A CLUE TO THE TRIGGER FOR BOTH THE TYPE III
SOLAR RADIObURST AND THE SOLAR FLARE

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Abstract. Recent observations of ‘neutral line absorbing features’ in the solar atmosphere may give
an important clue to the mechanism whereby both type III solar radiobursts and solar flares are
triggered. It is suggested that as new satellite magnetic flux emerges at the edge of an active region
in an area of opposite polarity a neutral sheet builds up between the new and old flux. When the
sheet has a length of about a megametre its thermal insulation from the surrounding plasma is
effective enough for a thermal instability to occur. The resulting compression and inflow of plasma
is observed in Hα on the disc as a neutral line absorbing feature. Furthermore, the electric field of
the accompanying collisionless tearing mode instability in a thin slab near the centre of the sheet
exceeds the runaway field; it may therefore accelerate electrons to high enough energies to produce
the type III burst which usually occurs at the same time as the absorbing feature. Perhaps the flare
which sometimes ensues is triggered when the quasi-equilibrium state is destroyed by the develop-
ment of turbulence in the neutral sheet.

1. Introduction

The purpose of this note is to give a theoretical model for so-called ‘neutral line ab-
sorbing features’, which are situated in the solar chromosphere or lower corona and
appear to be associated with solar type III radio bursts. Some fascinating observations
of them in Hα photographs have recently been reported by Martres et al. (1972) and
Axisa et al. (1973). The main observations to be explained are as follows:

(i) Absorbing features are interpreted as locally dense and cool material.

(ii) A particular type, which we refer to as ‘a neutral line absorbing feature’ is
situated at the edge of an active region near an $H_{\parallel}=0$ line, where the line of sight
component of the photospheric magnetic field is zero.

(iii) The feature typically consists of two parts which meet along the $H_{\parallel}=0$ line
with possibly some spatial overlapping. One moves upward and the other downward
with line-of-sight speeds between 0 and 30 km s$^{-1}$ though typically 10 km s$^{-1}$.

(iv) Each part of the feature appears with a rise time of a few minutes, followed by
a decay over a few tens of minutes. The two parts are not necessarily coincident in time,
but some temporal overlapping is the rule.

(v) A type III radio burst is nearly always triggered during the development of the
absorbing feature, somewhere near its maximum.
(vi) Sometimes, after the appearance of the feature, a solar flare occurs and is often survived by the feature (most of the observations to date are of small flares or flaring features).

When satellite spots (Martres et al., 1966, 1968; Rust, 1968, 1972) appear at the edge of active regions in an area of opposite polarity, it is likely that the emerging magnetic field presses against the field which is already present. In the atmosphere above the photosphere is then formed a neutral current sheet (or neutral sheet, for short) in which there are strong currents and the magnetic field reverses in sign (Green, 1965; Priest and Raadu, 1974). Further, since the satellite magnetic field emerges from below, the neutral sheet will in general be inclined at an angle, as shown in Figure 1.

![Figure 1](image_url)

**Fig. 1.** A schematic representation of the emergence of satellite flux at the edge of an active region. A neutral current sheet of length $L$ forms between the new and old flux.

We suggest that, when the neutral sheet is sufficiently long, a thermal instability occurs, producing locally dense, cool plasma (the absorbant feature). This is consistent with observations (i) and (ii) above when one remembers that the active region field is in general much more complex than shown in Figure 1; the significance of the observed photospheric $H_{||} = 0$ line is that it probably marks the boundary between the old and emerging flux. The condensation produces an inflow to the neutral sheet as indicated by heavy-headed arrows in Figure 2. When viewed from the Earth (the top of the figures), the motions are consistent with observation (iii); typical speeds are estimated in the next section. We suggest, further, that particles are accelerated in the neutral sheet up to high enough energies to emit type III radiation; some comments are given in the third section. It should be noted that the most favourable
place for the occurrence of the thermal instability is a neutral current sheet. Elsewhere, thermal conductivity tends to suppress the instability and, even if it occurs, the resulting build up of large magnetic fields tends to limit it. On the other hand, in a neutral current sheet the plasma is more effectively insulated by the magnetic field against thermal conduction; in addition, the accompanying annihilation of magnetic flux by a fluid tearing mode instability means that the plasma compression is not inhibited by the buildup of a large magnetic pressure (Kuperus and Tandberg-Hanssen, 1967).

