POLARIMETRY OF ST LMI (CW1103+254)

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Abstract

White light simultaneous photometry and linear and circular polarimetry is presented for the AM Her variable ST LMi. Linear polarization evident throughout the faint phase is tentatively attributed to electron scattering from gas in the accretion column at heights greater than $5R_{wd}$ above the surface. The values of inclination and magnetic colatitude are revised to take into account the height and extent of the cyclotron emitting region which are also determined. A model of two closely connected emitting regions is proposed to account for the asymmetries observed in the light curve and polarization data for this and other AM Her systems. The cyclotron and hard x-ray emitting regions are found to be coincident, which eliminates the region above the shock as the source of polarized light. The shock height is found to be too low and the soft x-ray flux too large for the standard radiative shock model to apply.

1 Observations

The observations were all made with the UCT Polarimeter (Cropper 1985) in the simultaneous linear and circular polarimetry and photometry mode at the Sutherland site of the South African Astronomical Observatory. The 1.0m telescope was used for the runs which were taken during the two month period 24 April - 20 June 1985 and cover a total of ~14 orbits. A white light bandpass (3200 – 9200Å) was used. These data were folded on the orbital period then averaged into phase bins (150 for the photometry and 50 for the polarimetry). They are shown in fig 1. Note that the data are plotted over two phases for clarity. The features in fig. 1 relevant to the subsequent discussion are:-

(i) The star was in a typical bright state at the time i.e. magnitude ~15–16.5 in V.

(ii) The light curve has a faint phase lasting for 0.62 of an orbit and a bright phase lasting 0.38 of an orbit.

(iii) The circular polarization is zero during the faint phase and ~ -18.5 per cent during the bright phase. The rise in the absolute value of the circular polarization starts and ends at the same instant as the bright phase starts and ends. There is no overshoot (as seen in the similar system VV Puppis — Liebert and Stockman 1979) in the polarization.

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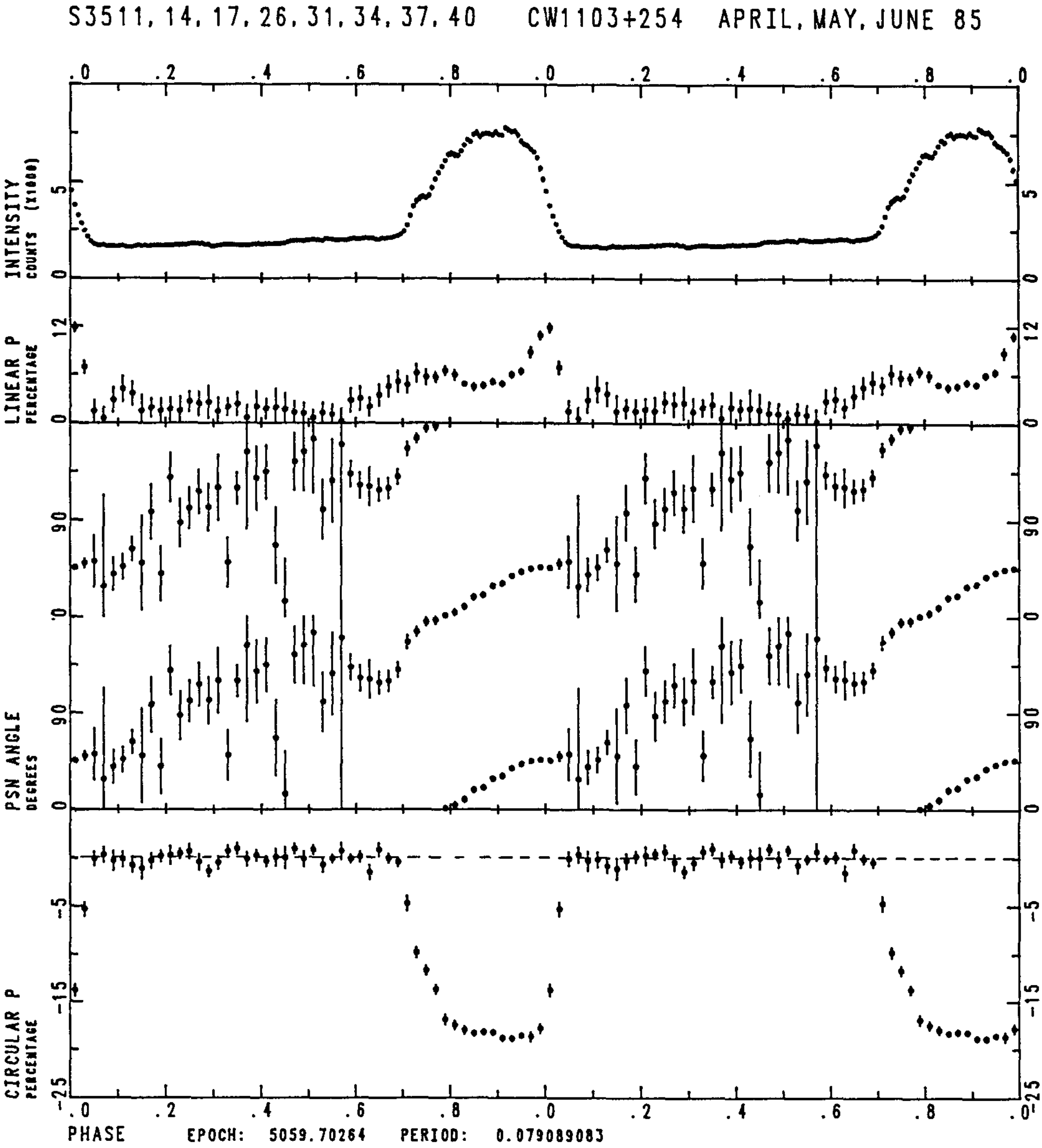

