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Reflection Effect in Close Binaries

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Abstract. A method has been developed to compute lines formed in the tidally and rotationally distorted atmosphere of the primary component of a close binary star, irradiated by the secondary component. We used the two-level-atom approximation with complete redistribution.

It is found that the self-radiation produces the absorption line and the combination of self-radiation and irradiation from the secondary component produces emission.

1. Introduction

Peraiah & Srinivasa Rao (1998) treated the line transfer problem with reflection effect when the irradiation component is an extended source. The irradiation from the secondary on the primary is calculated using a one dimensional rod model. The components of close binaries are distorted mainly due to two physical effects. (i) S elf-rotation of the component and (ii) the tidal effects due to its companion. Non-sphericity changes the density distribution of the matter through which the radiation passes and as a consequence, the lines formed in such a medium are modified. In addition to this, the presence of the secondary component's light falling on such distorted surfaces of the components will affect the line profiles formed in the atmosphere. One also encounters mass motions in the atmospheres of the stars.

2. Calculation of Self-Radiation of the Primary Star

We need to estimate the source function due to self-radiation (S_s) of the primary component. This is done by solving the line transfer equation for a Non-LTE two-level atom in the comoving frame in spherical symmetry (Peraiah 2002). We employed complete redistribution in the line formed in a scattering medium.

2.1. Equation of Distorted Surface

We compute the distorted surface by solving the following seventh degree equation (Peraiah 1970)

$$\alpha\eta^7 \sin^6\theta + \beta\eta^5 \sin^4\theta + \left(\gamma \sin^2\theta + J\right)\eta^3 - \left(1 - Q\right)\eta + 1 = 0\,, \tag{1}$$

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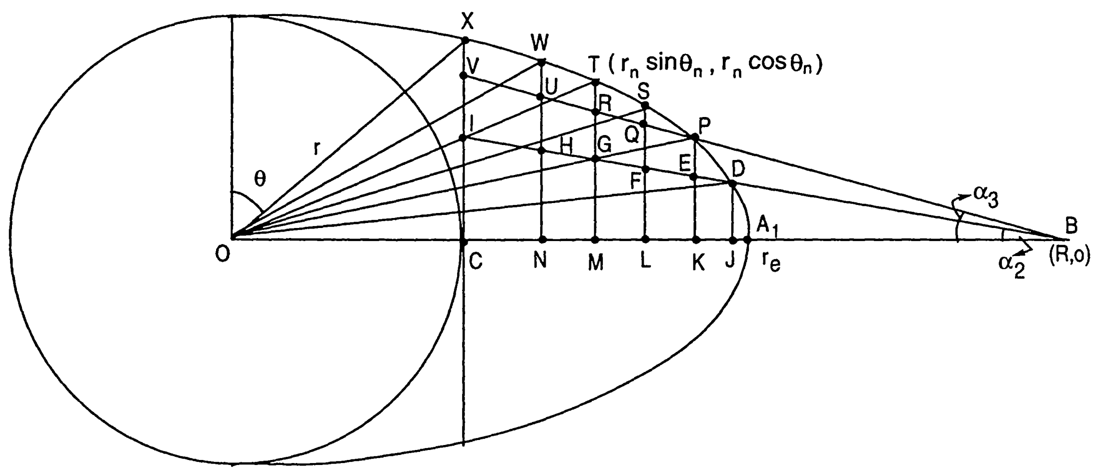

Figure 1. Schematic diagram of the distorted atmosphere of the primary component

where

$$J = Q\left(3\sin^2\theta\cos\phi - 1\right), \tag{2}$$

and θ and ϕ are the colatitude and the azimuthal angles, respectively. Further, $\eta = r/r_p$, where r and r_p are the radius at any point on the surface and the radius at the pole, respectively, and

$$\alpha = \frac{f(X-1)^2}{6X^2}\left(\frac{r_p}{r_e}\right)^7 \quad ; \qquad \beta = \frac{f(X-1)^2}{2X^2}\left(\frac{r_p}{r_e}\right)^5 \quad ;$$

$$\gamma = \frac{f}{2X^2}\left(\frac{r_p}{r_e}\right)^3 \quad ; \quad Q = \frac{1}{2}\mu\left(\frac{r_p}{r_e}\right)^3 \quad ; \qquad \mu = \frac{m_2}{m_1}\left(\frac{r_e}{R}\right)^3 .$$

