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Cyclotron versus free-free emission from the intermediate polar RX J1712.6-2414

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Abstract. The intermediate polar RX J1712.6-2414, discovered by Buckley et al. (1995), turned out to have a phase-dependent circular polarization of up to -5% in the I_c band, the largest value observed in any intermediate polar. By comparing the slope of the observed polarized flux with theoretical models, Buckley et al. (1995) obtained an estimate of 8 MG for the magnetic field strength. In this fit, only the polarized flux in the I_c band is dominated by cyclotron radiation. Toward shorter wavelengths, the polarization is caused by free-free emission.

We reexamine this fit and investigate its consequences. By also taking into account the magnitude of the observed polarized flux, we conclude that this system must be at a small distance (5-50 pc), because the polarized flux from free-free emission is very low. This would make this system the closest intermediate polar yet discovered. Furthermore, the unpolarized background flux present in this system must be lower than that in RE 0751+14 by about a factor 10^3.

As an alternative, we examine whether cyclotron radiation can cause all of the observed polarization. We find that the resulting fit is still consistent with the observations with the most likely magnetic field strength such that cyclotron radiation turns from optically thin to optically thick in the I_c band. As a consequence, the magnetic field strength in this system may be significantly higher than the value obtained by Buckley et al. (1995). Furthermore, the resulting distance and unpolarized background flux are consistent with those of other known intermediate polars. For a range of likely white dwarf masses ($0.4 - 0.8$ $M_\odot$) and specific accretion rates ($0.1 - 1$ g cm^{-2} s^{-1}), we obtain magnetic field strengths at the pole ranging from $9 - 20$ MG, though it may be as high as $15 - 27$ MG with a different dipole inclination.

Key words: polarization – stars: RX J1712.6-2414 – stars: magnetic fields – novae, cataclysmic variables

1. Introduction

In magnetic cataclysmic variables (MCVs), a low mass main sequence star transfers matter via Roche lobe overflow onto a magnetic white dwarf with a field strength sufficiently strong in order to channel the accreting matter onto or near the white dwarf's magnetic pole (e.g., Frank et al. 1992). Above the surface, the accreting matter passes through a strong shock, as it has to decelerate from supersonic speeds to essentially zero velocity at the white dwarf's surface. In the post-shock region the matter is very hot ($kT \sim 10$ keV) and emits hard X-ray radiation. If the magnetic field is strong enough, then this accretion region is also the source of strong cyclotron radiation at optical/near IR wavelengths (e.g., Cropper 1990). From observations, two distinct classes of MCVs have been detected (e.g., Chanmugam 1992). On the one hand, there exist synchronous systems in which $P_{\rm spin} \approx P_{\rm orbit}$, where $P_{\rm spin}$ is the spin period of the white dwarf and $P_{\rm orbit}$ is the orbital period of the system. These systems are also known as AM Hers after their prototype. In the optical and near IR, these stars emit strong ($\sim 10\%$) phase-dependent linear and circular polarization, which is why these systems are also referred to as polars (Cropper 1990). From the polarization and observations of Zeeman and cyclotron lines, magnetic field strengths B between $\sim 7 - 80$ MG have been determined. It is this strong magnetic field combined with a short orbital separation (most polars have $P_{\rm orbit} < 4$ hr, though some systems with longer orbits are now known) which causes the synchronous rotation of the white dwarf (e.g., Joss et al. 1979; Lamb et al. 1983; Campbell 1990; King et al. 1990; Katz 1991; Wu & Wickramasinghe 1993).

On the other hand, there are the asynchronous systems with $P_{\rm spin} \ll P_{\rm orbit}$, which are also called DQ Hers (Patterson 1994) or intermediate polars (IPs). Most of these systems do not emit polarized radiation in the optical/near IR. Therefore, there exists no direct evidence for a magnetic field in these systems. However, these systems emit radiation at optical and X-ray wavelengths that is modulated at $P_{\rm spin}$. In order to explain this, the white dwarf must have a field with $B \gtrsim 5 \times 10^4$ G such that the accreting matter is forced to flow to the magnetic pole.

The most straightforward explanation for the differences between synchronous and asynchronous MCVs is that the IPs have much weaker magnetic fields ($\leq$ 1 MG) than the polars (Lamb & Patterson 1983; Wickramasinghe et al. 1991). Nevertheless, there are arguments for the existence of strong magnetic fields in IPs. Chanmugam & Ray (1984) pointed out that IPs have, in general, longer orbital periods than the polars. Because of the resulting larger separation, IPs could remain asynchronous and still have a fairly strong field ($\sim$ 10 MG). In addition, they suggested that IPs evolve into polars if the field strength is sufficiently strong. As a critical value, they gave $B \sim 3$ MG. King et al. (1985) also suggested that these two classes of MCVs have similar magnetic fields in order to explain their orbital period distribution, and they supported the evolutionary scenario of Chanmugam & Ray (1984).

If it is true that IPs have magnetic field strengths similar to polars and that at least some of the IPs can evolve into polars, then one would expect to observe at least a few IPs that display polarization in the optical/IR. Indeed, three such IPs are now known. The first to be discovered was BG CMi. Penning et al. (1986) measured -0.239 ± 0.030% circular polarization in the I band, and West et al. (1987) observed -1.74 ± 0.26% circular polarization in the J band. From this, Chanmugam et al. (1990) determined a field strength of $3 - 10$ MG with a preferred value of $\approx$ 4 MG. However, as such a field strength is only slightly above the critical value, it is not certain that this system will synchronize. The second IP in which polarized radiation was discovered is RE 0751+14 (Rosen et al. 1993; Piirola et al. 1993). The circular polarization from this system was observed to be modulated at the spin period of 13.9 min, and the observed degree of circular polarization reached -4.2 ± 0.6% in the I band (Piirola et al. 1993). The same authors also reported the discovery of linear polarization in this system in the I band. By fitting the data to cyclotron emission models by Wickramasinghe & Meggitt (1985) and Wickramasinghe et al. (1991), they obtained a field strength of $8 - 18$ MG. This IP was reexamined by Väth et al. (1996). They not only modeled the optical/IR light curves but also the light curves at hard X-ray energies. Furthermore, they took into account the stratified shock structure and used the magnetic field of a displaced dipole. They obtained a magnetic field at the poles of $9 - 21$ MG consistent with the estimates of Piirola et al. (1993).

The third and last IP exhibiting polarized radiation known to date is RX J1712.6-2414 (hereafter RXJ1712). Discovered by Buckley et al. (1995) from the ROSAT Galactic Plane Survey, these authors found a maximum degree of circular polarization in the $I_{\rm c}$ band of -5%. This is the largest value of polarization yet found in an IP. In addition, these authors observed polarized radiation in three other filters in the optical and in white light. From this they could calculate the polarized flux and compare it to the models by Wickramasinghe et al. (1991). They found a value for the field strength of 8 MG.

Here we reexamine RXJ1712. In particular, we investigate the fit of Buckley et al. (1995) in Sect. 2, and we examine how important free-free emission can be at optical wavelengths, which causes the polarization shortward of the $I_{\rm c}$ band in their fit. As an alternative, we suggest cyclotron radiation as the source of all the polarization observed in the optical, which results in a higher field strength. In Sect. 3, we construct models that can reproduce the observed light curves and thus derive new estimates of the magnetic field strength of this system for a range of possible parameters. Final conclusions are presented in Sect. 4.

2. Cyclotron versus free-free emission

Buckley et al. (1995) obtained an estimate of the magnetic field strength B of RXJ1712 by first deriving from the observations the maximum circularly polarized flux $F_{\rm c}^{\rm obs}$, which is calculated by multiplying the observed degree of circular polarization $P_{\rm c}^{\rm obs}$ with the observed flux $F^{\rm obs}$. The advantage of using $F_{\rm c}^{\rm obs}$ is that this quantity is not influenced by the unpolarized background radiation present in the system (e.g., emission by the white dwarf and the main-sequence companion). Instead, its only source is the hot accretion region on the white dwarf's surface. It therefore can be compared directly to the theoretical polarized flux $F_{\rm c}^{\rm mod}$ predicted by models of the optical/IR radiation emitted by the accretion region. For the effective wavelengths of the different filters, they used 7300 Å for the $I_{\rm c}$ band, 6400 Å for the $R_{\rm c}$ band, 5500 Å for the V band and 4500 Å for the pseudo B band. For this latter band, they combined white light polarimetry and photometry with the latter being most sensitive at short wavelengths.