2. The Thermal Instability

Kuperus and Tandberg-Hanssen give the following expression for the cooling time $\tau_c$ in a neutral sheet:

$$
\tau_c = 3.2 \times 10^{-10} \frac{T_1^2}{p_1} \beta \log \left( 1 + \frac{1}{\beta} \right) - 1, \tag{1}
$$

where $p_1$ and $\beta p_1$ are the external gas and magnetic pressures, respectively, and $T_1$ is the initial temperature. In Table I, we show the value of $\tau_c$ for a pressure $p_1 \approx 10^{-3}$ N m$^{-2}$ (characteristic of the high chromosphere or low corona) and a series of values of $\beta$ and $T_1$. Observation (iv) of neutral line absorbing features indicates that they appear on a time scale of several $10^2$ s. From Table I we see that this agrees with $\tau_c$ if a temperature of $5 \times 10^4$–$10^5$ K is adopted. According to Allen (1963) the corresponding height above the photosphere is roughly 7 Mm (=7000 km).

<table>
<thead>
<tr>
<th>$T_1$</th>
<th>$\beta$</th>
<th>5</th>
<th>3</th>
<th>1</th>
<th>0.5</th>
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<td>$10^6$</td>
<td>$2 \times 10^4$</td>
<td>$5 \times 14$</td>
<td>$10^5$</td>
<td>$2 \times 10^3$</td>
<td></td>
</tr>
<tr>
<td>$5 \times 10^5$</td>
<td>$5 \times 10^3$</td>
<td>$10^4$</td>
<td>$2.5 \times 10^4$</td>
<td>$5 \times 10^4$</td>
<td></td>
</tr>
<tr>
<td>$10^5$</td>
<td>$2 \times 10^3$</td>
<td>$4 \times 10^2$</td>
<td>$10^3$</td>
<td>$2 \times 10^8$</td>
<td></td>
</tr>
<tr>
<td>$5 \times 10^4$</td>
<td>50</td>
<td>$10^2$</td>
<td>$2.5 \times 10^2$</td>
<td>$5 \times 10^8$</td>
<td></td>
</tr>
<tr>
<td>$10^4$</td>
<td>2</td>
<td>4</td>
<td>10</td>
<td>20</td>
<td></td>
</tr>
</tbody>
</table>

We can now estimate roughly as follows the mean flow speed $\langle v \rangle$ into the sheet. If $q_1$ and $q_2$ are the initial and final densities and $d$ is the thickness of the final sheet of condensed plasma, the equation of mass continuity in the plane of the figures implies

$$
q_1 \langle v \rangle \tau_c \approx q_2 d. \tag{2}
$$

Observations suggest $d$ to be less than or of order 1 Mm and $\tau_c$ is given by Equation (1). In Table II we show an upper limit on the input velocity $\langle v \rangle$ calculated from Equation (2) for various values of $\beta$ and the compression ratio $q_2/q_1$. $T_1$ is taken to be $10^5$ K; a smaller value will produce a correspondingly larger $\langle v \rangle$. 

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TABLE II
The mean inflow velocity \( \langle v \rangle \) in km s\(^{-1}\) into a neutral sheet for an initial temperature of 10\(^4\)K

<table>
<thead>
<tr>
<th>( q_2/q_1 )</th>
<th>5</th>
<th>3</th>
<th>1</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
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<td>50</td>
<td>25</td>
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<td>50</td>
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<td>10</td>
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<tr>
<td>50</td>
<td>250</td>
<td>125</td>
<td>50</td>
<td>25</td>
</tr>
</tbody>
</table>

The fact that the absorption feature is visible in Hz means that the final temperature \( T_2 \) must be at least as small as 10\(^4\) K so that neutral hydrogen can be formed. If we assume approximate pressure equilibrium \( q_1 T_1 \approx q_2 T_2 \), this puts a lower limit on \( q_2/q_1 \) of 10 (neglecting the effect of the magnetic field). Further, higher compression ratios than about 50 are likely to lead to the presence of shock waves, since the magnetosonic speed is \((1 + \beta)^{1/2} C_s\), where the sound speed \( C_s \) is about 30 km s\(^{-1}\).