Here X is the ratio of angular velocities at the equator and pole, f is the ratio of centrifugal to gravity forces at the equator, $\frac{m_2}{m_1}$ is the mass ratio of the two components and $\frac{r_e}{R}$ is the ratio of the radius at the equator to the separation between the centers of gravity of the two components. The ratios $\frac{r_p}{r_e}$ can be obtained from a third degree equation given by

$$\left(\frac{r_e}{r_p}\right)^3 - u\left(\frac{r_e}{r_p}\right)^2 - \frac{1}{2}\ \mu = 0, \tag{3}$$

where

$$u = 1 + \frac{f\,(X^2 + X + 1)}{6X^2} + \mu\,. \tag{4}$$

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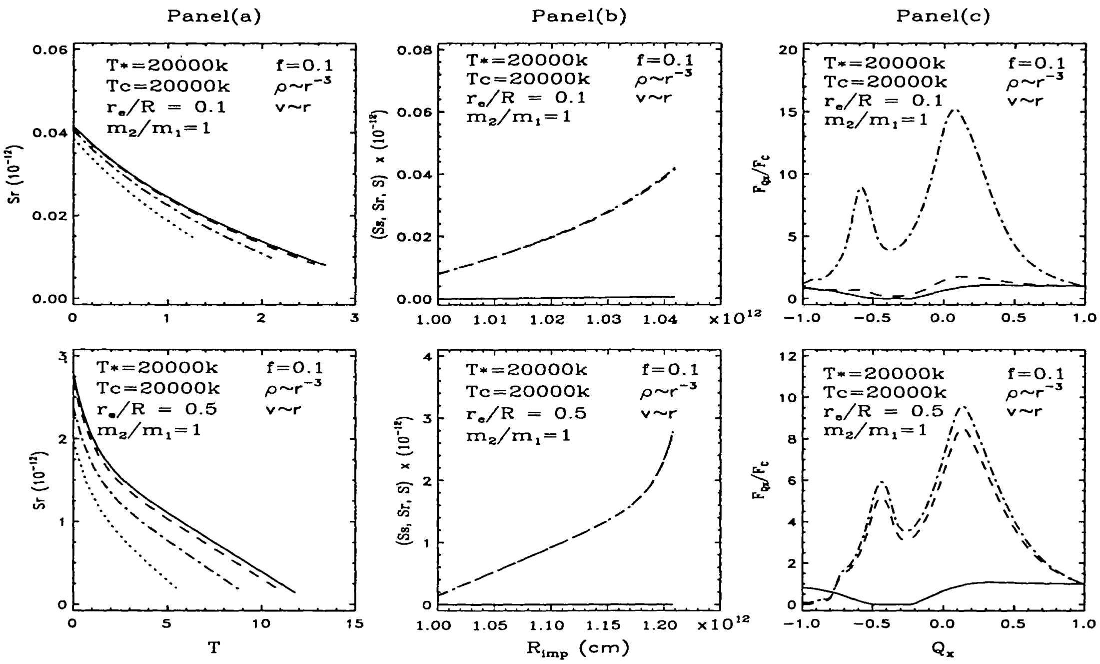