As a comparison, Buckley et al. (1995) used the models by Wickramasinghe et al. (1991). These models assume that an accretion disk is disrupted at a distance from the white dwarf corresponding to the corotation radius

$$r_c = (GMP_{\rm spin}^2/4\pi^2)^{1/3}. \quad (1)$$

At distances larger than $r_{\rm c}$, the matter in the accretion disk rotates too slowly as to couple to the magnetic field lines of the white dwarf. As the matter is not expected to couple at a fixed distance but rather over a range of radii, the Wickramasinghe et al. (1991) models assume a range extending from $0.5r_{\rm c}$ to $r_{\rm c}$. The result of this model is an extended ribbon on the surface of the white dwarf with the geometry being determined entirely by the inclination δ of the centered dipole. For the radiation emitted by the accretion region, Wickramasinghe et al. (1991) include cyclotron and free-free emission. As Buckley et al. (1995) had already concluded from the observed variations of the radial velocities of emission lines that the system is seen nearly pole-on, i.e., that the inclination $i \approx 0°$, they used those models by Wickramasinghe et al. (1991) with $i = 0°$, combined with $\delta = 0°$ (Buckley 1995; private communication), and they obtained a good fit for $B = 8$ MG (however, as the degree of circular polarization from RXJ1712 varies, the inclination must be at least slightly different from zero). This fit is shown in Fig. 1, which is adapted from Fig. 16 of Buckley et al. (1995). Like these authors, we also show in Fig. 1 as a comparison the observed polarized flux of RE 0751+14 together with a fit by Piirola et al. (1993) using $i = 60°$ and $B = 8$ MG with the Wickramasinghe et al. (1991) models. The abscissa is expressed in

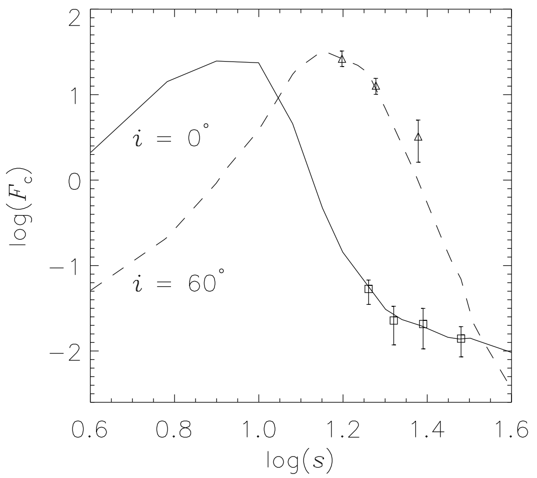

Fig. 1. The observed polarized flux of RXJ1712 (squares) adapted from Fig. 16 of Buckley et al. (1995) together with their fit using the Wickramasinghe et al. (1991) models with B = 8 MG and i = 0° (solid). Also shown is F_c^{obs} of RE 0751+14 (triangles) adapted from Fig. 5 of Piirola et al. (1993) together with a fit (dashed) with B = 8 MG and i = 60° again using the Wickramasinghe et al. (1991) models

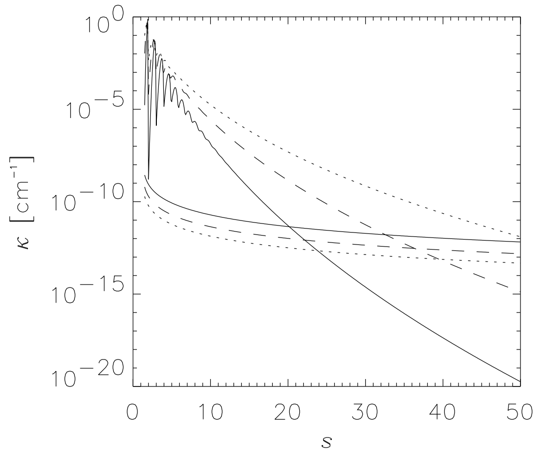

Fig. 2. Cyclotron opacity κ_{cyc} and free-free opacity κ_{ff} for θ = 90° and B = 10 MG as a function of the harmonic ratio s. Temperatures kT and electron number densities n are kT = 9.51 keV and $n = 3.8 \times 10^{15}$ cm^{-3} (solid), kT = 17.8 keV and $n = 2.8 \times 10^{15}$ cm^{-3} (dashed), kT = 29.3 keV and $n = 2.2 \times 10^{15}$ cm^{-3} (dotted). The curves with steep slopes correspond to κ_{cyc}, while the shallow curves correspond to κ_{ff}

terms of the harmonic ratio $s = \omega/\omega_c$, where ω is the frequency and $\omega_c = eB/mc$ is the cyclotron frequency. Because of the logarithmic scale in both axes, a change in the magnetic field strength or a change in the normalization of F_c^{obs}, which is arbitrary in this diagram, simply shifts the observed data in the diagram.

In the following, we will discuss the behavior of the cyclotron and free-free opacities in some detail. This has been done before (e.g., Meggitt & Wickramasinghe 1982; Väth & Chanmugam 1995). However, it is important to repeat it here, as our claim that the magnetic field of RXJ1712 may be significantly higher than the 8 MG stated by Buckley et al. (1995) is based mainly on the characteristics of these opacities.

Polarized radiative transfer using the Stokes parameters I, Q, U and V is described by three opacities commonly denoted as κ, q and v (e.g., Pacholzcyk 1977; Meggitt & Wickramasinghe 1982; Väth & Chanmugam 1995). Now $I \geq \sqrt{Q^2 + U^2 + V^2}$ (Rybicki & Lightman 1979), and as I is mainly determined by the opacity κ (e.g., Pacholzcyk 1977), it is best to compare the cyclotron absorption coefficient κ_{cyc} and the free-free opacity κ_{ff} when trying to determine the relative strengths of cyclotron and free-free emission. This we do in Fig. 2, in which we show κ_{cyc} and κ_{ff} as a function of s. These opacities are shown for the temperatures kT = 9.51, 17.8 and 29.3 keV, which correspond to the temperatures at the shock for accretion onto a white dwarf with a mass M = 0.4, 0.6 and 0.8 $M_\odot$, respectively. Thereby, we determine the radius R from the Nauenberg (1972) mass-radius relation for a pure carbon white dwarf. As the electron number densities n entering the calculations of these opacities, we use those at the shock resulting from a specific accretion rate of $\dot{m}$ = 0.5 g cm^{-2} s^{-1}. For the angle θ between the magnetic field and the line of sight, we choose 90°, as κ_{cyc} is maximal for this θ (for $s \gg 1$, which is mainly of interest here, κ_{ff} is independent of θ). For B we select 10 MG (when plotted against s, the opacities do not depend strongly on B). Furthermore, we assume that the electron and ion temperatures are identical. It has been suggested that two temperature effects are important (Imamura et al. 1987; Woelk & Beuermann 1996). In this case, the electron temperature remains low across the shock (Woelk & Beuermann 1996) and reaches its maximum further down the post-shock region. In contrast, for a one temperature plasma, the maximum electron temperature is reached at the shock and is determined solely by the Rankine-Hugoniot jump conditions (e.g., Frank et al. 1992), and it decreases monotonically in the post-shock region because of cooling. Because of this, the temperature at the shock is characteristic for the shock structure and a useful quantity for our discussion. The electron number density at the shock is also solely determined from the Rankine-Hugoniot jump conditions.

