circumstances its brightness may not only achieve the actual brightness of the star S but appear even brighter by 0.5^m for the minimum angular distance in Figure 1.

On the right side of Figure 1 is the 'relative orbit' of the image S_1 with respect to the always brighter image S_2. The 'magnitude rays' are not drawn. For that part of the 'orbit' between the dashed lines the image S_1 is brighter than the actual brightness of the star S.

Thus under extreme circumstances a nearby black hole may cause short-lived detectable changes in the brightness and in proper motions of other stars. It may be worth trying to examine past observations of stars' positions from this point of view, to check the duplicity of stars, the 'strange' orbits of visual double stars and the changes in proper motions.

Figures 2 to 4 present examples of what may happen under different circumstances when the distance, the mass of deflecting body and the minimum angular distances are varied. Since the results are unaffected by whether the distant star is at a distance of 1000 pc or many Mpc, the calculations have all been made for the star at 1000 pc.

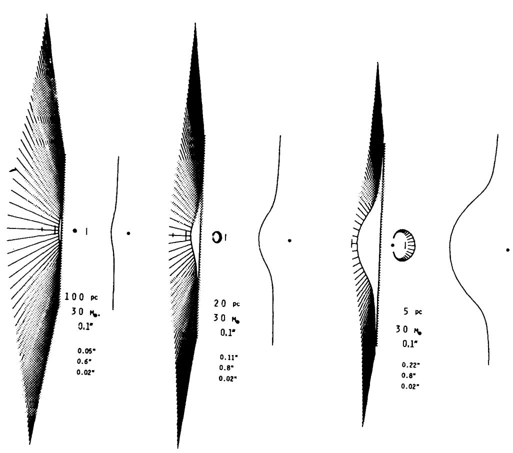

Figure 2. Three examples of light deflection and changes in brightness to show the effect of varying the distance of the black hole.

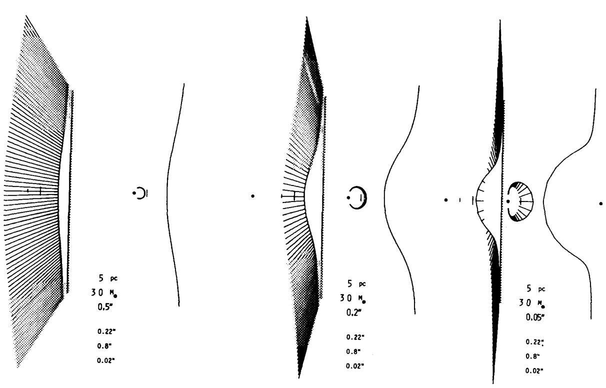

Figure 3. Three examples of light deflection and changes in brightness to show the effect of varying the angular distance between the black hole and the distant star.

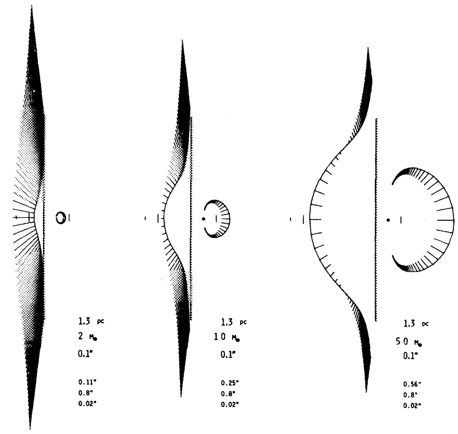

Figure 4. Three examples of light deflection and changes in brightness to show the effect of varying the mass of the black hole. In these cases 'the relative orbits' are omitted.

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Can Spontaneously Emitted Langmuir Waves Account for Type III Solar Radio Bursts?

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Introduction

One of the major problems in the theory of type III solar radio bursts concerns the development of the two-stream instability. On the one hand, Sturrock (1964) argued that one expects the instability to develop rapidly, and if it does it should prevent the stream from propagating through the corona, contrary to observation. On the other hand, one appears to require that the instability develop partially, in the sense that there is some significant amplified emission of Langmuir waves, in order to account for the observed emission.

Perhaps the most widely accepted view is that the two-stream instability develops partially and is then suppressed by nonlinear effects, e.g. see the reviews by Kaplan *et al.* (1974) and Smith (1974). My purpose here is to explore an alternative possibility, namely that the two-stream instability might not develop at all. In particular, for the purpose of the present discussion, I shall assume that the instability does not develop and that the only Langmuir waves generated by the stream are those generated through spontaneous emission. I then ask the question: Can one account for the observed radio emission in terms of the spontaneously emitted Langmuir waves?

