EXCITATION OF HIGH-*m* TEARING MODES AT THE SOLAR FLARE SITE

(Research Note)

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Abstract. It is shown that high-*m* drift tearing modes can be excited under the conditions prevalent at the solar flare sites. Since the growth rate of the high-*m* tearing modes is larger than that for low-*m* macroscopic tearing modes and smaller than that of microscopic ion-acoustic instability, these modes warrant accommodation in the scheme of instabilities possibly operating in the hybrid model of solar flares suggested by Spicer.

A critical assessment of the two possible models of the sporadic release of large amounts of energy in the form of solar flares has been recently attempted by Spicer (1981a). The two models are: the current interruption model of Alfvén and Carlqvist (1967) and the tearing mode model (TMM) of Spicer (1976, 1977). Although both models start with a current flowing parallel to the magnetic field in the arch or the loop geometry, they advocate instabilities of different nature to be responsible for the release of solar flare energy. The revised Alfvén and Carlqvist (1967) model (RACM) invokes a micro-instability like ion-acoustic instability to account for the anomalous resistivity (Krishan, 1978) whereas Spicer's TMM uses the properties of macroscopic tearing modes which can be excited in a sheared magnetic field. The growth rates of microscopic instabilities are generally large ($\sim 10^6\ \mathrm{s}^{-1}$) and they are known to saturate in few growth times in which case it would be hard to justify that these instabilities could play a role over time scales characteristic of the flare phenomenon. On the other hand, the growth rate of the double tearing modes has been found to be $\sim 9.7 \times 10^{-2}\ \mathrm{s}^{-1}$ which gives the right estimate for the energy release rate (Spicer, 1981a). Spicer has suggested a hybrid model where microinstabilities are assumed to be maintained by an external driver of current over time scales of the order of ≥ 10 s and macroinstabilities could be excited simultaneously depending upon the current build-up time. It is at this point that we would like to introduce high-*m* tearing modes with growth rates that lie somewhere between the growth rates of the micro and macroinstabilities.

The anomalous electron energy transport observed in the tokamak experiments has been attributed to the presence of magnetic field fluctuations which have been associated with the excitation of high-*m* microscopic tearing modes. In contrast to the low-*m* tearing modes which thrive on the apparent discontinuity of the magnetic field gradient (in a direction perpendicular to that of the magnetic field) at the mode rational surface, described by the tearing mode parameter $\Delta' > 0$, the high-*m* modes derive their energy

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from electron temperature gradient, since $\Delta' < 0$ for these modes (Rosenberg *et al.*, 1980; Dominguez *et al.*, 1981). The characteristic frequency of the high-*m* modes is the electron diamagnetic frequency ω_e, which is much less than the electron-ion collision frequency ν_e.

The linear kinetic theory of high-*m* modes in a planar geometry with temperature and density gradients in a magnetic field configuration given by $\mathbf{B} = \mathbf{B}_0[\hat{z} + x/L_s\hat{y}]$ is available where a guiding centre drift kinetic equation is solved using a Fokker-Planck electron-ion collision operator (Rosenberg *et al.*, 1980). Here, L_s is the shear length and $\hat{z}$ and $\hat{y}$ are unit vectors. The purpose of this note is to investigate the relevance of high-*m* tearing modes for the solar flare phenomenon. One would like to make an estimate of the growth rate of high-*m* microscopic modes for the solar flare parameters and see if the time scales fall in the range defined by the time scales of the microscopic ion-acoustic instability and the macroscopic low-*m* tearing modes. The frequency ω and growth rate γ of the high-*m* drift tearing modes are found to be (Rosenberg *et al.*, 1980):

$$\omega \simeq \omega_e[1 + 1.8\eta_e],$$

$$\gamma = 0.4\left[\eta_e\omega_e\left(\frac{\omega}{\nu_e}\right) - \nu_e C_0\right] \quad \text{for} \quad \omega \ll \nu_e, \tag{1}$$

where

$$\omega_e = [k_y^H C T_e/eB_0]L_n^{-1},$$

$$L_n^{-1} = -\frac{\mathrm{d}}{\mathrm{d}x}\ln n_0, \qquad \Omega_i = \frac{eB_0}{M_i C},$$

$$\eta_e = \frac{\partial \ln T_e}{\partial \ln n_0}, \qquad \beta_e = \frac{8\pi n_0 T_e}{B_0^2},$$

and

$$C_0 = \beta_e^{-4/3}\left(\frac{m_e}{M_i}\right)\left[\frac{2L_n T_e(k_y^H)^2}{L_s M_i \Omega_i^2}\right]^{2/3}.$$