One can distinguish three cases for the emission from the accretion region. If $\kappa \times l$, where l is the geometric path length, is larger than one, then the emission is optically thick. As the emitting electrons can be assumed to be in local thermal equilibrium, the emitted flux will vary as $F \propto \omega^2$. On the other hand, if $\kappa \times l$ is smaller than one, then the emission is optically thin, and the flux will be approximately proportional to κ (some complications arise because of the polarized radiative transfer). As l is typically of the order of a fraction of R, i.e. $l \sim 10^7 - 10^8$ cm, the transition from the optically thick to the optically thin region will occur where κ_{cyc} is larger than κ_{ff}. At even higher frequencies, κ_{ff} will eventually become larger than κ_{cyc}. In this region, the decrease of the flux with increasing ω will be much slower than the decrease in the optically thin cyclotron region. One can see from Fig. 2 that κ_{ff} is below $\sim 5 \times 10^{-12}$ cm^{-1} in the region where it dominates the total opacity for kT = 9.51 keV. If kT is higher than that, then κ_{ff}

is even lower. In other words, the flux emitted by the emission region in the free-free opacity dominated region can be below the flux emitted in the cyclotron opacity dominated region by orders of magnitude.

Now the degree of polarization in the I band is higher for RXJ1712 than for RE 0751+14, and the polarized radiation from the latter system was successfully modeled to be caused by cyclotron radiation (Piirola et al. 1993; Väth et al. 1996). In addition, the polarized radiation from BG CMi, where the degree of polarization only reaches 0.24% in the I band, was also modeled successfully with cyclotron radiation (Chanmugam et al. 1990). Thus it is surprising that free-free radiation should be the source of polarized radiation in RXJ1712 over most of the optical region. If this is indeed the case, then the unpolarized radiation present in RXJ1712 (caused for example by the white dwarf and the red dwarf companion) must be lower than that present in RE 0751+14 by orders of magnitude (provided that the areas of accretion in those two systems do not differ fundamentally). Furthermore, as these two systems are of comparable brightness ($m_V \approx 14.5^{\rm mag}$ for RE 0751+14; Mason et al. 1992; $m_V \approx 14^{\rm mag}$ for RXJ1712; Buckley et al. 1995), it follows that RXJ1712 must be much closer than the 400 pc estimated as the distance to RE 0751+14 (Patterson et al. 1994). From Fig. 2 one can see that the optical depth of the accretion region of RXJ1712 may be of the order $\sim 10^{-3} - 10^{-4}$ if free-free emission causes most of the observed polarization. Say the flux from the accretion region was lower by a factor 10^3 in the case of RXJ1712 than in RE 0751+14. Then it follows that the total radiation from RXJ1712 is lower by a factor 10^3 than that of RE 0751+14. From this, using the respective magnitudes, one arrives at a distance of $\sim$ 10 pc for RXJ1712, which would make this system by far the closest IP known to date (Patterson 1994).

For these reasons, we examine as an alternative the possibility that all the observed polarized radiation in the optical is caused by cyclotron radiation. Because of the high degree of polarization in the $I_{\rm c}$ band observed from RXJ1712 and because models for RE 0751+14 indicate that the cyclotron radiation is marginally optically thin in the I band (Piirola et al. 1993; Väth et al. 1996), we may expect that the transition from optically thin to optically thick cyclotron radiation occurs in the $I_{\rm c}$ band. One immediate consequence of this is that the resulting magnetic field strength is significantly higher than the 8 MG derived by Buckley et al. (1995). In Fig. 3, we show a fit to the Wickramasinghe et al. (1991) model used in Fig. 2 but with B changed to 18 MG. The normalization of the observed data is changed such that $F_{\rm c}^{\rm obs}$ increases by a factor 700 (note that the normalization is completely arbitrary in this figure). Though the resulting fit is not as good as the one shown in Fig. 1, the cyclotron model can nevertheless reasonably reproduce $F_{\rm c}^{\rm obs}$ in the $I_{\rm c}$, $R_{\rm c}$ and V band given the large error bars. Only in the pseudo B band is $F_{\rm c}^{\rm mod}$ significantly lower than $F_{\rm c}^{\rm obs}$. However, one may argue that the effective wavelength of the pseudo B band should be at a longer wavelength than the 4500 Å used by Buckley et al. (1995). These authors said that the white light photometer has an effective wavelength somewhere between the V band and the B band, but that it should be closer to the B band for blue objects like IPs. However, if the polarization is indeed caused by cyclotron radiation as we claim here, then most of the polarized light originates at longer wavelengths, which increases the effective wavelength of the white light polarimetry. In Fig. 3, we indicate by an arrow how the position of $F_{\rm c}^{\rm obs}$ of the pseudo B band changes if its effective wavelength is at 5000 Å. One can see that the fit with B_0 = 18 MG improves significantly in this case. Given the error bars, this fit can no longer be rejected. In the following section, we will examine in more detail the effect that the polarized flux in the pseudo B band has on the quality of the fit. Ideally, one would like to fold $F_{\rm c}^{\rm mod}$ over the responses of the different filters before comparing it to $F_{\rm c}^{\rm obs}$. However, in order to do that, we need detailed information about the wavelength dependence of the response of the filter/detector system used by Buckley et al. (1995). As we do not have this information, we have to content ourselves with a comparison between $F_{\rm c}^{\rm obs}$ and $F_{\rm c}^{\rm mod}$ as shown in Fig. 3.

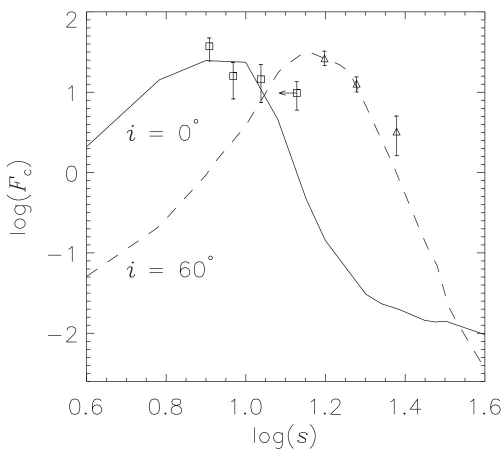

Fig. 3. Same as Fig. 1 but with the magnetic field of RXJ1712 changed to 18 MG and the normalization changed such that $F_{\rm c}^{\rm obs}$ is increased by a factor 700

3. Polarized radiation from RXJ1712

In the previous section, we argued on fairly qualitative grounds that all the observed optical polarized radiation may be caused by cyclotron radiation and that none of it is caused by free-free radiation. As a result, the magnetic field in RXJ1712 could be significantly higher than the 8 MG suggested by Buckley et al. (1995) using the same model as these authors. In this section, we want to support this claim by calculating the polarized flux and comparing its magnitude to the magnitude of $F_{\rm c}^{\rm obs}$. Also we make a more complete parameter study in order to find which magnetic field strengths are possible.

3.1. The model

Our model of the accretion region, which is the source of the cyclotron radiation, is similar to the one we used previously for modeling RE 0751+14 (Väth et al. 1996). We assume that accretion occurs onto both poles of a white dwarf with the magnetic field of a dipole written as $\mathbf{B}(\mathbf{r}) = (B_0/2)(R/r)^3$ $(3\cos\Theta\sin\Theta\cos\Phi, 3\cos\Theta\sin\Theta\sin\Phi, 3\cos^2\Theta - 1)$ with the polar coordinates r, Θ, Φ measured from the center of the dipole. It is the value of B_0, the magnetic field at the pole, that we are interested in here. We keep the dipole centered, as the available light curves can be reproduced this way.