The values of about 50 km s\(^{-1}\) in Table II are consistent with the observations, which indicate that its line of sight component is several tens of kilometers per second. Evidently a detailed model of one dimensional condensation in a neutral sheet is required in order to better these order of magnitude estimates; such a model is at present being studied. In addition, it is possible that the absorbant feature is plasma being squeezed out of the ends of the sheet at the Alfvén speed rather than condensing into the sheet from the sides.

The effect of heat conduction along the lines of force is very important and enables us to calculate the minimum length \( L_{\text{min}} \) of the neutral sheet for the thermal instability to occur. The characteristic time to equalise a temperature drop of \( \Delta T \) along the field over a distance \( L \) is

\[
\tau_\parallel = \frac{L^2 T}{\kappa_\parallel \Delta T},
\]

where the coefficient of thermal conductivity is, with the number density \( n \) measured in m\(^{-3}\) and \( T \) in K,

\[
\kappa_\parallel = 10^{1.2} \lambda^{-1} n^{-1} T^{5/2} \quad M^2 \quad s^{-1}
\]

and

\[
\lambda = 22.5 - 1.15 \log n + 3.5 \log (T/11400).
\]

For \( T \approx \Delta T = 2 \times 10^5 \) K and a density of \( 10^{15} \) m\(^{-3}\), we have

\[
\tau_\parallel \approx 9 \times 10^{-10} L^2.
\]

If \( L \) is so small that \( \tau_\parallel \) is less than the time scale \( \tau_c \approx 2 \times 10^2 \) s of the thermal instability, then the heat conduction will ensure that the instability does not occur. Thus equating \( \tau_\parallel \) and \( \tau_c \) we find

\[
L_{\text{min}} \approx 0.5 \text{ Mm}.
\]
This value is consistent with the observations. The thickness of the absorbing feature is generally of order a Mm; also, a neutral sheet could not be much longer than about 10 Mm, because the effect of perspective would certainly then produce more overlapping of the absorbing feature ribbons and less correlation with the $H_{\parallel} = 0$ photospheric line. The subsequent disappearance of the absorption feature over, say, $2 \times 10^3$ s may be explained by thermal heating of the cooled gas if, due to photospheric motions during the instability, the length of the sheet becomes somewhat larger than $L_{\text{min}}$, say of order 1.5 Mm.

Axisa et al. report some slight asymmetry between the upward and downward moving parts of the neutral-line absorbing feature. For instance, the upward part tends to be seen first – perhaps the thermal instability starts on the side of the neutral sheet nearest to the emerging flux and then a disturbance propagates across the sheet, triggering the instability on the other side. Also the type III burst tends to be triggered during the development of the downward moving part – perhaps the triggering occurs therefore, as the disturbance crosses the neutral line, or maybe particles accelerated on the active region side of the neutral line can escape more easily. However, the evidence for such asymmetry is not yet strong. More observations are needed in order to obtain firmer statistical results. Also a time resolution better than the present Hα picture per minute and more comparison with high resolution magnetograph data would be invaluable.

Neutral line absorbing features are often observed about a day before a more stable active region filament (prominence) is formed (Mercier, 1973). This can be explained in terms of a slow growth of a current sheet (Priest and Raadu, 1974). At the beginning of the emergence of the new satellite flux, the neutral sheet is so small that thermal conduction can prevent the occurrence of the thermal instability. Then a period exists during which the length of the sheet is of order a Mm so that an absorbing feature can form and disappear. Finally the sheet is so large that the thermal instability can produce a stable filament in the manner suggested by Kuperus and Tandberg-Hanssen (1967) and developed by Raadu and Kuperus (1973) and Kuperus and Raadu (1973). Occasionally homologous absorption feature events are observed for several successive days; we would suggest that in such a case the length of the neutral sheet was not changing much from the 1 Mm value. This does not necessarily mean that the satellite fields are stationary, since, as two dipole fields approach, the length of the resulting neutral sheet increases, remains fairly constant for a while and eventually decreases (Priest and Raadu, 1974). It would be interesting to know whether active filaments form after homologous events.