The Spectrum of Spontaneously Emitted Langmuir Waves

Firstly, consider the power emitted spontaneously in Langmuir waves by an electron with speed $v = 0.3c$. This is

$$P = \frac{e^2 \omega_p^{\ 2}}{v} \ln \frac{v}{V_e} = 3 \times 10^{-15} f_p^2 \text{ erg s}^{-1}, \qquad (1)$$

where f_p is the plasma frequency in megahertz and where the electron temperature $T_e = m_e V_e^{\ 2}$ has been set equal to 1.5×10^6 K. With say 10^{31} electrons in a stream at the plasma level $f_p = 100$ MHz, the total power generated spontaneously in Langmuir waves would be 3×10^{20} erg s^{-1}. The observed power in type III emission is between 10^{19} and 10^{20} erg s^{-1}. Consequently, due to spontaneous emission alone, a stream containing $> 10^{31}$ electrons generates enough power in Langmuir waves to account for the observed emission provided the conversion processes of the Langmuir waves into escaping transverse waves are efficient enough.

For further discussion an explicit expression for the effective temperature in Langmuir waves is required. Consider a stream with n_s electrons per unit volume all with speed v, and with a pitch angle distribution $\phi(\alpha)$ (normalization $\int_{-1} d\cos\alpha\, \phi(\alpha) = 1$. The maximum possible effective temperature of Langmuir waves which can be achieved through spontaneous emission is when spontaneous emission is balanced by collisional damping. This maximum effective temperature is

$$T^e(k,\theta) = \frac{4\pi^2 e^2 \omega_p^2 n_s}{k^3 v \nu} F(k,\theta), \qquad (2)$$

where Boltzmann's constant is set equal to unity and where the energy in Langmuir waves is assumed to decay as $\exp(-\nu t)$ due to collisions. In (2) the function $F(k,\theta)$ depends on the pitch-angle distribution with θ the angle between the wave vector **k** of the Langmuir waves and the direction $\alpha = 0$. For

$$\phi(\alpha) = \begin{cases} \dfrac{1}{1-\cos\alpha_o} & \text{for } \alpha < \alpha_o \\ 0 & \text{for } \alpha > \alpha_o \end{cases}, \qquad (3)$$

one finds

$$F(k,\theta) = \frac{1}{\pi(1-\cos\alpha_o)} \begin{cases} \pi & \text{for } \alpha_o > \theta + \chi \\ \frac{\pi}{2} + \arcsin \dfrac{\cos\theta \cos\chi - \cos\alpha_o}{\sin\theta \sin\chi} & \text{for } |\theta - \chi| < \alpha_o < +\chi \\ 0 & \text{for } \alpha_o < |\theta - \chi| \end{cases} \qquad (4)$$

with $\chi = \arccos(\omega_p/kv)$. Landau damping has been neglected, and consequently (2) ceases to apply for sufficiently large k. In fact (2) applies only for

$$x V_e \lesssim \frac{\omega_p}{k} \leqslant v = 63\, V_e \left(\frac{v}{c}\right), \qquad (5)$$

with $x \approx 7$.

Fundamental Plasma Emission

Fundamental plasma emission is attributed to scattering of Langmuir waves into transverse waves by thermal ions. Fundamental plasma emission is quite insensitive to the angular distribution of the Langmuir waves and the emission due to the spectrum (2) with (4) is essentially independent of α_o. Hence we can replace α_o by π in (4), which then gives $F(k,\theta) = ½$, and use results derived by Melrose (1974, 1975) for plasma emission from isotropic electrons. Thus the resulting brightness temperature T_1^t of the fundamental is given by

$$T_1^{\ t} = T_{10}^{\ t}(e^\tau - 1), \qquad (6)$$

with

$$T_{10}^{\ t} = \frac{2xv}{3V_e} T_i, \quad \tau = \left(\frac{3\pi}{2}\right)^{1/2} \frac{1}{8x^{3/2}} \frac{n_s}{n_e} \frac{\omega_p^3 e^2 L_N}{v V_i T_i c} \left(\frac{V_e}{U_s}\right)^{3/2} \qquad (7)$$

and with $L_N = |\text{grad}(\ln n_e)|^{-1}$. Inserting the numerical values chosen above, with $L_N = 3 \times 10^{10}$ cm, one finds

$$T_{10}^{\ t} = 1.3 \times 10^8 \text{ K}, \qquad \tau = 1.9 \times 10^5 \frac{n_s}{n_e} f_p \qquad (8), (9)$$

with f_p again in megahertz.

Second Harmonic Plasma Emission

A difficulty encountered in treating second harmonic plasma emission from amplified Langmuir waves is that it is not possible for two such Langmuir waves to coalesce directly into a second harmonic transverse wave. The reason is that the two coalescing Langmuir waves need to be nearly anti-parallel. This difficulty does not occur for the spontaneously emitted Langmuir waves, as was first pointed out by H. Rosenberg (private communication, 1975). The point is that for

$$\alpha_o \gtrsim x \frac{V_e}{v} \qquad (10)$$

the spectrum (2) contains Langmuir waves at $\theta > \frac{\pi}{2}$, and anti-parallel waves are contained in any distribution which includes $\theta = \frac{\pi}{2}$.