The geometry of the accretion region is determined from where matter couples to the magnetic field lines of the white dwarf. If material links to the field at a position (r, ϕ) in the orbital plane, then this matter will land on the surface of the white dwarf at a magnetic colatitude ϵ given by (Wickramasinghe 1988)

$$\sin\epsilon = (R/r)^{1/2}\left[1 - \sin^2\delta\cos^2\phi\right]^{1/2}. \qquad (2)$$

Here r is the distance from the center of the white dwarf, ϕ is the azimuthal angle measured from the projection of the magnetic axis onto the orbital plane and δ is the inclination of the dipole axis to the rotation axis of the white dwarf (the latter will be parallel to the orbital axis after only a small amount of matter has accreted onto the white dwarf). Similar to Wickramasinghe et al. (1991), we extend the coupling region from 0.5 r_c to r_c. We select a range of $-45° \leq \phi \leq 45°$, as it is this region where most matter is expected to couple to the magnetic field (Wickramasinghe et al. 1991). For simplicity, we keep $\dot{m}$ constant across the accretion region.

For given M, $\dot{m}$ and B (the latter is only relevant if cyclotron cooling is important), the shock structure can be determined. We calculate the shock structure with the closed-integral formula of Wu et al. (1994), but in contrast to Väth et al. (1996), where bremsstrahlung was the only cooling source taken into account for the shock structure of RE 0751+14, we include cyclotron cooling as well. The relative importance of the two types of cooling can be expressed in terms of the ratio ϵ_s of the bremsstrahlung cooling time t_{br} to the (optically thick) cyclotron cooling time t_{cyc} at the shock. It is (Wu et al. 1994)

$$\epsilon_s = \left.\frac{t_{br}}{t_{cyc}}\right|_s \approx 9\times10^{-3}\left(\frac{B}{10\ \mathrm{MG}}\right)^{2.85}\left(\frac{T_s}{10^8\ \mathrm{K}}\right)^2 \times\left(\frac{10^{16}\ \mathrm{cm}^{-3}}{n_s}\right)^{1.85}\left(\frac{10^7\ \mathrm{cm}}{x_s}\right)^{0.85}, \qquad (3)$$

where T_s and n_s are the temperature and electron number densities at the shock, B is the magnetic field in the accretion region and x_s is the shock height. As the magnetic field does not vary strongly across the accretion region, we use its mean value at the base of the shock for B in Eq. 3. Because x_s depends on the cooling mechanism, i.e., it is a function of ϵ_s, one has to solve the equations for the shock structure as given by Wu et al. (1994) iteratively until one finds a self-consistent solution for ϵ_s.

Our model of the accretion region assumes homogeneous accretion. However, there are indications that accretion in polars is very inhomogeneous and occurs in form of blobs (e.g., Kuijpers & Pringle 1982; Frank et al. 1988; Ramsay et al. 1995), which could be the case in IPs as well. This would significantly decrease the optical path length, with all other parameters kept constant, which in turn would shift the transition point of optically thin to optically thick cyclotron radiation towards longer wavelengths. Therefore, when one goes from homogeneous to inhomogeneous or blobby accretion, the field estimate increases if all other parameters are kept constant.

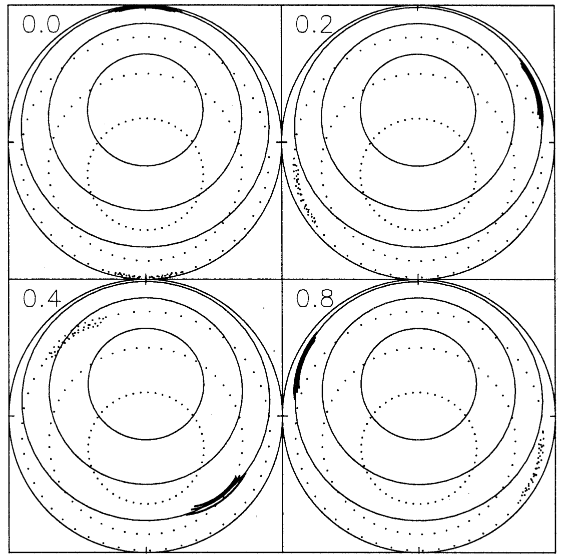

Fig. 4. Apparent position of the accretion region for different phases for $\delta = 55°$ and $i = 15°$. Hidden regions are dotted. Also shown are the colatitudes 25°, 45°, 65° (solid), and 115°, 135°, 155° (dotted)

3.2. Fitting the slope of the polarized flux

Buckley et al. (1995) did not observe any radial velocity variations of the emission lines at the spin period. From this they concluded that the system must be seen nearly pole-on. Because P_c^{obs} was observed to vary nearly sinusoidally (Buckley et al. 1995), the system must be seen slightly inclined. We select for now $\delta = 55°$ and $i = 15°$. The resulting apparent position of the accretion region for $M = 0.6\ M_\odot$ is shown in Fig. 4. Though the base of the accretion region on the far side is always hidden from the observer, some radiation reaches the observer nevertheless because of the finite shock height. The circular polarization from this pole will have the same sign as that of the pole on the near side, so this is consistent with the observations of a negative P_c^{obs} over the entire spin period. The selected values for δ and i can reproduce P_c^{obs}. This is shown in Fig. 5. We do not have detailed information of the response of the filter/detector systems used by Buckley et al. (1995). Nevertheless, we fold the calculated degrees of circular polarization at different wavelengths over the response curves of the filters as provided to us by Buckley (1995; private communication). The model used for this comparison has the parameters $M = 0.6\ M_\odot$, $\dot{m} = 1\ \mathrm{g\ cm^{-2}\ s^{-1}}$, $B_0 = 10$ MG. For such a comparison, one has to add an unpolarized background to

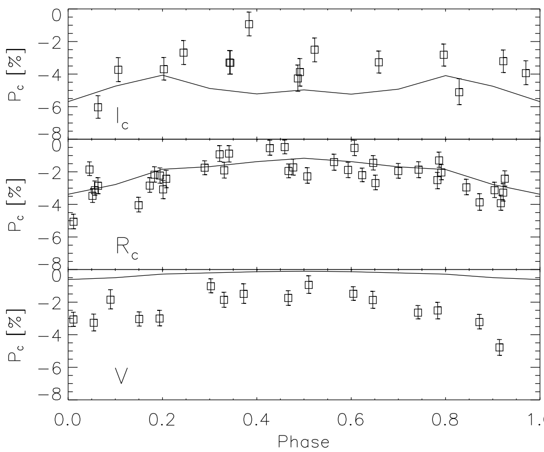

Fig. 5. Comparison between the theoretical and observed degree of circular polarization in the I_c, R_c and V bands. The observed data are extracted from Buckley et al. (1995) and are shifted in phase by 0.18. For this comparison, a phase-independent and wavelength-independent unpolarized background has been added

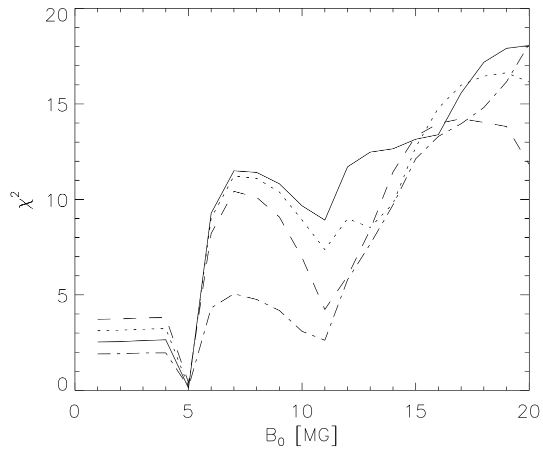

Fig. 6. χ^2 as a function of B_0 for models using $M = 0.6\ M_\odot$ and $\dot{m} = 1$ g cm^{-2} s^{-1}. The different curves result when one uses as the central wavelength of the pseudo B band 4500 Å (solid), 5000 Å (dotted) and 5500 Å (dashed), and if one ignores the data point corresponding to the pseudo B band (dash dotted)

