POLARIZED RADIATION FROM AM HERCULIS STARS

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ABSTRACT

Calculations of polarized cyclotron radiation from magnetized hot plasmas are modified to include the effects of collisions and photon scattering. These effects produce a general reduction in both the linear and circular polarization. The background unpolarized flux which had previously been invoked, in an ad hoc manner for the collisionless case, is no longer required to bring agreement with observations. The most striking effect is at small viewing angles with the magnetic field, where the fractional circular polarization is reduced from nearly 100% to close to 0%. The calculations also show that the shape of the linear polarization pulse is essentially unchanged.

1. INTRODUCTION

AM Herculis stars are binary systems comprised of a magnetic white dwarf (magnetic field $\approx$ few $\times 10^7$ gauss; see e.g. Chiappetti, Tanzi, and Treves, 1980, Chanmugam and Dulk, 1981) and a lower-main-sequence star. The strong magnetic field controls the motion of the plasma in a sphere containing both stars. As a result both stars are in synchronous orbit and the accreted matter is funnelled directly onto the surface of the white dwarf at one or both of the magnetic poles. It is in this region that the X-ray, UV, and optical fluxes originate. Earlier calculations showed that the observed large fractional polarization ($\sim$ 10%) is emitted at cyclotron harmonic number $\approx$ 5 to 10 from the cooler ($\sim$ 1keV) region of the plasma column just above the shock-heated region near the polar cap (Chanmugam and Dulk, 1981, c.f. Meggitt and Wickramasinghe, 1982). These earlier calculations assumed a collision-less plasma in LTE emitting cyclotron radiation. In this paper calculations of the cyclotron absorption coefficients are modified to include absorption of radiation from electron-ion collisions (inverse bremsstrahlung) and Thomson scattering. These modifications give better agreement between the calculated and the observed polarization.

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2. CALCULATIONS

The absorption coefficients are calculated using the method developed by Pavlov et al (1980). The method involves calculating the dielectric tensor, at a given frequency ω, which is expanded in a series of terms each of which corresponds to the contribution from cyclotron harmonic number s (see e.g. Stix 1962). The effects of collisions and photon scattering are incorporated by including an imaginary term in the argument of the plasma dispersion function $W(z_s)$. Hence $z_s = (\omega - s\omega_c)/\nu_D + i\nu/\nu_D$, where ω is the frequency of the radiation, ω_c the cyclotron frequency, ω_D the Doppler frequency and ν the effective collision frequency. Here $\nu = \nu_c + \nu_r$ where ν_c is the electron-ion collision frequency and ν_r the radiative damping frequency due to Thomson scattering. The case $\nu = 0$ corresponds to the collisionless plasma. The absorption coefficients μ_o, μ_x for the ordinary and extraordinary modes are then deduced from the imaginary part of the complex index of refraction. The equations of radiative transfer are then solved for the case of large Faraday rotation (Ramaty 1969).

3. RESULTS

Numerical calculations were done at cyclotron harmonic numbers 4,6 and 8 for a tenuous plasma slab at a temperature of 1keV ($\simeq 10^7$K) and width $L=10^8$ cm. The plasma slab was set parallel to the stellar magnetic field ($B=3\times10^7$ gauss). The dimensionless parameter $\Lambda \equiv \omega_p^2 L/\omega_c c = 10^8$ where ω_p is the plasma frequency, so that the electron number density is 10^{16} cm^{-3}. Figures 1a and 2a are curves of the absorption coefficients versus $\cos\alpha$ where α is the angle between the line of sight and the magnetic field, for harmonic numbers 4 and 6, respectively. The corresponding linear and circular polarization curves are shown in Figs. 1b and 2b. From Figs. 1a and 2a we note for the collisionless case that $\mu_{o,x}$ is largest for $\alpha \approx \pi/2$ and decreases strongly with decreasing α. Furthermore, $\mu_{o,x}$ decreases strongly as the cyclotron harmonic number increases. The effects of collisions on $\mu_{o,x}$ are not as strongly dependent on α or the harmonic number and hence become more important at high frequencies and small α. This is clearly demonstrated in Figs. 1a and 2a. For harmonic numbers $\lesssim 6$, the collisionless approximation is adequate in determining the cyclotron absorption coefficients except at small α. The absorption coefficients at the higher harmonics ($\omega/\omega_c > 7$) become angle independent and have approximately the same value for the two modes.