Figure 1: The white light data folded on the orbital period, averaged into 150 photometry and 50 polarimetry bins and plotted twice. The photometry is shown in the top graph, followed below by the linear polarization, the position angle (also plotted twice vertically for clarity) and the circular polarization.

(iv) There is strong linear polarization during the bright phase which peaks during the decline to the faint phase. A flatter peak is evident at the beginning of the bright phase. There is also significant linear polarization both before and after the bright phase.

(v) The position angle of the linear polarization is well determined during the bright phase; however, the generally increasing position angle during the faint phase indicates that there is also significant linear polarization during the faint phase. The position angle of the linear polarization just before and just after the bright phase is smaller than expected from the trend during the bright phase.

(vi) There are standstills during the rise to the bright phase which are also evident in the circular polarization data, in earlier data presented in Stockman *et. al.* (1983) and in hard x-ray data presented in Beuermann *et. al.* (1984).

The x-ray data from EXOSAT presented by Beuermann *et. al.* (1984) show a similar light curve to the optical in both soft and hard x-rays, but with a soft x-ray bright phase of longer duration.

2 Discussion

2.1 The Source of the Faint Phase Linear Polarization

The reality of the linear polarization before and after the bright phase is certain. The reality of the linear polarization during the faint phase is less assured, but, because the position angle follows a roughly linear trend which, moreover, meets smoothly with the polarization before and after the bright phase, it is unlikely that this polarization is interstellar or results from incorrect sky subtraction. Cyclotron radiation and the white dwarf photosphere can be excluded as the souce of the linear polarization by the absence of any circular polarization, which would predominate for the angles at which the system is viewed during the faint phase. The most likely alternative is electron scattering of the cyclotron emission from the proposed (Liebert and Stockman 1985) reservoir of gas threading the field lines above the accreting pole. The heated face of the secondary and the stream closer to the secondary can be excluded as the scattering source by the manner in which the position angle varies before and after the bright phase. The scattering region has to be at a height $\geq 5R_{wd}$ in order to remain visible throughout the faint phase.

2.2 Refining the Geometry

Both poles are seen alternately in this system. Only one is accreting in the optical, hence the orbit is divided into a bright phase and a faint phase (depending on which pole is in view). The current estimates for the inclination and colatitude of the magnetic pole must be modified to take into account the effects of the height and extent of the optical emission region. An upper limit on the height ($h \leq 0.005R_{wd}$) is available from the absence of any circular polarization overshoot. The area of the emission region, the inclination and the colatitude of the magnetic pole can be solved for, using the duration of the bright phase, the position angle variation and the rise and fall times at the beginning and end of the bright phase. The inclination is then 56° ± 4°, the colatitude is 134° ± 4° and the area is $\sim 10^{-3}A_{wd}$. The rise time at the beginning of the bright phase is longer than the fall time at the end of the bright phase,