the calculated cyclotron radiation. For simplicity, we keep the background phase-independent (also there is no observational evidence that the background flux varies at $P_{\rm spin}$). In addition, we use the same magnitude for the background at all three wavelengths, as its wavelength dependence is not known a priori. At 6400 Å the cyclotron flux is 7% of the unpolarized background flux. This results in a total flux at 500 pc (a distance used a bit further down) of 6.9×10^{-15} erg cm^{-2} s^{-1} Å^{-1}, while the observed flux is $(4.6 \pm 0.9) \times 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1} (Buckley et al. 1995). An agreement within a factor two would be sufficient given the uncertainties. The calculations of $P_c^{\rm mod}$ can reasonably reproduce the observations in the I_c and R_c band. Only in the V band is the resulting amplitude of $P_c^{\rm mod}$ clearly too low, though its qualitiative variation with phase is correct. Finally, we want to point out that for this particular combination of δ and i, the angle θ between the local magnetic field in the accretion region and the line of sight reaches 80° to 90°. We find that a lower value of δ requires a lower i in order to reproduce the variation of $P_c^{\rm obs}$, and θ will thus be lower. As we stated above, $\kappa_{\rm cyc}$ reaches its maximum at 90°. Therefore, $\kappa_{\rm cyc}$ in the accretion region will be lower at lower δ. Now we argue here that the transition from optically thick to optically thin cyclotron radiation occurs near the I_c band. Therefore, if δ is significantly lower than the 55° adopted here, then the actual value of B_0 will be higher. As a result, we derive a lower limit for B_0 by adopting this value for δ.

In Fig. 6 we display χ^2 as a function of B_0. It is obtained by fitting $F_c^{\rm mod}$ with model parameters $M = 0.6\ M_\odot$ and $\dot{m} = 1$ g cm^{-2} s^{-1} to $F_c^{\rm obs}$ for B_0 ranging from 1 to 20 MG and always normalizing $F_c^{\rm mod}$ such that χ^2 is minimized. The three lines show the result when the effective wavelength of the pseudo B band is at 4500 Å (the value used by Buckley et al. 1995), 5000 Å and 5500 Å. One can see from this figure that there exist two clear local minima of χ^2. One occurs at $B_0 = 5$ MG and corresponds to the case that the source of polarized radiation is free-free emission shortward of the I_c band. The other minimum occurs at $B_0 = 11$ MG, when the transition from optically thin to optically thick cyclotron radiation occurs near the I_c band. Obviously, the fit with free-free emission as the source is of much better quality. However, this diagram also shows that the quality of the fit with $B_0 = 11$ MG depends strongly on the exact position of the effective wavelength of the pseudo B band. The further it is moved to longer wavelengths, the better the fit becomes.

Because the band width of the pseudo B band is very broad, the flux in this band multiplied by the corresponding degree of circular polarization is not equivalent anymore to the polarized flux folded over the response of this band. Therefore it is worthwhile making a fit but ignoring the data point corresponding to the pseudo B band. The resulting χ^2 is also shown in Fig. 6. The minimum value of χ^2 corresponding to cyclotron emission being dominant over the entire observed range is still at $B_0 = 11$ MG. At the 1σ level ($\Delta\chi^2 = 1$; Press et al. 1992), B_0 is larger than 9 MG. However, at the 2σ level ($\Delta\chi^2 = 4$), one cannot rule out anymore the possibility of B_0 having any value between 5 MG and 11 MG. It is thus not certain anymore that the transition region from optically thin to optically thick cyclotron radiation is lying in or near the I_c band. Nevertheless, as this is still the most likely scenario, we will proceed on the assumption that this is the case. Future observations in the near IR will be able to settle this question.

3.3. Fitting the slope and the magnitude of the polarized flux

Up to now, we have neglected the magnitude of $F_c^{\rm obs}$ and simply normalized it in order to only fit the slope of $F_c^{\rm obs}$ with the slope of $F_c^{\rm mod}$. From now on, we also take the magnitude of $F_c^{\rm obs}$ into account. From Fig. 1 of Buckley et al. (1995), we obtain $F^{\rm obs}(\lambda) \approx 5 \times 10^{-15}$ erg cm^{-2} s^{-1} Å^{-1} at λ = 6400 Å. We use the maximum value of $P_{\rm c}^{\rm obs}$ = 5% in the $I_{\rm c}$ band, and by changing the units, we obtain for the polarized flux $F_{\rm c}^{\rm obs}(\omega) \approx 5.4\times10^{-28}$ erg cm^{-2} s^{-1} Hz^{-1}. Next we normalize the values of $F_{\rm c}^{\rm obs}$ that we extracted from Fig. 16 of Buckley et al. (1995) to this value at 6400 Å and compare $F_{\rm c}^{\rm obs}$ with $F_{\rm c}^{\rm mod}$ in Fig. 7a. As we normalized $F_{\rm c}^{\rm obs}$ to its maximum value, we have to compare it to models at a phase when $F_{\rm c}^{\rm mod}$ is maximal. This is the case at phase 0 (see Fig. 5). For this comparison, we use a distance of d = 500 pc to this system. The model parameters are as before M = 0.6 M$_\odot$ and $\dot{m}$ = 1 g cm^{-2} s^{-1}. The best fitting model is B_0 = 11 MG. For these model parameters, the transition from optically thin to optically thick cyclotron radiation occurs in the $I_{\rm c}$ band. Now, it is possible to fit the observed data with a model with significantly lower B_0 such that the polarized flux shortward of the $I_{\rm c}$ band is caused by free-free emission. We demonstrate this in Fig. 7b using as model parameters M = 0.6 M$_\odot$, $\dot{m}$ = 1 g cm^{-2} s^{-1} and B_0 = 6 MG. As $v_{\rm ff} \propto \cos\theta$ in the case of free-free emission, and as $\kappa_{\rm ff}$ is largely independent of θ, the polarized flux in the case of free-free emission reaches its maximum when θ = 0°, which is just the opposite to cyclotron radiation. Therefore, we have to use phase 0.5 for the comparison shown in Fig. 7b. However, in order to fit $F_{\rm c}^{\rm obs}$, we have to increase the polarized flux from RXJ1712 by a factor 1100, which means that this system must be closer by a factor 33, and we obtain a distance of 15 pc. Of the IPs for which Patterson (1994) gives a distance estimate, the by far closest IP is V471 Tau with d = 45 pc. All other IPs have distances ranging from 90 pc to 1100 pc. Thus RXJ1712 would be by far the closest IP known to date! RXJ1712 would be exceptional for its distance as well as its strong circular polarization. This has also consequences for the magnitude of the unpolarized background flux of this system. As $P_{\rm c}^{\rm obs}$ is even higher in RXJ1712 than in RE 0751+14, the unpolarized background radiation in RXJ1712 must be lower by a factor $\sim 10^3$ than in RE 0751+14, provided that these two systems have comparable accretion geometries.

Next we want to compare $F_{\rm c}^{\rm mod}$ with $F_{\rm c}^{\rm obs}$ for a range of parameters. For this we need to choose values for $\dot{m}$ and M. For RE 0751+14, Väth et al. (1996) were able to estimate lower and upper limits on $\dot{m}$ and M from observations at hard X-ray energies. Unfortunately, only soft X-ray observations exist for RXJ1712 (Buckley et al. 1995). The soft X-ray flux from MCVs is emitted from parts of the atmosphere of the white dwarf that are heated by the hard X-rays which originate from the post-shock region (e.g., Cropper 1990). Thus soft X-rays do not originate directly from the post-shock region, and soft X-ray observations are therefore not very suitable for estimating $\dot{m}$ and M. We therefore adopt a typical range of values for our calculations. We use here M = 0.4, 0.6 and 0.8 M$_\odot$ and $\dot{m}$ = 0.1 and 1 g cm^{-2} s^{-1}. We calculate the cyclotron and free-free emission from the emission region for values of B_0 = 5−35 MG in 5 MG steps. As we explained previously, we want to select values of δ and i such that θ of the accretion region is close but not above 90°. Also, the variation of $P_{\rm c}^{\rm obs}$ with phase should be reproduced. We therefore have to use δ = 48°, i = 14°