The principal effect due to the inclusion of collisions is an overall reduction in both the linear and circular polarization which is brought about by the increased opacity. The most striking effect is for the circular polarization at small viewing angles. For the collisionless case, the circular polarization approaches 100% whereas when collisions are included it approaches 0%.

At the fourth harmonic the plasma is optically thick for $\cos\alpha \lesssim$

0.7 and the polarization becomes negligible in this region. For small viewing angles ($\cos\alpha \gtrsim 0.7$), the plasma becomes optically thin and there is a circular polarization pulse reaching a peak of 40%. For harmonic numbers 6 and 8 the plasma is optically thin for most α and there is significant circular polarization which reaches values of about 35% and 15% respectively. The sharp linear polarization pulse at α close to $\pi/2$ is not noticeable for increasing frequency until the sixth harmonic where it has a maximum pulse height of 50% polarization. Collisional effects do not change the shape of the linear polarization pulse: only the maximum pulse height decreases.

4. CONCLUSIONS

The principal result of our inclusion of collisional effects is that both the linear and circular polarizations are reduced. Furthermore, at small viewing angles the fractional circular polarization approaches 0% whereas in the collisionless case it approaches 100%. This is most encouraging since observations of AM Her (Tapia 1977) indicate that the circular polarization approaches zero at small viewing angles. For the collisionless case, Chanmugam and Dulk (1981) postulated an unexplained background flux to dilute the polarization so that it agreed with observations. This postulate is no longer necessary.

Our results confirm the earlier results (Chanmugam and Dulk 1981) that for systems with fields $\gtrsim 5 \times 10^7$ gauss the polarization shifts into the UV making their detection difficult-since UV polarimetry is not developed. However such systems are likely to be spectacular UV sources because of high harmonic, self-absorbed cyclotron emission from the shock (Lamb and Masters 1979). Observations of 7 cataclysmic variables with the IUE have not revealed the strong UV emission expected from systems with strong fields (Bond and Chanmugam 1982). This suggests that there is a paucity of systems with strong magnetic fields ($\gtrsim 5 \times 10^7$ gauss).

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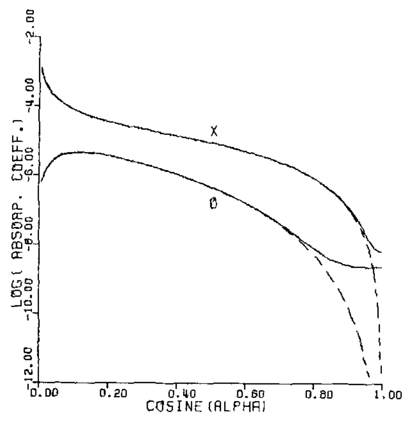

