AN INTERPRETATION OF SOLAR FLARE MICROWAVE SPIKES AS GYROSYNCHROTRON MASERING

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Repeated bursts of microwave emission were observed by Slottje (1978) during the solar flares of April 11 and April 28, 1978. The high brightness temperatures which are inferred for these bursts indicate that a coherent mechanism must be responsible for the observed radiation. Slottje suggests that the emission is plasma radiation at the fundamental plasma frequency. We consider here the alternative possibility that the emission is coherent gyrosynchrotron radiation.

The physical picture which we consider is that electrons are accelerated to energies on the order of 100 keV near the top of the flaring loop and stream downward toward the base of the loop. Since the magnetic field increases downward, their pitch angles increase and they are eventually mirrored at some point near the base of the loop. As has been demonstrated by Ramaty (1969) and by Melrose (1973), if the particle distribution becomes highly anisotropic so that most of the particle momentum is perpendicular to the ambient magnetic field, the distribution will be unstable to gyrosynchrotron masering. For an initial particle distribution which is physically reasonable, however, we do not expect such a high degree of anisotropy to develop. The distribution of reflected particles will nevertheless be depleted of particles with parallel momentum, and we find that the resulting loss cone distribution is unstable to gyrosynchrotron masering near the electron gyrofrequency. This has been independently demonstrated by Wu and Lee (1979) for lower energy auroral electons.

For Slottje's observation frequency of 3 GHz, gyrosynchrotron emission at the first harmonic requires a magnetic field strength of 1,000 gauss. Following the analysis of Wu and Lee, we have calculated the scale length which is required for significant amplification to occur. We have taken the density of the ambient plasma to be 10^9-10^{10} cm^{-3}, giving a plasma frequency which is 0.3 to 0.1 of the observation frequency and, hence, the electron gyrofrequency. In accordance with the particle densities which are required to produce the spontaneous gyrosynchrotron and hard x-ray emission which is observed during flares, we have taken the ratio of the number density of reflected, non-thermal electrons to the

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density of thermal electrons to be 10^{-3}-10^{-4}. These parameters yield an (negative) absorption coefficient of 10^{-6}-10^{-4} cm^{-1} and hence a scale-length for amplification which is less than 10 km. This radiation is emitted predominantly at large angles to the magnetic field and, since both the radius of a typical loop flux tube and the time scale of the bursts yield an available physical scale length on the order of 1,000 km, this emission process can easily yield the observed brightness temperatures. The emission is primarily in the extraordinary mode and, hence, the high polarizations observed by Slottje during the April 11 flare are expected.

An important difficulty with this mechanism is that thermal gyro-absorption is significant. Because of the high mean streaming speed of the distribution of reflected electrons, the amplified gyrosynchrotron radiation is doppler shifted to a frequency which is greater than the electron gyrofrequency and, hence, can escape absorption by the ambient thermal plasma. In order to escape from the interior of the loop, however, the radiation must pass through a region of decreasing magnetic field strength and, hence, is subject to resonant absorption at higher harmonics of the electron gyrofrequency. We in fact find that second harmonic absorption is sufficient to prevent the escape of the emission from the loop. We wish to point out, however, that scattering or refraction may be able to direct a significant fraction of the amplified gyrosynchrotron emission along the magnetic field within the loop. Since resonant absorption rapidly falls to zero for wave propagation along the direction of the magnetic field, a sufficient intensity of the highly amplified first harmonic emission may be able to escape from the loop. In this case we would expect the emission to be detectable only in a small cone along the direction of the magnetic field within the loop. We are presently studying this possibility in more detail.

Barring the observation of redirected first harmonic emission, coherent gyrosynchrotron emission must be produced in the second or third harmonic in order to be observed. For a plasma temperature of 10^6K and density of 10^9 cm^{-3}, and an absorption scale length of 10 km, we find that second harmonic emission is marginally able to escape third harmonic thermal absorption. We are presently doing detailed calculations of the second and third harmonic "absorption" coefficients for the loss cone type of particle distribution. Our preliminary calculations indicate that the second and third harmonic emission can be sufficient to yield the observed microwave spike fluxes.

In conclusion, we find that gyrosynchrotron masering is a viable and attractive mechanism for producing the microwave spike emission observed by Slottje. First harmonic emission may be observed after it is scattered or refracted within the flaring loop, while second or third harmonic emission can escape and be directly observable.

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DISCUSSION

Kaufmann: For what frequency range would this amplification mechanism be more efficient?

Holman: Gyrosynchrotron masering can occur at the electron gyrofrequency and its lowest harmonics. The emission frequency depends upon the magnetic field strength which is assumed. (At observation frequencies much greater than, say, 10 GHz, the magnetic field strength which is required becomes prohibitively large.)

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