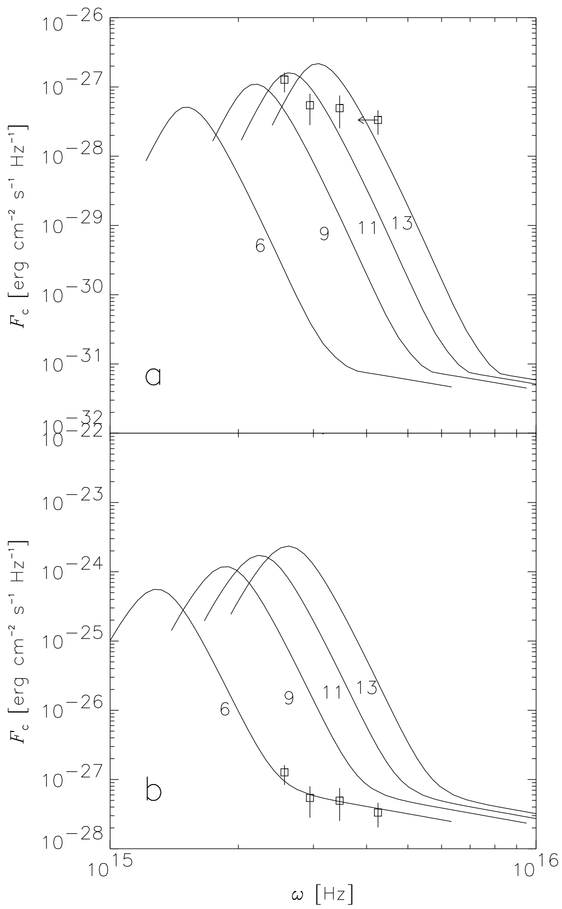

Fig. 7. Fits to $F_{\rm c}^{\rm obs}$ using B_0 = 6, 9, 11 and 13 MG (as indicated by the numbers next to the curves) with $F_{\rm c}^{\rm obs}$ = 5.4×10^{-28} erg cm^{-2} s^{-1} Hz^{-1} at the central wavelength of the $R_{\rm c}$ band. In **a** a distance of 500 pc to RXJ1712 is assumed, while in **b** a distance of 15 pc is used. The arrow in **a** indicates how the position of $F_{\rm c}^{\rm obs}$ would change if the effective wavelength of the pseudo B band was changed to 5000 Å

for M = 0.4 M$_\odot$ and δ = 58°, i = 16° for M = 0.8 M$_\odot$. A summary of our model parameters is given in Table 1. This table also shows $\epsilon_{\rm s}$ and $x_{\rm s}$ for selected values of B_0. The mean magnetic field strength in the accretion region is lower than B_0 by about 3% for M = 0.4 M$_\odot$, 2% for M = 0.6 M$_\odot$ and 1% for M = 0.8 M$_\odot$. Note that when bremsstrahlung is the only significant source of cooling, then $x_{\rm s}$ does not depend on $\dot{m}$ and is only a function of M. Furthermore, if cyclotron cooling is dominant, then the average temperature in the post-shock region is strongly reduced (see Wu et al. 1994 and Woelk & Beuermann 1996 for more detailed discussions of the effects of cyclotron cooling).

From Fig. 8 one can see that the polarized cyclotron flux increases with increasing M. This is caused by the increasing temperature in the shock (in the Rayleigh-Jeans limit, the total flux is proportional to the temperature, and the peak of $F_{\rm c}^{\rm mod}$ is influenced strongly by this limit). In contrast, the polarized flux caused by free-free radiation decreases with increasing M. This

Table 1. Accretion column on a magnetic white dwarf

M ($M_\odot$)	R (cm)	$\dot{m}$ (g cm^{-2} s^{-1})	kT_s (keV)	n_s (cm^{-3})	B_0 (MG)	ϵ_s	x_s (cm)	r_c/R
0.4	1.09×10^9	0.1	9.51	7.68×10^{14}	5	0.013	1.90×10^8	9.62
					15	0.330	1.70×10^8	
					25	1.899	1.20×10^8	
					35	7.994	6.84×10^7	
		1.0		7.68×10^{15}	5	0.001	1.91×10^7	
					35	0.380	1.67×10^7	
0.6	8.75×10^8	0.1	17.8	5.62×10^{14}	5	0.039	4.81×10^8	13.7
					15	1.153	3.52×10^8	
					25	9.675	1.60×10^8	
					35	56.40	6.19×10^7	
		1.0		5.62×10^{15}	5	0.004	4.88×10^7	
					35	1.329	3.39×10^7	
0.8	7.08×10^8	0.1	29.3	4.37×10^{14}	15	3.644	5.18×10^8	18.7
					25	44.91	1.49×10^8	
		1.0		4.37×10^{15}	5	0.009	1.03×10^8	
					35	4.294	4.85×10^7	

is explained by the temperature dependence of the corresponding opacities. For our purposes, the most important effect of decreasing $\dot{m}$ is that the polarized flux from free-free emission decreases. This is caused by the strong (quadratic) dependence of the free-free opacities on the number densities. Thus the distance derived from Fig. 7 (M = 0.6 $M_\odot$, $\dot{m}$ = 1 g cm^{-2} s^{-1}) for a B_0 in the case that free-free emission is dominant is higher than the ones resulting for models with $\dot{m}$ = 0.1 g cm^{-2} s^{-1} and those with $M > 0.6$ $M_\odot$. We list the parameters of the best fitting models with free-free emission being dominant in the optical in Table 2 and with cyclotron emission being dominant in Table 3. We thereby ignore the data from the pseudo B band. Models with values of B_0 between those for which calculations were made are obtained by interpolating on a s scale. As we pointed out above, F_c^{mod} for free-free emission is highest if θ is smallest, which is just the opposite of cyclotron emission. Correspondingly, we use in Table 2 models at phase 0.5, while models at phase 0 are used in Table 3. In the case of free-free emission, distances range from 4.8 to 30 pc. Thus the system is close enough in order to detect the parallax of this system from ground based observations. All these values would make RXJ1712 by far the closest IP (Patterson 1994). However, if cyclotron emission is indeed dominant in all observed filters, then distances are typical of other IPs (Patterson 1994). The resulting field strengths are about twice as high as in the case of free-free emission and range from $B_0 \approx 9 - 20$ MG with the error being mostly due to the uncertain values of M and $\dot{m}$. An increase in M and in $\dot{m}$ results in a decrease in B_0.

We also examine a geometry in which θ is close to 0°. This we do with $\delta = 0°$ and $i = 3°$. The parameters are also listed in Tables 2 and 3. In the case of free-free emission, the resulting distance increases. But for most values of M and $\dot{m}$, RXJ1712 still remains the closest IP known. Only for M = 0.4 $M_\odot$ and $\dot{m}$ = 1.0 g cm^{-2} s^{-1} does the distance become comparable to that of V471 Tau, which is the closest IP previously known (Patterson 1994). The resulting values of B_0 if cyclotron radiation dominates are higher than in the case of $\delta \approx 55°$, and they represent an upper limit for the possible field strength for given M and $\dot{m}$ because $\theta \approx 0°$. We obtain values of $15 - 27$ MG.

Table 2. Field strength and distance in the case of free-free emission

		$\delta \approx 55°$		$\delta = 0°$	
M ($M_\odot$)	$\dot{m}$ (g cm^{-2} s^{-1})	B_0 (MG)	d (pc)	B_0 (MG)	d (pc)
0.4	0.1	11	8.9	16	23
	1.0	10	30	13	52
0.6	0.1	10	7.1	15	15
	1.0	6	14	10	36
0.8	0.1	9	4.8	15	11
	1.0	5	12	9	31

One may argue that the area onto which accretion occurs may be significantly higher than in our calculations. This would result in an underestimate of the distances derived by us. However, for δ = 0° and M = 0.4 $M_\odot$ accretion occurs onto a fractional area of 3.4% (it is smaller for other parameters) for two pole accretion. The resulting total accretion rate for $\dot{m}$ = 1 g cm^{-2} s^{-1} is $\dot{M}$ = 5.1 × 10^{17} g s^{-1}. In the list by Patterson (1994), the average value is $\dot{M}$ = 1.1 × 10^{17} g s^{-1}. Thus our values of $\dot{M}$ are certainly not biased towards values that are too low compared to other IPs, and our distance estimates are not systematically too low, either.