I shall consider two cases. One corresponds to (10) being marginally satisfied and the other is the isotropic distribution corresponding to $\alpha_o = \pi$. In both cases the solution for the brightness temperature T_2^t of the second harmonic is written in the form (Melrose 1974, 1975)

$$T_2^t = T_{20}^t \tau^2 \qquad (11)$$

where reabsorption of the transverse waves is ignored.

Detailed calculations give, for the former case

$$T_{20}^{t} = \frac{128\pi}{15\sqrt{3}} \frac{x^6}{\alpha_o^3} \frac{V_i^2 V_e^2 U_s}{\omega_p^2 r_o L_N c^3} T_e \quad (12a)$$

where r_o is the classical radius of the electron, and where an average over angles of emission has been performed. For the latter case, one finds

$$T_{20}^{t} = \frac{32\pi}{15\sqrt{3}} x^3 \frac{V_i^2 U_s^4}{\omega_p^2 r_o L_N c^3 V_e} T_e \quad (12b)$$

(Note that Melrose (1975) overestimated plasma emission at the second harmonic by a factor $(2\pi)^3$.) Inserting the numerical values adopted above, with $\alpha_o = x V_e/v$ in (12a), one finds

$$T_{20}^{t} = \begin{cases} 1.5 \times 10^{12} \ f_p^{-2} \ \mathrm{K} & (13a) \\ 3.7 \times 10^{11} \ f_p^{-2} \ \mathrm{K} & (13b) \end{cases}$$

for the two cases respectively, and where f_p is again in megahertz. The neglect of reabsorption of the second harmonic transverse waves is justified provided T_2^t remains less than the value

$$(T_2^t)_{max} \approx 2 \times 10^{20} \left(\frac{n_s}{n_e}\right) f_p^{-1} \ \mathrm{K} \quad (14)$$

It is interesting that the second harmonic emission is only weakly dependent on the value of α_o provided condition (10) is satisfied.

Discussion

A notable feature of the foregoing results is that the predicted brightness temperatures depend on the ratio n_s/n_e and other parameters which are well-determined (with the possible exception of L_N). Hence one can draw specific conclusions with some confidence.

To account for a moderately bright plasma emission (10^9K say) with T_{10}^{t} and T_{20}^{t} given by (8) and (13a or b) requires τ of order unity. With f_p = 100 MHz, τ = 1 in (9) requires $n_s/n_e \approx 10^{-7}$, i.e. $n_s \approx 10$ cm^{-3} in view of $n_e \approx 10^8$ cm^{-3} being implied by $f_p \approx$ 100 MHz. The value $n_s \approx 10$ cm^{-3} for type III streams in the corona seems quite reasonable, e.g. it is consistent with the value adopted by Zheleznyakov and Zaitsev (1970). Consequently, one might be tempted to conclude that the spontaneously generated Langmuir waves are adequate to account for the observed plasma emission in type III burst. However, I shall argue that the value $n_s \approx 10$ cm^{-3} is probably too high.

It has been assumed that the spectrum (2) of Langmuir waves is formed due to spontaneous emission being balanced by collisional damping. This requires that the stream take longer than a collision time to pass a fixed point, and this requires that the stream be longer than about 3 x 10^{10} cm at the 100 MHz plasma level. Furthermore, the brightness temperature of around 10^9K is that of the actual source only if the actual source has an area roughly equal to the apparent area. A typical apparent area is about 3 x 10^{21} cm^2. Consequently, the assumptions made require that the volume of the stream be at least of order 10^{32}cm^3. Hence the requirement $n_s \approx 10$ cm^{-3} implies at least 10^{33} electrons per stream. Now although type III streams at the orbit of the Earth contain about 10^{33} electrons (Lin 1974) they probably come from many individual type III streams in the corona, and about 10^{31} to 3 x 10^{31} electrons per stream in the corona would be more plausible.

Conclusions

The following conclusions may be drawn from this discussion of plasma emission due to spontaneously emitted Langmuir waves.

1. The inferred plasma emission could account for observed type III emission only if the number density of the stream satisfied $n_s \gtrsim 10$ cm^{-3} at the 100 MHz plasma level.
2. Actual streams probably have $n_s \lesssim 1$ cm^{-3} and consequently the spontaneously emitted Langmuir wave probably cannot account for the observed emission. In other words, one probably needs to invoke some amplification of Langmuir waves in the two-stream instability.
3. The inadequacy of the spontaneously emitted Langmuir waves is due to the relative inefficiency of their conversion into transverse waves. In principle, an alternative to invoking amplification in the two-stream instability would be to seek more efficient conversion into transverse waves, e.g. due to the presence of ion sound turbulence.

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Stellar

Period Changes of SV Centauri

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SV Cen is an eclipsing variable of the Beta Lyrae type and is especially known by its rapid changes of period. The system was studied photometrically and spectroscopically by Irwin and Landolt (1972). According to the previous study by O'Connell (1951) the system exhibits a 34-year periodicity.