3. Particle Acceleration

The question of how the charged particles which excite type III radio bursts are accelerated to energies of about 40 keV is one of the most fundamental facing solar physicists at the present time. A solution of this problem is evidently outside the scope of this note, but we can make some general remarks. The main one is that the as-
sociation of type III bursts with absorbing features near a neutral line indicates that the acceleration is likely to occur in a neutral current sheet. Furthermore, the existence of the accelerating electric field should be closely associated with the thermal instability responsible for the absorbing feature.

For the parameters of the last section the plasma is fairly collisional; a temperature of $10^5$ K and a number density of $10^{16}$ m$^{-3}$ give an electron-ion mean free path of 100 m. We consider below the possibility of particle acceleration in a central slab of the neutral sheet with a thickness $l_s \approx 100$ m in the plane of the figures.

This central slab is subject to a collisionless tearing mode instability (Furth, 1962; Pfirsch, 1962), during which the acceleration of charged particles can occur. For a two-dimensional model with gyroradii much less than $l_s$, Biskamp and Schindler (1971) estimate the resulting electric field $E$ to be of order $\gamma B_s l_s$, where $B_s$ is the magnetic field at the edge of the central slab and $\gamma$ is the growth rate, given in terms of the electron thermal speed $v_e$ and gyroradius $q_e$ by

$$\gamma \approx k v_e (q_e/l_s)^{1/2}.$$ 

We shall accept this value as representative even though the gyroradii are not small and the configuration may not be two dimensional. It can then be shown as follows that the tearing mode gives rise to an important electric field. Assuming a linear dependence of magnetic field across the whole current sheet (of thickness 1 Mm, say) the field $B_{\text{ext}}$ at the edge of the whole sheet is just $10^4 \times B_s$. Thus, with $B_{\text{ext}}$ in Wb m$^{-2}$ and the wave number $k$ approximately $2\pi l_s^{-1}$, the electric field produced by the collisionless tearing mode is

$$E \approx 15 (B_{\text{ext}})^{1/2} \text{ V m}^{-1}$$

and may be compared with the runaway field (Alfvén and Fälthammar, 1963)

$$E_r \approx 1.3 \times 10^{-12} n_e T_e^{-1} \approx 0.13 \text{ V m}^{-1}.$$ 

If the external magnetic field $B_{\text{ext}}$ is larger than $10^{-4}$ Wb m$^{-2}$ (= 1 G), we find $E > E_r$, so that runaway electrons can be created provided their acceleration is not impeded by some microinstability mechanism. If it is not impeded, the energy $\varepsilon$ acquired by the electrons over the whole breadth (1 Mm, say) of the sheet (normal to the plane of the figures) with $B_{\text{ext}} = 10^{-4}$ Wb m$^{-2}$ is then

$$\varepsilon = 150 a \text{ keV},$$

where $a$ is a constant smaller than unity representing qualitatively the effect of various limiting processes. The electric field can produce acceleration at any point in the slab, since in general there is a component of the magnetic field normal to the plane of Figure 2 and therefore parallel to the electric field. As a result, an upper limit on the number of electrons accelerated in the process is the total number in the slab; if the sheet has dimensions 100 m, 1 Mm, 1 Mm, with a density of $10^{16}$ m$^{-3}$, we find a value of $10^{30}$ for this upper limit. The actual number accelerated and the energy at-
tained by them is also limited by the amount of magnetic energy which is available for conversion into particle energy. Only \(10^4\) J of magnetic energy is actually present in the central slab; but, in the 1 s during which we assume the particle acceleration to occur, \(5 \times 10^{14}\) J of magnetic energy is carried towards the central slab from both sides by the thermal instability. If we assume that all of this energy is supplied to the electrons, then \(10^{29}\) of them would be accelerated to an energy of 40 keV, which compares favourably with observations (Axisa, 1973; Smith, 1970a). However, many of the above assumptions can be justified only by the success of a more detailed study.

Fig. 2. When \(L\) grows to \(L_{\text{min}}\) a thermal instability occurs in the hatched region and produces the inflow indicated by open arrows.

