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Linear polarization in binaries with grey atmosphere I. Conservative Rayleigh scattering

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Abstract. This paper presents a method for calculating linear polarization from binaries whose surfaces are distorted due to tidal and rotational forces. The atmospheres in stars are grey, plane-parallel and pure scattering. The polarization as high as 3.51% is calculated for a single star and 2.89% for a binary with a mass ratio q=0.3. The method has been applied to some early type binaries to calculate polarizations in them.

Key words : binary - grey atmosphere - pure scattering - linear polarization

1. Introduction

Based on the geometry of Harrington & Collins (1968), Peraiah (1976) and Barman & Peraiah (1992) computed the emergent polarization from binaries using an approximate form of the tidal force of the secondary component and using the velocity law of the form $\Omega = b_1 + b_2 W^2$. In this paper we have used the same geometry of Harrington & Collins (1968) but used the exact form of the tidal force and the higher order of velocity law of the form :

$$\Omega = b_1 + b_2 W^2 + b_3 W^4 \tag{1}$$

We have calculated the linear intrinsic polarization as a function of the mass-ratio (q) between the primary and the secondary and the polar radius (r_p) of the primary for some different values of the angle of inclination (β) (see Figs. 1 & 2). We have applied the method to some early type binaries.

2. Theoretical model

Let $P(r,\theta,\phi)$ be any point on the surface of the binary star. Following the idea of Harrington & Collins (1968) we consider two rotations. One is the rotation of x-y plane about the z-axis through an angle α and the other rotation of x-z plane about the y-axis through an angle $\pi/2-\beta$, where β is termed as an angle of inclination. Then the amount of polarization (Harrington & Collins (1968, Barman & Peraiah 1992) is given by :

$$P = \frac{\int\int (I_r - I_l)\, r^2 \cos 2\zeta \sin\theta\, [g(\tilde{n}.\tilde{I})] / g_r\, d\phi\, d\theta}{\int\int (I_r + I_l)\, r^2 \sin\theta\, [g(\tilde{n}.\tilde{I})] / g_r\, d\phi\, d\theta} \qquad (2)$$

where ñ is the unit vector normal to the surface of the star; the components I_l and I_r of the emergent intensity I have been calculated from the equation 49 (Chandrasekhar 1960, p. 240) in the fifth approximation which is accurate up to three decimal places. The quantities g, g_r, $g(\tilde{n}.\tilde{I})$ and $\cos 2\zeta$ of equation 2 can be worked out following the procedure of Barman & Peraiah (1992).

3. Discussion of the results and its application

(a) Discussion of the results

In this paper we consider the combined effects of gravity darkening, rotational distortions and conservative Rayleigh scattering controlled by electrons, which together cause intrinsic linear polarization. The atmosphere is assumed to be grey and plane-parallel. Conservative grey atmosphere does not represent a real atmosphere due to the wavelength independence of opacity and the absence of absorption. Still conservative grey atmosphere calculations have some significance in the sense that : (1) the consistency of the exact results can be tested with direct numerical methods. (2) the results of non-conservative non-grey atmosphere can be compared with the results of conservative grey atmosphere.

As a first order approximation observing the geometric effects of a component of a binary is same as observing the geometric effects of a single star of Harrington & Collins (1968), but in the binary the potential arising from the other component have to be counted.

(1) When q=0, b_2=0, b_3=0, i.e., a single star (primary) is rotating uniformly, then our expressions reduce to those of Harrington and Collins (1968). Harrington & Collins (1968) have computed polarization as a function of the fraction of break-up velocity without mentioning any particular value for the polar radius r_p and found the polarization as high as 1.7%. Our results for r_p=0.2 agrees excellently with theirs; but as r_p increases polarization also increases and we obtained a polarization as high as 3.51% for r_p=0.7.

(2) From Fig. 1 we see that as the mass-ratio q increases from 0 to 1, the polarization increases up to 0.50% at the equator. For the sake of interest q is stretched up to q = 3 where we see that after q = 1 the polarization is increasing very steeply up to 8.61% at the equator. As q increases, the distortion increases due to tidal forces from the secondary component. From Fig. 2 we see interestingly that as the polar radius r_p increases from 0.2 to 0.7, the polarization increases up to 1.13 % at the equator. As r_p increases, r_e also increases and hence the distorted surface area increases. It then proves that if the distorted surface area increases, the emergent polarization also increases.

