ON NEUTRAL LINE ABSORBING FEATURES

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ABSTRACT

Recent observations of "Neutral line absorbing features" in the solar atmosphere are briefly recalled. It is suggested that as new magnetic flux emerges, a current sheet builds up between the new and old flux. When the sheet reaches a length of about 500 km, the thermal conduction becomes sufficiently ineffective for a thermal instability to occur. The resulting compression and inflow of plasma is observed in Hα on the disk as a neutral line absorbing feature. It is shown that the electric field developed in the accompanying collisionless tearing mode instability may accelerate electrons to high enough energies to produce the type III burst which usually occurs at the same time as the absorbing feature.

1. OBSERVATIONAL FACTS

We shall first recall the observations in order to outline the requirements that the theory should fulfill. These have in their majority already been presented at the CESRA meeting in Bordeaux (Axisa et al., 1973). Detailed reports can be found in her papers by Axisa, Martres, Pick and Soru-Escaut (1972, 1973, 1974). The main points are:

1) The transient Hα absorbing feature is observed on filtergrams both in- and off-band. Figure 1 shows the time development of such a perturbation, which looks very much like the formation of filamentary matter; however unlike a filament it is not in a stable state.

2) The feature consists of two parts, one on each side of the line of separation between a large photospheric polarity and an opposite "satellite" polarity.

3) Assuming that the difference in the intensity of the two Hα wings is due to a Doppler shift, the observation reveals that one part of the feature rises whereas the other falls. We stress the fact that the "blue-" and "red-wing" features do not coincide spatially. This behaviour may be regarded as similar to that of filament activation (Tlachica and Takakura, 1962); simply, in the present case the "activated" matter was not observable as an Hα absorbent before. Typical velocities along the line of sight are of the order of 10 km/s. Much larger velocities are not accessible to this observational technique, however.

4) The phenomenon has a typical duration of 20 minutes. It is worth noting that the formation of the absorbing feature takes only a few minutes, whereas its disappearance is very gradual. Some cases show a definite delay between the blue wing phenomenon, which appears first, and the red wing one, which follows several minutes later. Figure 1 shows one such case.

5) These chromospheric perturbations have been recognized to be associated with type III bursts, emitted when no flare was in progress. However, the absorbing features produce type III bursts, only when they form at the border of active regions presumably because the accelerated electrons can then escape more easily. The type III burst is usually emitted when the red wing absorption is most intense, that is a number of minutes after the beginning of the perturbation.

6) OGO V's X-ray data reveal that soft X-rays are produced (Kane et al., 1974). Figure 2 shows one such observation. The X-ray emission is of a gradual rise and fall type.

7) The perturbation is often observed to recur at the same place during a number of hours. In some cases a stable plage filament is observed to have been formed about one day later along the same inversion line of the photospheric polarity (Mercier, 1973).

8) As a second step a flare sometimes follows the appearance of the absorbing feature, which often continues to remain visible during the flare progress. The two flare knots form on each side of the absorbing feature, and then expand in two ribbons that run alone it.

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2. FORMATION OF THE ABSORBING FEATURE

It is quite natural to think that the satellite polarity involved in the phenomenon (point 2 above) is actually some emerging flux. The emerging field would press against the already existing one as to form a current sheet in the atmosphere of the sun. The growth of such a sheet has been studied by Priest and Raadu (1974). In such a newly formed current sheet, a thermal instability will occur, and the plasma will concentrate to form dense and cool material there. Since the parasitic fields emerge from below, the current sheet will in general be inclined at an angle, as shown in figure 3. The plasma, condensing towards the sheet while cooling, will be observed to have an ascending component of its velocity towards the observer on one side of the sheet, and a receding one on the other side. This would be consistent with the points 2) and 3). Typical speeds on this process can be estimated by the following argument. According to Kuperus and Tandberg-Hanssen (1967) the time scale for the cooling in this structure scales as:

$$\tau_c = 3.2 \times 10^{-10} \frac{T_1^2}{p_1} f(\beta),$$  \hspace{1cm} (1)

where $T_1$ is the temperature, $p_1$ and $\beta p_1$ the gas and magnetic pressures outside the sheet, $f(\beta)$ has been tabulated by those authors. The point 4) above indicates that $\tau_c$, if it determines the time scale of formation of the absorbant, should be about $10^2$ seconds. This is obtained for temperatures and pressures typical of the low corona, namely $p_1 = 10^{-3}$ N/m$^2$, $T_1 \sim 5 \times 10^5$, $10^5$ $\text{K}$. The altitude of the phenomenon would then be about 7000 km. This is approximately the altitude of stable plage filaments, which is satisfactory in view of point 7. Now, the mean flow speed $<v>$ can be estimated. Let $\rho_1$ and $\rho_2$ be the initial and final densities, and $\delta$ the final thickness of the sheet of cooled matter. The equation of mass continuity implies:

$$\rho_1 <v> \tau_c = \rho_2 \delta$$  \hspace{1cm} (2)