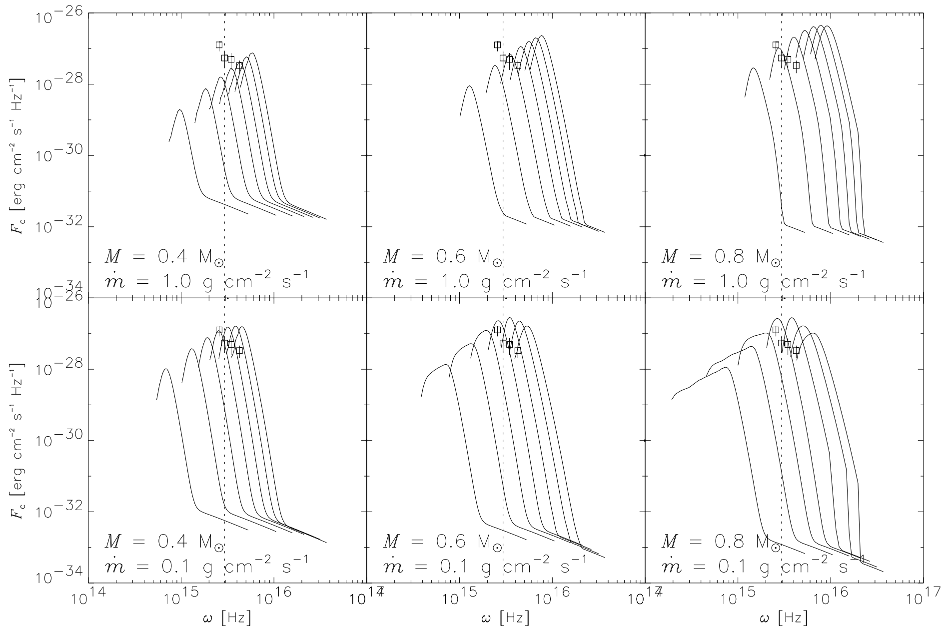

Fig. 8. Comparison of F_c^{mod} with F_c^{obs} for different M and $\dot m$ as indicated in each panel, with F_c^{mod} calculated for a distance of 1000 pc. In each panel, the magnetic field B_0 of the models increases from 5 MG to 35 MG in steps of 5 MG (from left to right). For these models δ = 55° and i = 15° for M = 0.6 M$_\odot$. The observed data are indicated by squares and error bars. The dotted line highlights the effective wavelength of the R_c band

Table 3. Field strength and distance in the case of cyclotron emission

		$\delta \approx 55°$		δ = 0°	
M (M$_\odot$)	$\dot m$ (g cm^{-2} s^{-1})	B_0 (MG)	d (pc)	B_0 (MG)	d (pc)
0.4	0.1	20	951	27	1270
	1.0	14	318	21	1120
0.6	0.1	19	1240	26	1230
	1.0	11	589	17	1040
0.8	0.1	19	1400	26	1230
	1.0	9	808	15	977

Here we also want to briefly address the question whether the observed radial velocity modulations of the emission lines can rule out any of the accretion geometries considered here. Buckley et al. (1995) detected low variations at the beat period of at most $K \sim 20$ km s^{-1} and no variations at all at the spin period with an upper limit of 10 km s^{-1}. Garlick (1996) investigated the radial velocity variations of emission lines in diskless IPs and applied his findings to RXJ1712. He argues that i is very close to 0° as an inclination of 2° would already result in radial velocity variations larger than 50 km s^{-1}, in conflict with observations. In this case, however, our models would not be able to reproduce the variations of P_c^{obs}, as we need an inclination of at least $\approx 3°$ for that. We cannot resolve this conflict here. Nevertheless, the work by Garlick (1996) at least seems to rule out our models of $\delta \approx 55°$ for which $i \approx 15°$. This rather increases the field estimate.

In addition, we want to look at the question whether our high field estimates are consistent with the asynchronism of RXJ1712. Patterson (1994) gives as a condition for synchronism that the field be higher than $(B_{synch}/\mathrm{MG}) \approx 2.2(M/\mathrm{M}_\odot)^{3.1}(P_{orb}/\mathrm{hr})^{2.8}$. A mass-radius relation and an average $\dot M$-P_{orb} relation enter that formula. For RXJ1712 with P_{orb} = 3.4 hr (Buckley et al. 1995), we thus obtain $B_{synch} \approx$ 4 MG for M = 0.4 M$_\odot$, $B_{synch} \approx$ 14 MG for M = 0.6 M$_\odot$ and B_{synch} = 34 MG for M = 0.8 M$_\odot$. By comparing this constraint to Table 3, it seems that it rules out M = 0.4 M$_\odot$ and some of the parameters for M = 0.6 M$_\odot$, while all estimates of B_0 for M = 0.8 M$_\odot$ are below B_{synch}. However, many assumptions enter this relation for synchronism. Furthermore, given the uncertainties in theories of synchronization (e.g., Campbell 1990; Wu & Wickramasinghe 1993), one may be best advised not to reject a 0.4 M$_\odot$ white dwarf simply based on the above listed values for B_{synch}.

4. Conclusion

The magnetic field of RXJ1712, which is the IP with the highest observed degree of polarization discovered so far, was determined by Buckley et al. (1995) to be 8 MG. From their fit to F_c^{obs} it follows that the polarized radiation in the R_c, V and pseudo B band is caused by free-free emission. Cyclotron radiation is only significant in the I_c band and longward of it.

We reexamine this fit and its consequences. By comparing F_c^{obs} to the polarized flux obtained from models in which free-free emission dominates in the optical, we conclude that RXJ1712 must be very nearby. For model parameters of M = 0.4 − 0.8 M$_\odot$ and $\dot m$ = 0.1 − 1 g cm^{-2} s^{-1}, we obtain distances of 5 − 50 pc. Thereby, low M and high $\dot m$ (because of the temperature and density dependence of the free-free opacities) result in a higher flux and thus in a larger distance. Thus RXJ1712 would be the closest IP known to date. Certainly, its parallax should be measurable from ground based observations. Another consequence of fitting F_c^{obs} shortward of the I_c band with free-free emission is that the unpolarized background radiation (caused for example by the white dwarf, the red dwarf companion etc.) must be very low in this system. As P_c^{obs} is higher in RXJ1712 than in RE 0751+14, we estimate that the unpolarized background flux in RXJ1712 must be lower than that in RE 0751+14 by a factor $\sim 10^3$. All these points make it seem unlikely that free-free emission is the source of the observed polarization. In addition, we obtain a lower limit for the distance to RXJ1712 from the Roche lobe filling secondary. The period-mass relation $(M_2/\mathrm{M}_\odot) \approx 0.11(P_{\rm orb}/\mathrm{hr})$ (e.g., Frank et al. 1992) results in a mass of the secondary of M_2 = 0.37 $\mathrm{M}_\odot$. By making the simplifying assumption that the secondary has the structure of a main sequence star, we can obtain an absolute magnitude of $M_V = 9.8^{\rm mag}$ using the data listed by Aller (1976). By assuming that all the flux observed in the V band originates from the secondary, we derive a distance of 70 pc to RXJ1712 using $m_V = 14^{\rm mag}$ (Buckley et al. 1995). However, much of the light in this band is emitted from sources other than the secondary. Therefore, the actual distance must be larger than the above derived value. However, this lower limit contradicts the upper limit of 50 pc obtained from the magnitude of the polarized flux in the case that it is caused by free-free emission. This largely rules out the free-free hypothesis.