A major problem is to explain why the acceleration is not impeded by microinstabilities which are driven by the runaway electrons. Various methods have been proposed:

3.1. **Nonlinear stabilisation of the beam of accelerated particles**

Present studies indicate this is unlikely (Smith and Fung, 1971; Heyvaerts and Verdier de Genouillac, 1973). However, it has not been studied in detail with the present range of parameters.

3.2. **Loss of turbulent waves due to the small thickness of the slab**

This effect is also unlikely because the time (about \(10^{-4}\) s) it takes for plasma waves to traverse the sheet at the group velocity is probably longer than the growth time of the turbulence.
3.3. DAMPING OF THE TURBULENCE TO A SUFFICIENTLY LOW LEVEL BY COULOMB COLLISIONS

Other mechanisms can be found in the paper by Smith (1970b). It is important to note in this respect that the acceleration mechanism does not have to create a monoenergetic spectrum of electrons. Harvey (1974) has developed a theory which supposes that type III bursts are generated by the sudden release of a wide spectrum of energetic electrons. Such a spectrum may possibly be formed from the turbulence generated by the runaway electrons in our model. This point however necessitates further study.

We therefore assume that a stabilization mechanism exists and suggest the following model for the triggering of type III radio bursts. The thermal instability produces a compression of the neutral sheet, which stimulates a collisionless tearing mode instability in a thin slab about the centre of the sheet. The resulting electric field grows and, when it reaches the runaway value, the bulk of the $10^{30}$ electrons in the central slab are accelerated to energies between 10 and 100 keV. When they reach the edge of the sheet, the accelerated electrons are channelled by coronal magnetic field lines at the edge of the active region; up to 40% of the electrons are able to escape along open field lines (Newkirk, 1973), where they produce most of the observed type III radiation.

4. Conclusion

We have here presented the suggestion that a neutral-line absorbing feature is the manifestation of a thermal instability near a sufficiently long neutral current sheet. The accompanying electric field, developed during a collisionless tearing mode instability, can exceed the runaway field and hence accelerate electrons to high enough energies to produce type III radio bursts. Occasionally a solar flare follows the development of an absorbing feature and may be outlasted by it, presumably because of the efficient thermal insulation normal to magnetic field lines.

The storage of energy in the magnetic field above the photosphere before a flare has been suggested by many people, since appreciable changes down in the photosphere have not in the past been observed during the flare, (though they may be important (Heyvaerts, 1974)). Storage may be accomplished by twisting the magnetic field to form a force-free configuration, as in the solar flare mechanism of Low (1973). Alternatively, two topologically separate fields may be pressed together to form a 'quiet' neutral sheet with a very low level of magnetic field dissipation due to Coulomb collisions and external plasma motions at very small Alfvén Mach numbers.

The flash phase of the solar flare may, on the other hand, be due to an 'active' neutral sheet, in which the magnetic field is dissipated very rapidly along the lines first suggested by Petschek (1964) and external plasma motions at a significant fraction of the Alfvén speed. Theoretical work by Sonnerup (1970), Yeh and Axford (1970) and, more recently, Parker (1973), Priest (1973) and Fukao and Tsuda (1973) has shown that magnetic field energy can indeed be released in an active neutral sheet on
a time scale short enough to explain a flare. However, the details of the trigger which converts the quiet neutral sheet into an active one are by no means clear (Coppi and Friedland, 1971). The clue which we can offer is the importance of the thermal tearing mode instability which may give rise to neutral-line absorbing features. Perhaps the high energy particles, accelerated during the instability and evidenced by the concurrent type III burst, can provide the trigger in some circumstances. Alternatively, perhaps plasma turbulence which develops during the nonlinear phase of the instability is able, through its influence on the effective electrical resistivity, to change rapidly the current in the quiet neutral sheet. This would then destabilise the magnetic configuration, which may develop into a quasi-steady active neutral sheet. The answers to these questions may come from further observations, which we eagerly await, of neutral-line absorbing features and their relation to type III bursts and solar flares. In particular, it is crucial to know what extra conditions are necessary for the appearance of a solar flare after the absorption feature has developed.

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