Observations suggest $\delta$ to be of the order of or less than 1000 km, and $\tau_c$ is given by (1). The existence of neutral hydrogen in the cooled matter means that $\tau_c$ the temperature must have lowered to at most $10^4$ $\text{K}$. Assuming that an approximate pressure equilibrium exists between the interior of the cooled sheet and the outer medium, we arrive at the conclusion that $\rho_2/\rho_1$ is larger than about 10. $<v>$ is then found to be about 50 km/s, consistent with the observed line of sight velocity reported on point 3).

The cooled gas is in contact with the hot corona both at the top and bottom of the sheet (fig.3).

Thermal conduction is most effective along field lines. The time needed to smooth out a temperature drop $\Delta T$ over a distance $L$ is found from the heat equation to be

$$\tau_{//} = \frac{L^2}{K_{//}} \frac{T}{\Delta T},$$  \hspace{1cm} (3)

where $K_{//}$ is the thermal conductivity along field lines. Let us take $T = \Delta T$. The condition for the thermal instability to occur is that the radiative cooling proceeds faster than the conductive heating. The inequality $\tau_{//} > \tau_c$ defines a minimum length of the sheet for the perturbation to occur, which turns out to be approximately 500 km. These ideas suggest the following history for the growth of the current sheet: at the very beginning of the emergence of new satellite flux, the current sheet is so small that thermal conduction prevents the instability occurring. Then the sheet slowly grows and a period exists during which $\tau_{//}$ is barely smaller than $\tau_c$, i.e., L is of the order of 1000 km. During this period transient absorbing features would form quickly and then disappear slowly as they are heated by thermal conduction. If finally the sheet becomes so large that thermal conduction becomes ineffective, a stable plage filament would form in the manner suggested by Raadu and Kuperus (1973).

3. PARTICLE ACCELERATION

The observational point 5) indicates that an impulsive acceleration occurs during the process of the thermal instability. It could be produced by the electric field induced in the tearing mode instability of the current sheet. For the parameters of the last section ($10^5$ $\text{OK}$, $10^{16}$ electrons m$^{-3}$), the plasma is effectively collisional, the electron mean free path being in this case of the order of 100 meters. The most rapid processes should then take place in the collisionless central slab of the sheet, the width of which would be of the order of the mean free path. The growth rate for this instability has been given for the most realistic two-dimensional configuration by Biskamp and Schindler (1971). The induced electric field turns out to be of the order of...
\[ E_{\text{merging}} = k \nu_{Te} \sqrt{\frac{\rho_e}{\ell_s}} B_s \ell_S \]

where \( k \) is the wavenumber of this merging-mode instability, \( \nu_{Te} \) is the electron thermal velocity, \( \rho_e \) the electron gyroradius in the field \( B_s \) at the edge of the collisionless slab; accepting this value as representative for the present case, the induced electric field is estimated to be approximately

\[ E_{\text{merging}} \approx 15 \sqrt{B_{\text{ext}}} \text{ Volts/m} \]

where \( B_{\text{ext}} \) (Tesla) is here the magnetic field out of the layer that suffers the thermal instability. This field compares with the Dreicer field, which is 0.13 Volts/m for the above parameters. Thus if \( B_{\text{ext}} \) is larger than 1G, runaway electrons are likely to be produced. If they are accelerated freely along the whole sheet (1000 km) they would reach energies of the order of 150 keV. Type III bursts are believed to be produced by 40 keV electrons, and so the possible reduction in acceleration due to the turbulence developed by the runaway electrons must not exceed a factor of 3 or 4. This is possible if, for example, the central slab is sufficiently inhomogeneous to ensure that the resonance between particles and unstable waves can exist in small regions only.

A number of problems remain to be solved here, however, especially that of the number of particles accelerated. This number is believed to be of the order of \( 10^{30} \) for weak type III bursts (Lin et al., 1933). This represents an energy far larger than the magnetic energy contained in the central collisionless slab. Energy should then be brought into the region which is subject to the merging instability, where it can finally be efficiently transferred to the electrons. The way this inflow of energy proceeds requires a special study and is the main problem.

REFERENCES

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Lin, Evans, Fainberg: 1973, Preprint
Figure 1. Development of an absorbing feature phenomenon (From Axtia et al., 1973, Solar Physics)
Figure 2. Soft X-ray phenomenon accompanying an absorbing feature (From Kane et al., 1974)

Figure 3. A schematic view of the formation of an absorbing feature