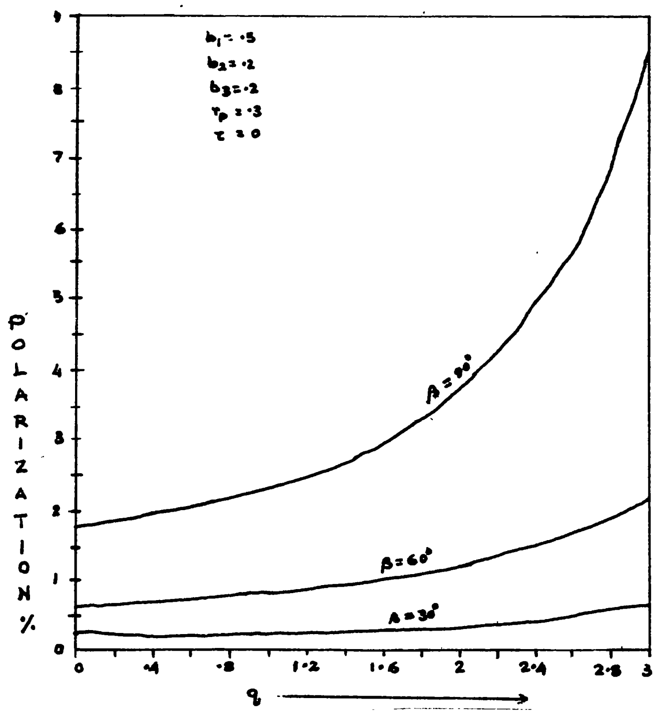

Figure 1. Polarization versus mass-ratio q for β=30°, 60°, 90°.

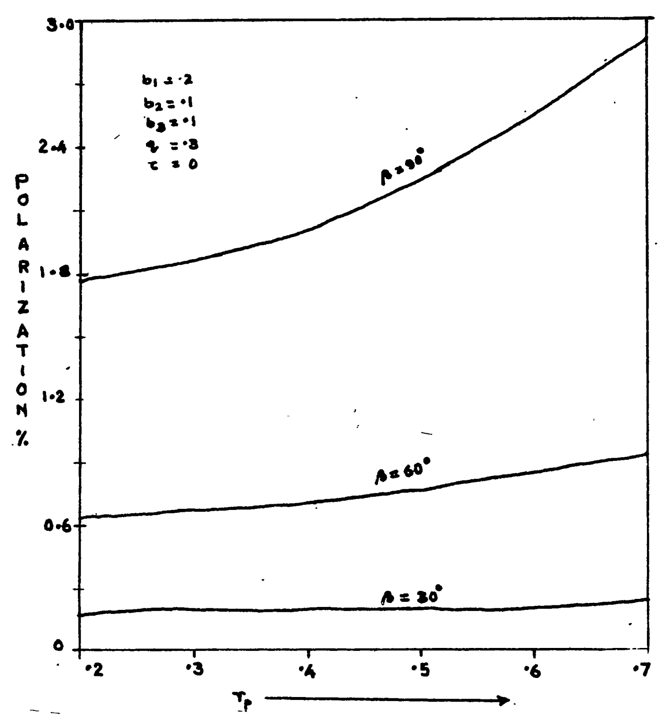

Figure 2. Polarization versus mass-ratio r_p for β=30°, 60°, 90°.

(b) Application

Using tables 7-1 to 7-7 of Kopal (1959) we calculate the position angle I, the ratio between angular velocities at the equator and the pole Ω_e/Ω_p, and the polarization at the angle of inclination β=I for the three early type binaries. For the binary WW Aur the angle I, the ratio Ω_e/Ω_p (primary) and the polarization % (primary) are respectively 77°.4, 1.0 and 1.18; for the y Cyg the values are 73°.4, 1.01 and 1.06; for the V Puppis the values are 67°.7, 1.0 and 0.94.

A reference (Cranmer 1993) quotes a value for the angle of inclination of V Puppis to be 79°. The results are however yet to be compared with the observed results if available.

4. Conclusion

The polar radius r_p, in addition to the angle β and the mass-ratio q, plays an important factor to change the polarization. The non-conservative non-grey atmosphere can be taken up to find the characteristic differences.

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