Here, k_y^H is the wave vector and other symbols have their usual meaning. Now, the spatial ordering of high-*m* modes goes as: $k_x^H \simeq k_y^H \gg L_n^{-1}$, in contrast to the low-*m* modes which follow $k_x^L \simeq L_n^{-1} \gg k_y^L$ and $|k^L|\, a < 1$, where a is the magnetic field gradient scale length. We shall take a clue from the value of a usually used in the literature (Spicer, 1981a) in order to deduce the approximate magnitudes of electron temperature and density gradient scale lengths. If $a \simeq 10^7$ cm, then $\lambda^L \geq 2\pi a$ or the minimum value of $\lambda^L = \lambda^L_{\min} \sim 6 \times 10^7$ cm which should be much greater than the density gradient scale length L_n, hence $L_n \ll \lambda^L_{\min} = 6 \times 10^7$ cm. The wavelength of high-*m* modes λ^H can be obtained from the condition $k_y^H = (2\pi/\lambda^H) \gg L_n^{-1}$. Thus the inequality is $\lambda^H \ll L_n \ll \lambda^L_{\min}$. Spicer (1981b) has presented a mechanism of heating and particle acceleration by fast tearing modes in which it is emphasized that the temperature and pressure gradients parallel to the magnetic field will in general be very small. Since the diffusion coefficient perpendicular to the magnetic field is much less than the parallel diffusion coefficient, the temperature gradients are more likely to be developed in a direction perpendicular to the magnetic field ($\partial T_e/\partial x$ in the present case). This combined with the slow expansion of the plasma in the perpendicular direction can provide a value of η_e, favourable to the excitation of high-m modes.

In order to estimate the growth rate, we adopt the values of the solar flare site parameters approximately the same as chosen by Spicer (1981a), taking care of the spatial ordering of the high-m modes. Let $T_e \simeq T_i \simeq 10^6$ K. $L_s \simeq 10^7$ cm, $L_n \simeq 1.4 \times 10^6$ cm, $k_y^H = (k_0/1.4 \times 10^6)$ cm^{-1} where $k_0 \gg 1$, $B_0 = 100$ G, $\nu_e = 80$ s^{-1}, $\beta_e = 0.09$, and $\eta_e \simeq 1$. With these values of the parameters, we find that the stabilizing term $\nu_e c_0$ in Equation (1) is quite small. We find

$$\gamma \simeq 10^{-8} k_0^2 \text{ s}^{-1} .$$

Since $k_0 \gg 1$, one notices that the growth rate of the high-m modes has a value that lies between the two limiting cases of the ion-acoustic instability and the low-m tearing modes. The behaviour of the growth rate with respect to various parameters like shear, (T_e/T_i) and wavelength can be studied using Equation (1). The growth rate of the high-m tearing modes becomes comparable to that for the low-m tearing modes for $k_0 = 10^3$ and thus can give a right rate of energy release. For solar flares, especially in the hybrid model proposed by Spicer (1981a), these high-m modes have a central place in the spectrum containing fast growing microinstabilities and the slow growing low–m macroscopic tearing modes.

The nonlinear theory of high-m tearing modes shows that the coupling of the modes of different wavelengths results in transfer of energy from the linearly unstable part of the spectrum to both low-m and high-m mode. On the other hand a sharply peaked high-m fluctuation spectrum necessarily transfers energy to long wavelength modes (Dominguez *et al.*, 1981). This would provide an additional source of long wavelength modes. The ambient system may have a temperature gradient which will be further enhanced by the excitation of low-m tearing modes due to parallel diffusion coefficient being larger than the perpendicular diffusion coefficient. Since the high-m modes have a large growth rate, one expects the generation of low-m modes to occur over a faster time scale through transfer process than the time required to generated low-m modes directly. This means that we have low-m modes with large growth rates which can enhance the energy release rate. Of course, one must calculate the transfer rate of high-m to low-m modes before making any quantitative statement. In addition the flattening of the temperature gradient due to the excitation of high-m modes can lead to an increase in the resistivity thereby preventing the slowing of the dissipation rate by the low-m tearing modes.

The application of the results of the high-m mode theory to the solar flare phenomenon presented here can be considered only indicative of the possibility of exciting high-m

modes in addition to the low-*m* modes, since the results depend on the magnetic field geometry. As has been emphasized by Spicer (1981b) and shown by Krishan (1981), the extension of the results obtained in a planar geometry to cylindrical geometry is not trivial; we are working on the detailed behaviour of high-*m* modes and the spatial dependence of the electron and heat conductivity in a Lunquist field, which may be a better representation of the magnetic field configuration at the flare site.

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