As an alternative, we propose here that the polarized radiation at all observed optical wavelength bands is caused by cyclotron emission and that optical free-free emission from the accretion region is not significant in RXJ1712. We have shown that the observations seem at first sight to rule out this possibility mainly because of the observed polarized flux in the pseudo B band, which is almost as high as that in the R_c and V band. However, it is not certain that the effective wavelength of this band is at 4500 Å, as suggested by Buckley et al. (1995), and it may well be at a longer wavelength, as this band actually corresponds to white light observations. In this case, a fit to F_c^{obs} using cyclotron radiation as the sole cause of polarized radiation improves significantly. The transition from optically thin to optically thick cyclotron radiation is then in or near the I_c band, whose effective wavelength is about 7300 Å (Buckley et al. 1995).

One immediate result of fitting F_c^{obs} with cyclotron emission in the transition from optically thin to thick instead of free-free emission is that the resulting magnetic field is higher. For example, using the same model as Buckley et al. (1995), we obtain a field strength of 18 MG instead of 8 MG. We investigate the possible values of B_0 by calculating models for a range of M and $\dot{m}$. The parameters δ and i are selected such that the observed variation of the degree of polarization can be reasonably reproduced and that the angle θ between the line of sight and the magnetic field in the accretion region reaches values near 90°. That way, for particular values of M and $\dot{m}$, we obtain a lower estimate for B_0, as lower values of θ result in a higher B_0 because of the strong angle dependence of the cyclotron opacities. We obtain values for B_0 ranging from $\approx 9-20$ MG. with higher values of M and $\dot{m}$ resulting in a lower B_0. We also calculate models with δ being at its other extreme. This results in an upper limit for B_0 for a given M and $\dot{m}$. In this case, we obtain values of B_0 ranging from 15 to 27 MG. The calculations illustrate the large uncertainty in B_0 caused by the still unknown and from the optical observations not constrained M and $\dot{m}$. In principle, one can determine or at least constrain these from hard X-ray observations (e.g., Väth et al. 1996). Unfortunately, such observations have not yet been made or at least not yet been published.

Another consequence of our proposed fit of the observed polarized flux with cyclotron radiation is that IR observations (say in the J and K bands) of the polarized flux should result in a lower polarized flux than that observed in the I_c band, because the cyclotron radiation is optically thick in these wavelength bands. In contrast, if free-free emission is dominant shortward of the I_c band and cyclotron radiation becomes dominant in the I_c band, then the polarized flux should strongly increase as one goes from the I_c band into the IR. To make this discussion more quantitative, we want to consider the case of M = 0.6 $\mathrm{M}_\odot$, $\dot{m}$ = 1 g cm^{-2} s^{-1} and δ and i with values as in Fig. 8. With B_0 = 11 MG, F_c^{mod} reaches its maximum in the I_c band. In the J band (not shown in Fig. 8), the circular polarization changes its sign. The reversal of the sign when going from optically thin to optically thick cyclotron radiation in models with inhomogeneous temperature structure was already pointed out by Wickramasinghe & Meggitt (1985). In the K band, F_c^{mod} reaches about one tenth of F_c^{mod} in the V band, but circular polarization may not be observable as F_c^{mod} only reaches a few percent of the total flux emitted by the emission region. However, if free-free emission is dominant in most of the optical region, which is the case for B_0 = 6 MG, then F_c^{mod} reaches its maximum at the long wavelength end of the J band with a factor 1000 above F_c^{mod} in the V band. The K band is again optically thick and the circular polarization reverses its sign at the long wavelength end of this band. To summarize, the resulting behavior of F_c^{obs} in the IR band is very different for the two alternative models of the optical polarization of RXJ1712.

Finally, we want to point out the consequences of not detecting any polarization in the IR or the parallax being below the observable limit. For one, it rules out free-free emission as the source of observable polarization in the optical in this system. Thus RXJ1712 becomes the third IP after BG CMi (Chanmugam et al. 1990) and RE 0751+14 (Piirola et al. 1993; Väth et al. 1996) in which cyclotron radiation is the sole source of observed polarization. Though the number of such objects is still small, it starts to become unlikely that free-free emission from the accretion region can cause observable polarization in the optical in IPs. Secondly, it implies a much higher magnetic field strength in RXJ1712 than the one derived by Buckley et al. (1995). Our models typically result in a B_0 that is about a factor 2 higher in the case of cyclotron radiation in the optical than in the case of free-free emission. Unfortunately, the value of B_0 in the cyclotron emission models is still very uncertain mainly because of the unknown values of M and $\dot{m}$. To constrain these, X-ray observations may prove to be very useful. Nevertheless, the possibly high value of B_0 (maybe even higher than in RE 0751+14) makes RXJ1712 a prime candidate for an IP that may synchronize and turn into a polar, an evolutionary scenario suggested by Chanmugam & Ray (1984) and King et al. (1985).

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References

Aller C.W. 1976, Astrophysical Quantities, Athlone Press, London
Buckley D.A.H., Sekiguchi K., Motch C. et al. 1995, MNRAS 275, 1028
Campbell G.C. 1990, MNRAS 244, 367
Chanmugam G. 1992, ARA&A 30, 143
Chanmugam G., Frank J., King A.R., Lasota J.-P. 1990, ApJ 350, L13
Chanmugam G., Ray A. 1984, ApJ 285, 252
Cropper M. 1990, Space Sci. Rev. 54, 195
Frank J., King A.R., Lasota J.-P. 1988, A&A 193, 113
Frank J., King A., Raine D. 1992, Accretion Power in Astrophysics, Cambridge Astrophysics Series, Cambridge Univ. Press, Cambridge
Garlick M.A. 1996, MNRAS in press
Imamura J.N., Durisen R.H., Lamb D.Q., Weast G.J. 1987, ApJ 313, 298
Joss P.C., Katz J.I., Rappaport S.A. 1979, ApJ 230, 176
Katz J.I. 1991, Comments Ap 15, 177
King A.R., Frank J., Ritter H. 1985, MNRAS 213, 181
King A.R., Frank J., Whitehurst R. 1990, MNRAS 244, 731
Kuijpers J., Pringle J.E. 1982, A&A 114, L4
Lamb F.K., Aly J.-J., Cook M.C., Lamb D.Q. 1983, ApJ 274, L71
Lamb D.Q., Patterson J. 1983, in IAU Colloquium 72, Cataclysmic Variables and Related Objects, ed. M. Livio & G. Shaviv, Reidel, Dordrecht, p. 229
Mason K.O., Watson M.G., Ponman T.J. et al. 1992, MNRAS 258, 749
Meggitt S.M.A., Wickramasinghe D.T. 1982, MNRAS 198, 71
Nauenberg M. 1972, ApJ 175, 417.
Pacholczyk A.G. 1977, Radio Galaxies, Pergamon, Oxford
Patterson J. 1994, PASP 106, 209
Penning W.P., Schmidt G.D., Liebert J. 1986, ApJ 301, 881
Piirola V., Hakala P., Coyne G.V. 1993, ApJ 410, L107
Press W.H., Teukolsky S.A., Vetterling W.T., Flannery B.P. 1992, Numerical Recipes in FORTRAN: the art of scientific computing, Cambridge Univ. Press, Cambridge
Ramsay G., Cropper M., Mason K.O. 1995, MNRAS 276, 1382
Rosen S.R., Mittaz J.P.D., Hakala P.J. 1993, MNRAS 264, 171
Rybicki G.B., Lightman A.P. 1979, Radiative Processes in Astrophysics, Wiley, New York
Väth H., Chanmugam G. 1995, ApJS 98, 295
Väth H., Chanmugam G., Frank J. 1996, ApJ 457, 407
West S.C., Berriman G., Schmidt G.D. 1987, ApJ 322, L35
Wickramasinghe D.T., Meggitt S.M.A. 1985, MNRAS 214, 605
Wickramasinghe D.T., Wu K., Ferrario L. 1991, MNRAS 249, 460
Woelk U., Beuermann K. 1996, A&A 306, 232
Wu K., Chanmugam G., Shaviv G. 1994, ApJ 426, 664
Wu K., Wickramasinghe D.T. 1993, MNRAS 260, 141

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