnetic dispersion and subsequent focussing will lead the particles to remain away from the active centres or, in other words, the streams form a 'cone of avoidance'. This process is roughly represented in Figure 1. The edges of the cone on projection will appear to come from the adjacent areas of the active centres and that the corona overlying these active regions should possess large density and temperature due to associated large magnetic field forming coronal condensations. Further, the width of the cone is expected to be about 30^o-40^o near the maximum development of the active region and zero at the time of extinction of the spot (see Figure 2).

During the decaying phase the magnetic field of the active region is known to fall off rather sharply ejecting large magnetic field in the form of detached plasma clouds in accordance with the plasma ring experiment of Alfven et al. (1960). These detached plasma clouds are likely to form coronal regions of low density and temperature with open field line structures overlying the decaying spot - the CH. At the photospheric and low chromospheric level features like granulation, super granulation and oscillations will become indistinguishable with the neighbouring regions outside the spots. This indicates that the mechanical input passing up through the photosphere may be substantially the same inside and outside the holes. The radiative and conductive losses will be less due to low density and temperature in the holes. This results in an excess energy which goes into creating and accelerating a solar wind that emanates primarily from the regions of the holes. Further, extrapolating the observations of plasma ring

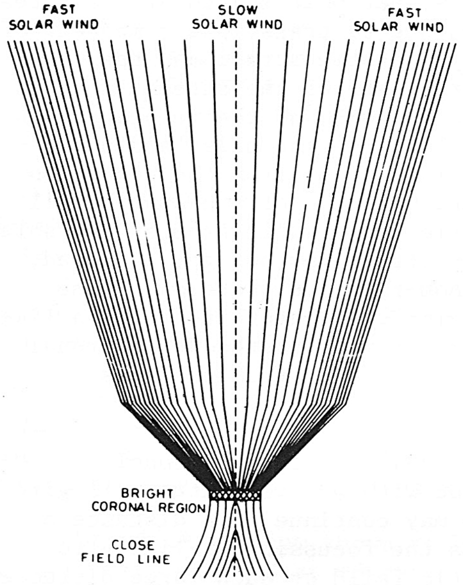

Figure 1. Figure illustrating qualitatively the effect of magnetic field on the focussing of solar ion stream and formation of 'cone of avoidance.'

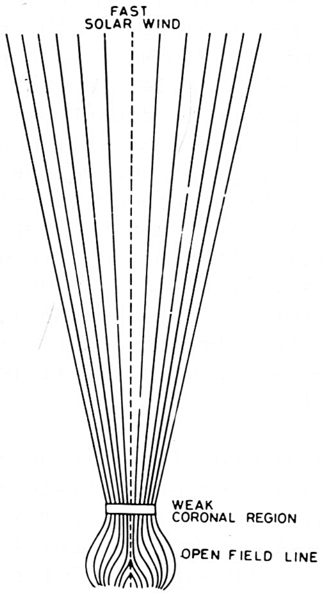

Figure 2. Structure of proposed solar beam at the time of extinction of solar active region.

experiment to incorporate the effect of large conductivity and magnetic field of neighbouring regions one should expect that the detached plasma clouds at the time of vanishing of parent active region should form closed field lines either with local field of another active region as shown in Figure 3 or with other weak field region including the general magnetic field of the sun. In the former event the coronal structure above the parent active region should disappear with the decay of active centre. During this phase, a large amount of energy in the form of Alfven waves will be imparted to this coronal structure enhancing considerably the solar wind speed at times > 650 km/s and enhanced proton temperature such that $T_p > T_e$ even. This thus throws light on the mechanism for explaining the observations of Feldman et al. (1976). On the other hand, in the latter case, there will be comparatively low feedback of Alfven wave energy creating high speed solar winds conceivably dwarfing the rather modest solar wind, to form a solar wind with variable wind velocity.

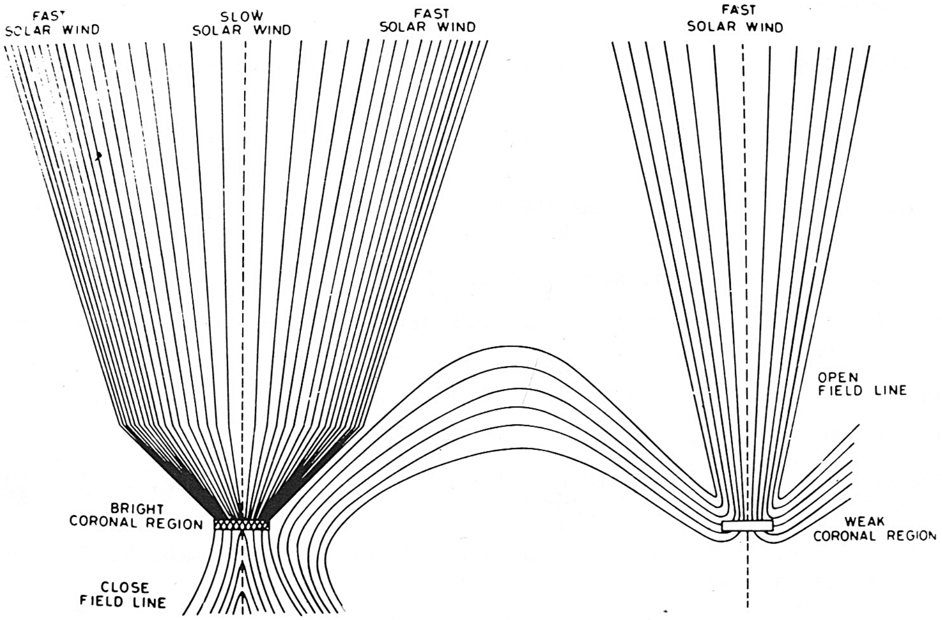

Figure 3. Structure of proposed solar bean when the activity of solar region (right) has died out.

During the high sunspot activity period the dispersed streams from the neighbouring active solar regions might collide with the solar plasma stream of decaying region and are likely to get disrupted into small clouds of space charge due to electrostatic instabilities. As we go towards the low sunspot activity period such interaction of solar plasma streams would be small and there is then a likelihood for the existence of a stable stream. By the time we reach the sunspot minimum period the frequency of these stable streams decreases since it is proportional to the number of parent active centers apart from their dependence on the frequency of disruption. Since frequency of disruption is also dependent on the number of active centres, one should expect maximum frequency for these stable streams about one or two years before the sunspot minimum as expected.

At times it may happen that a particular stream escapes collision for a considerably longer period. Such a possibility can occur only near the sunspot minimum. In this case the stream may last as long as 3-4 years and the projection of such a stream on the sun's surface should coincide with low coronal line regions - the equatorial CH. Converse of this may not be true. Further, it is also clear from Figures 1-3 that the CH will, in general, be associated with open field line structure.

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