Reprinted from
Proceedings of the Astronomical Society of Australia
Volume 2, Number 1, *pages* 56-57, *July* 1971

Possible Causes of Line Splitting in Drift Pair Solar Bursts

D. B. MELROSE AND W. SY

Department of Theoretical *Physics*, Faculty of Science,
Australian National University

In this paper possible causes of line splitting in emission near the local plasma frequency are considered in connection with drift pair solar radio bursts. The basic model envisaged for the bursts involves a bunch of electrons streaming through the solar corona at several times the thermal velocity of electrons. The emission process assumed is the transformation of coherently generated electron plasma waves (I-waves) into electromagnetic waves (t-waves) with little change in frequency.

PROPERTIES AND INTERPRETATIONS

Roberts[1] observed a number of drift pair bursts predominantly with reverse drifts (low to high frequencies). He argued that if the emission is at twice the local plasma frequency the calculated time delay between direct and reflected rays in the regular corona could account for the observed time delay of 1 to 2 sec. between the two traces. Roberts suggested that the fundamental should sometimes be observed.

Ellis[2] observed many drift pairs with negative frequency drifts in a narrow range around -1.2 MHz sec^{-1} and with a mean time separation of 1.2 sec at 30 MHz. Ellis found no evidence for emission at half the observed frequency (Ellis[3] pointed out a trace at roughly twice the frequency of a drift pair in Figure 7 (a) of reference 2). The two traces had a mean bandwidth of 0.4 MHz, neither showed significant (circular) polarization and there were a number of examples with a third weaker intermediate trace. Ellis found that the traces were split in frequency as well as in time; the later trace had a mean displacement of 0.8 MHz to higher frequencies.

The absence of emission at half the observed frequency suggests that the observed emission is at the fundamental rather than at the second harmonic. An echo of emission at the fundamental can arise only if the source is denser than its surroundings. The observed time delay requires that the source region be about four times denser than the surrounding regular corona. Such a density inhomogeneity is typical of a coronal streamer.[4] We assume that the bunch of electrons moves along a non-radial streamer.

Some line splitting mechanism is required to account for the mean frequency displacement found by Ellis.[2] An acceptable model for the emission should account for higher frequency emission in the backward direction, for the lack of significant polarization, for the bandwidth of the traces, should allow the possibility of a third intermediate trace and should not predict substantial emission at the second harmonic. We examine six line splitting mechanisms to see if they are compatible with these requirements.

MAGNETIC SPLITTING

We have considered three possible magnetic splitting mechanisms. These are splitting due to the angular dependence of the frequency of *l*-waves,[1, 5] splitting due to coherent emission of I-waves at different harmonic numbers and splitting in the scattering process.[6] The latter two mechanisms require impossibly large magnetic field strengths to account for the observed splitting. Splitting due to the angular dependence;

$$[\omega_l(\theta)]^2 = \tfrac{1}{2}(\omega_p^2+\Omega_e^2)+\tfrac{1}{2}[(\omega_p^2+\Omega_e^2)^2-4\omega_p^2\Omega_e^2\cos^2\theta]^{\frac{1}{2}},$$

o, = electron plasma frequency, Ω_e = electron gyrofrequency requires that the distribution of I-waves peak at two widely separated angles.[5] Such a distribution is not generated directly by coherent emission and if it were produced would lead to substantial emission at the second harmonic.[5]

Any appeal to magnetic effects in splitting of the fundamental implies that the emitted t-waves are in the ordinary mode. This is because one has

$$\omega_l(\theta) \leqslant [\omega_p^2+\Omega_e^2]^{\frac{1}{2}} < \omega_x = \tfrac{1}{2}\Omega_e+\tfrac{1}{2}(4\omega_p^2+\Omega_e^2)^{\frac{1}{2}}$$

where ω_x is the cutoff frequency for the extraordinary mode. The lack of observable polarization also suggests that magnetic effects are not important.

NON-MAGNETIC SPLITTING

We discuss three non-magnetic splitting mechanisms. The first appeals to a Doppler shift assuming that the source region (a coronal streamer) is falling towards the photosphere. For a backward directed ray to be at a fractional frequency of $0.8/30 \simeq 1/40$ higher than a forward directed ray requires a falling speed of $c/80$. This would imply the presence of a shock front for which there is no evidence.

The second appeals to a difference in density on the upper and lower sides of the streamer. The fractional density difference required is 1/20. The central region of the streamer needs to be partially opaque to the t-waves so that higher frequency waves from the lower side escape preferentially in the backward direction and lower frequency waves escape preferentially in the forward direction. Appealing to scattering of the t-waves due to microturbulence to achieve this opacity requires a level of microturbulence which entails substantial emission at the second and higher harmonics. A density distribution peaking in the centre of the streamer and falling off faster on the upper side than on the lower side can account for the backward forward asymmetry and also allows the possibility of a third intermediate trace due to partial transparency of the central region (higher frequency waves escaping in the forward direction then produce a trace at the same time as the leading trace but at a higher frequency; lower frequency waves escaping in the backward direction also produce an intermediate trace). On this model one expects the bandwidth of each trace to be comparable with the frequency displacement as observed. The special density distribution required in this model detracts from its plausibility.