Fig. 1a

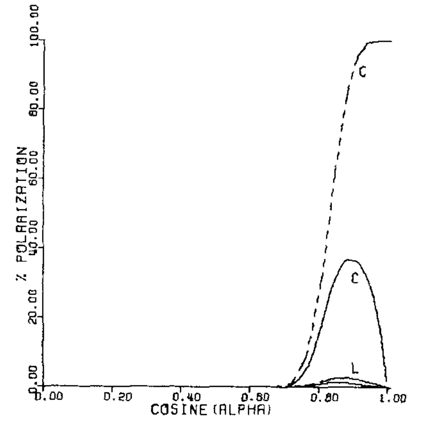

Fig. 1b

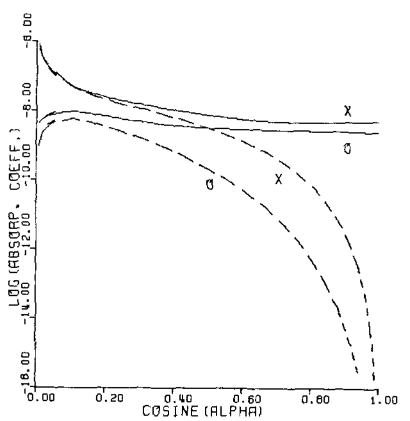

Fig. 2a

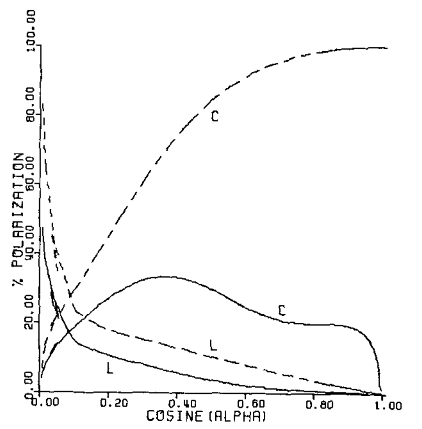

Fig. 2b

Figures 1a and 2a are curves of absorption coefficient versus angle for harmonic number 4 and 6 respectively. Ordinary and extraordinary modes are labeled O and X. Dashed lines correspond to the collisionless case. Figures 1b and 2b are curves of polarization versus angle for corresponding harmonic number. Linear and circular polarization are denoted by L and C. The plasma slab has a temperature of 1 keV and width of 10^8 cm.

DISCUSSION FOLLOWING G. CHANMUGAM'S TALK

TAPIA: I wanted to point out that in the collisional case the linear polarization seems to be significantly different from zero at very high angles with respect to the magnetic field. Is that possible?

CHANMUGAM: These are qualitative numbers, you shouldn't compare these immediately with observations.

LAMB: I think that the observations pose a challenge to present theoretical calculations, to explain how one can get a linear polarization pulse that is so broad. We are talking about a pulse that is something like 70 or 80 degrees wide.

CHANMUGAM: So this you think, is in the wrong direction.

LAMB: Yes.

CHANMUGAM: But the level has come down and that's good.

LAMB: I also want to remark that in our calculations the percentage of circular polarization does reach a maximum when you are looking down the field line but the polarized flux drops, because you have less optical depth through the emission region. Therefore, while the collisions do give you a turnover and can possibly account for the secondary minimum, our calculations give a fan beam and would naturally give a minimum when you look down the field lines, provided there is a constant background source of light. So I think it is probably not necessary to include these effects to get rather good agreement with the observations.

CHANMUGAM: That's what I said earlier. But the point is that in the previous calculations you get a very high polarization and you cut that down somehow, with some artificial background source.

LAMB: But the actual polarized flux is dropping, so if you have a constant background source of any kind you will get the right behaviour. Regarding your search for polarized UV emitters, I want to mention that whether the cooling is cyclotron dominated or not depends not only on the field strength, but also on the accretion rate. Therefore one should not look only for stars with high magnetic fields. If the field is a few x 10^7 Gauss, but the accretion rate is rather low, and therefore the density in the emission region is low. This would also tend to move the polarized cyclotron emission into the UV.

CHANMUGAM: The problem is that if you look at low accretion rates then it is difficult to observe them, the luminosity will be much lower.

LAMB: That depends, because the parameters of the system may change. For example, in AM Her stars the field is high enough but the stream is very small in cross sectional area, so the density is high and it is hard to get into the cyclotron dominated regime. On the other hand, in the long period DQ Her stars the field is weaker, but the disk comes in close and therefore the number of field lines that are accessible to the accreted matter is large and cover, probably, a substantial fraction of the stellar surface. So you can have the same overall accretion rate, but because the area is so much larger the density would be smaller and one would move into the cyclotron dominated regime.

CHANMUGAM: Yes, that's true.