Figure 2. Panel a) contains the ray source functions versus the optical depths along the ray for r_e/R =0.1, 0.5 for v_a = 0; v_b = 10 (mtu) and T_* is the temperature of the primary with center at O and T_c is the temperature of the star at B (see Fig. 1). Continuous line for ray 1, dashed line for ray 6, dashed dot for ray 12 and dotted line for ray 18 are given above. Panel b) shows the source functions versus R_{imp}, plotted for r_e/R=0.1, 0.5. Source functions for self-radiation (S_s) (continuous line), distorted for different source function of the distorted atmosphere (S_r) (dashed line), total source function (S) (dashed dot). Panel c) The normalized fluxes F_{Q_x}/F_C are shown against Q_x where F_c is the flux in the continuum and $Q_x = x/x_{max}$. Fluxes due to self-radiation (continuous line), fluxes due to distorted source function (dashed line), fluxes due to total source function (dashed dot).

Eq. (1) is solved for given set of parameters X, $\frac{m_2}{m_1}$, f and $\frac{r_e}{R}$. We always set X=1. Eq. (3) is solved by a Newton-Raphson method (Peraiah 1969).

2.2. Brief Description of the Method

We have drawn a schematic diagram in Fig. 1 for the purpose of computing the ray lengths. The points O and B are, respectively, the centers of the primary and secondary which is supposed to be a point source. The rays such as BA$_1$, BD, BP, ..., from the secondary (B) are incident on the distorted atmosphere (the surface of which is described by Eq. (1)) at points such as A$_1$, D, P, ... These points are joined to the center of the primary O. Further we draw perpendiculars from these points to the axis OB. These perpendiculars meet the rays at the points as shown in the Fig. 1. Now (1) we need to find the source functions along the

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rays BA_1, BD, BP, ..., to compute the radiation field in the medium generated by incidence of light from the secondary. (2) We also need to find the source functions along the perpendiculars such as DJ, PK, SL, ..., to calculate the radiation field along the line of sight and at the observers point at infinity. For this we have to calculate their geometrical lengths and optical depths for a given density distribution. Computation of these geometrical lengths and calculation of irradiation from the secondary (S_r) is described in Peraiah & Srinivasa Rao (2002).

The total source function is

$$S = S_r + S_s \, . \tag{5}$$

3. Computational Procedure and Discussion of the Results

We considered the atmosphere of a primary whose radius is twice as large as that of the primary with an inner radius set to 5×10^{11} cm and the outer radius set to 10^{12} cm. The distortion is considered from the outer radius (10^{12} cm) of the atmosphere. We considered velocity and density laws which obey the law of mass conservation, namely $\dot{M} = 4\pi r^2 \rho v$ where $\dot{M}$ is the mass loss rate, ρ is the density, v is the velocity. We have used the laws $v \sim r^{-1}$ and $\rho \sim r^{-1}$. We considered an electron density of 10^{14} cm^{-3} for calculating the optical depth. We set the velocities v_{a} and v_{b} at inner and outer radius of the primary component respectively. Using the above data we compute the source functions S_r along the rays BA_1JK ..., BDEFG ...., BPQR ....

Figure 2 contains three panels. The graphs are given for r_{e}/R =0.1 and 0.5. The first panel (a) contains the ray source functions against the total optical depths for rays 1, 6, 12, and 18 (the rays are numbered A_1C, correspond to ray 1 and DI correspond to ray number 2 and so on). The graphs in panel (b) contain the corresponding source functions S with respect to the R_{imp}=A_1O, JO, KO,.... The third panel (c) contains the corresponding line profiles along the line of sight. Fig. 2c contains the results for an expanding atmosphere with v_{a}=0 and v_{b}=10 mtu (mean thermal units) where v_{a} and v_{b} are the velocities at the bottom and top of the atmosphere for the above velocity law. The profiles due to the self-radiation (S_s) are almost non-existent while those due to irradiation (S_r) and combined (S_r+S_s) radiation are prominent emission lines with P Cygni characteristics. There is a perceptible change in the profiles when the parameter r_{e}/R is changed from 0.1 to 0.5.

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9. ATOMIC PHYSICS AND OPACITIES

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