The final splitting mechanism we consider involves the presence of a non-thermal distribution of sound waves (s-waves). Generation of t-waves can result from the coalescence process I + $s \rightarrow$ t and from the induced decay process I $\rightarrow$ t + s. Conservation laws for these require

$$\omega_t = \omega_l + \omega_s, \qquad \text{kt} = \mathbf{k}_l + \mathbf{k}_s \tag{1a}$$

and

$$\omega_t = \omega_l - \text{w,,} \qquad \mathbf{k}_t = \mathbf{k}_l - \text{k*} \tag{1b}$$

respectively. Assuming that the I-waves are generated by a stream with velocity $u \ll$ c one has

$$|\mathbf{k}_l| \simeq \frac{\omega_p}{u}$$

and $|\mathbf{k}_t| \ll |\mathbf{k}_l|$. The processes (la) and (lb) lead to the fractional frequency split

$$\frac{2\omega_s}{\omega_p} \simeq \frac{2v_s}{u}[1 + (V_e/\omega)^2]^{-\frac{1}{2}}, v_s = \left(\frac{m_e}{m_i}\right)^{\frac{1}{2}} V_e, \tag{2}$$

where $m_e V_e^2$ is the electron temperature in ergs. For drift pairs the streaming velocity is several times V_e. The frequency split (2) is of the order of that observed.

The distribution of I-waves is concentrated in the forward (streaming) direction. For $|\mathbf{k}_s| \gtrsim |\mathbf{k}_l|$ (la) and (lb) lead to backward emission while for $|\mathbf{k}_s| \lesssim |\mathbf{k}_l|$ both lead to forward emission. The required asymmetry can be achieved if s-waves with $|\mathbf{k}_s| \gtrsim \omega_p/u$ are concentrated in the backward direction and s-waves with $|\mathbf{k}_s| \lesssim \omega_p/u$ are concentrated in the forward direction. In this case (la) favours backward emission at the higher frequency and (lb) favours forward emission at the lower frequency. Both the remaining possibilities lead to an intermediate trace.

The s-waves can be generated naturally if the density n_1 of the stream satisfies[7]

$$n_1 > n_e \frac{v_s}{u}.$$

The s-waves are then generated preferentially in the backward direction with $|\mathbf{k}_s|$ % ω_p/u. Scattering of the s-waves proceeds faster than any other non-linear process and is accompanied by a decrease in $|\mathbf{k}_s|$.[8, 9] The distribution of s-waves required to account for the asymmetry in the emission could be produced as a result of this scattering.

The line-width of the t-waves is due to the natural spread in the frequency of Ewaves. For a velocity spread Au in the stream one has

$$\Delta\omega_t \simeq \Delta\omega_l \simeq 3\omega_p \left(\frac{V_e}{u}\right)^2 \left(\frac{\Delta u}{u}\right).$$

A stream with $u/V_e \sim 3$, $n_1/n_e \sim 0.1$, $\Delta u/u \sim 0.2$ can account for the observed properties of drift pairs. According to (2) the model predicts a correlation between frequency displacement and streaming velocity.

CONCLUSION

We conclude that a model for drift pairs based on emission at the fundamental is possible provided that the exciting agency moves along a non-radial coronal streamer. Line splitting is probably not due to magnetic effects.

[1] Roberts, J. A., *Aust. J. Phys.*, **12**, 327 (1959).
[2] Ellis, G. R. A., *Aust. J. Phys.*, **22**, 177 (1969).
[3] Ellis, G. R. A., private communication (1971).
[4] Newkirk, G., *Astrophys. J.*, **133**, 982 (1961).
[5] Tidman, D. A., Birmingham, T. J. and Stainer, H. M., *Astrophys. J.*, **146**, 207 (1966).
[6] Tsytovich, V. N. and Shvartsburg, A. B., *Zh. Tekhn. Fiz., 36, 1915 (1966)*. Trans. *Soviet Phys.-Tech. Phys.*, **11**, *1431 (1967)*.
[7] Melrose, D. B., *Aust. J. Phys.*, 23, *885 (1970)*
[8] Kadomstev, B. B., '*Plasma Turbulence*', Academic Press, New York *1965*
[9] Tsytovich, V. N., *Usp. Fir. Nank.*, **90**, 435 (1966). Trans. *Soviet Phys. Usp.*, 9, *805* (1967).

Simmons Limited, Glebe, Sydney.