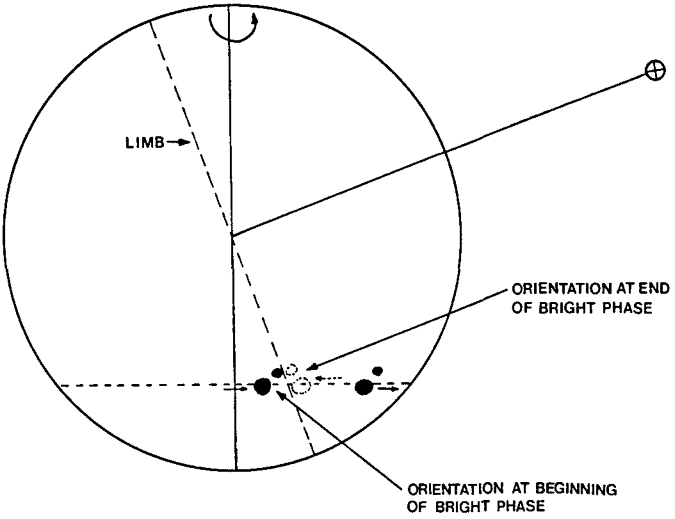

Figure 2: The model for the asymmetries and standstills in the intensity and polarization curves. At the beginning of the bright phase the two accreting regions appear sequentially (solid spots) and at the end of the bright phase they disappear simultaneously (dotted spots).

indicating that the accretion region is more extended in one direction than the other. As a start, an idealized model of two accretion regions close to each other and orientated so that the smaller region is closer to the equator of the primary and more advanced in phase (see fig. 2) explains both (a) the longer rise time and standstills in the intensity and circular polarization curves as first one region then the other rotates into view but rotate out of view simultaneously, and (b) the difference in the height of the linear polarization peaks since both regions are on the limb simultaneously during the decline from the bright phase but not during the rise to maximum light. A similarly elongated region can account for the asymmetries in the light and polarization curves of VV Puppis and BL Hyi (H0139-68) and for the unusual position angle variation during the linear polarization peak noted in EF Eri (Cropper, 1985) and other AM Her systems. The model is consistent with our expectations because the secondary lags the accretion region by ~ 0.1 in phase (Bailey *et. al.* , 1985) and the natural location for material penetrating deeper into the magnetosphere before threading onto the field lines to accrete is closer to the equator and ahead in phase of the main bulk of the accreting material.

2.3 Are the Hard X-Ray and Optical Emission Regions Coincident?

Lamb (1985) refers to the issue of whether the cyclotron radiation is emitted from within, above or around the hot postshock hard x-ray emitting region. Enough data are now available for this question to be answered for ST LMi. Because the height of the column was found to be $\leq 0.005 R_{wd}$ in the optical an extended region above the shock can be ruled out as the site of the cyclotron emission. It is not possible to use geometrical arguments to determine whether the two regions have the same area because the hard x-ray data are too noisy to determine the area of the hard x-ray emitting region. However, it is possible to determine the temperature of the two emitting regions in two ways. Firstly the hard x-ray region:-

1. Direct observation from EXOSAT set limits of 20–30KeV (Beuermann *et. al.* , 1984).
2. After using the distance to the system (136pc, Bailey *et. al.* , 1985), the temperature of the white dwarf (13400K, Szkody *et. al.* 1985) and apparent magnitude of $V \simeq 17.0$ to calculate the radius of the white dwarf, and the Hamada-Salpeter relation to derive an estimate of its mass (Hamada and Salpeter, 1961) as $0.54 \pm 0.2 M_{\odot}$, models by Immamura (Immamura, 1984) give a postshock temperature of $19 \pm 10 KeV$.

Then the cyclotron emitting region:-

1. Wickramasinghe and Meggitt's models (Wickramasinghe and Meggitt, 1985) give good agreement with the observed shape of the cyclotron emission continuum if a temperature of $15 - 30 KeV$ is used for the emitting region.
2. The area of the cyclotron emitting region and the flux observed in the optically thick part of the cyclotron continuum requires a temperature of $\sim 25 KeV$.

The agreement between the above temperatures rules out a low temperature ($\sim 1 KeV$) region around the x-ray emitting region as the location for cyclotron emission; the cyclotron radiation therefore arises from within the high temperature shock.

2.4 Consequences for Radiative Cooling Models

The duration of the soft x-ray bright phase (Beuermann *et. al.* 1984) depends on the noise level adopted, but it is clearly longer than the optical bright phase 15 months later. Again the rise to maximum intensity is slower than the decline to the faint phase, indicating that the region is elongated. The calculations used above to derive the size of the optical emitting region can also be used to determine the size of the soft x-ray emitting region giving $\sim 0.01A_{wd}$. Using Lamb (1985) equation (15), the ratio of the optical to x-ray emitting areas and the cyclotron flux emitted in the optically thick part of the spectrum (Bailey *et. al.* , 1985) requires that the soft x-ray flux is at the top end and the temperature at the bottom end of the ranges calculated in Beuermann *et. al.* (1984). The x-ray L_{hard}/L_{soft} ratio is then ~ 0.33 instead of $1.6 - 2$ expected from the standard radiative model for the cooling processes in the column. The low column height also poses problems for the model. Alternative models such as those proposed in Kuijpers and Pringle (1982) or Frank and King (1984) may be neccessary.

Acknowledgements

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