A Tomographic Study of the Classical Nova RR Pictoris

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ABSTRACT. We present the results of spectrophotometric observations of the old nova RR Pictoris performed in two spectral ranges, one centered in the Hα line, and other covering Hβ and Hγ spectral lines. From the Hβ radial velocity study, we found a primary radial semi-amplitude of \( K_p = 37(1) \text{ km s}^{-1} \) and a systemic velocity of \( \gamma = 1.8(2) \text{ km s}^{-1} \). With these new values, a mass diagram is constructed, constraining the possible mass intervals for the system. The possible orbital inclination range was restricted, given the fact that RR Pic presents shallow eclipses. A secondary mass range below the limit of a main-sequence star filling its Roche lobe indicates an evolved companion. We also calculated the Hα, Hβ, Hγ, He i \( \lambda 6678 \), and He ii \( \lambda 4686 \) Doppler tomograms. The most conspicuous differences are found between the He i and He ii tomograms; the former has a ring shape, while the second is filled at low velocities, suggesting that the low-velocity emission is not coming from the accretion disk. Radial emissivity profiles for these lines were also derived.

1. INTRODUCTION

Cataclysmic variables (CVs) are close binary systems composed of a white dwarf that accretes matter from a red dwarf or subgiant star via an accretion disk if the magnetic field of the primary is negligible. Classical novae are eruptive cataclysmic variables with only one high-amplitude outburst observed. The spectra of recent novae could show, depending on their evolutionary epoch after eruption, a complex superposition of the spectra of the accretion disk, shell permitted and forbidden lines, and finally the signatures of the secondary star (see Jones [1931] for a spectral evolution of RR Pic before eruption). The irradiation of the secondary by the shell ionizing source may induce additional line emission (Peraiah & Srinivasan Rao 2002), although the shielding of the white dwarf by the accretion disk should be relevant once the accretion has been reestablished.

Novae and some nova-like systems usually present intense He ii emission lines. The ratio He ii/Hβ is often much smaller for quiescent dwarf novae than for nova remnants and novae-like. The UX UMa–type nova-likes present a variable intensity of He ii \( \lambda 4686 \), as in IX Vel, where the He ii and C iii/N iii lines are present on some nights and absent on others (Hessman 1990). It has been suggested in the past that the He ii line is not produced by viscous heating in the accretion disk, but rather is a recombination line produced by photoionization in a region illuminated by the boundary layer ionizing photons (Williams 1980).

RR Pic is a cataclysmic variable classified as a classical nova, with eruption recorded in 1925. Van Houten & van Houten-Groeneveld (1966) observed periodic variations of its light curve, and also observed eclipses that did not occur in all conjunction phases. Vogt (1975) determined RR Pic’s orbital period from photometric observations as being \( 0.1450255(2) \) days. Warner (1986) presented RR Pic light curves from 1972 to 1984, showing an intense brightness modulation and active flickering. The presence of shallow and irregular eclipses is mentioned by Warner (1987).

Spectroscopy of the nova shell filaments was performed by Williams & Gallagher (1979) as part of their study of the physical conditions in novae ejecta. They also estimated the separation between the two main knots in the shell of RR Pic, first observed by van den Boos & Finsen (cited in Jones 1931). The observation of the shell knots at different epochs reveal their average expansion velocity. The last imaging of RR Pic showing the shell features and dimensions was taken by Gill & O’Brien (1998). They obtained a 30’ separation between two knots at opposite sides of the shell, so we could accept this value as an approximate value of the current apparent dimension of the shell.

Fast photometric variability was first detected by Warner (1976), with a period of about 30 s; the variability was confirmed (Warner 1981), with periodicities at 20 and 40 s, and with a more persistent period of 32 s. Fritz & Bruch (1998) performed a wavelet transform study of the flickering of some cataclysmic variables, including RR Pic. Such a study shows that RR Pic has intense, fast photometric activity when compared to other novae. This nova is also suspected of being an intermediate polar (Kubiak 1984), on the basis of the detection of a coherent brightness modulation of about 15 s in the \( U, B, \) and \( V \) bands. However, Haefner & Schoembs (1985) could not...
confirm the existence of this period using a large photometric database.

RR Pic’s orbital period is 0.14502545(7) days, calculated by Kubiak (1984). Haefner & Betzenbichler (1991) performed time-resolved spectroscopy of the \( \text{H}_\alpha \) line, presenting the first measurements of the line profile variations with orbital phase. Schmidtobreick et al. (2003) also studied the \( \text{H}_\alpha \) and \( \text{He}_\text{I} \) line profiles.

In this work we propose to locate and quantify the \( \text{He}_\text{I} \), \( \text{He}_\text{II} \), and Balmer-line sources, and to constrain the stellar masses in this system. The observations and data reduction are detailed in § 2. The radial velocity study, mass constraints, and Doppler tomography are shown in § 3. A discussion of the results is given in § 4. Finally, our conclusions are outlined in § 5.

2. OBSERVATIONS

Spectrophotometric observations of RR Pic were made from 2001 to 2003. The observations were performed with the 1.60 m Perkins-Elmer telescope at the Laboratório Nacional de Astrofísica (LNA) at Itajubá, Brazil, and with the 1.52 m ESO telescope at La Silla, Chile. In both cases we used Cassegrain spectrographs with a spectral resolution of about 2 \( \text{Å} \). The first observations were aimed at the \( \text{H}_\alpha \) line. The last ones were intended to cover the \( \text{H}_\beta \), \( \text{He}_\text{II} \), and \( \text{H}_\gamma \) spectral lines. For more details, see the journal of observations (Table 1).

The slit position angle was chosen to include a comparison star in the slit, and also to be at an angle that avoids the shell’s bright knots (see Gill & O’Brien [1998] for a shell image). The slit width was set to include a fraction of about \( \frac{1}{3} \) of the stellar seeing disk, so a negligible part of the shell emission is included in our spectra. In general, the contribution of the shell emission over the stellar profile is well subtracted by interpolating the local background along the spatial direction.

The observations were bracketed by arc lamp exposures on a regular basis to allow good wavelength calibration of the spectra. The interval between consecutive lamp exposures was estimated by considering the spectrograph mechanical flexure maps, with the aim of minimizing its effects in the derived velocities. The dispersion solutions were interpolated in air mass for each target exposure.

Differential spectrophotometry was performed using the integrated flux from the slit comparison star. In order to perform the absolute flux calibration of all the spectra, tertiary spectrophotometric standard stars were also observed (Hamuy et al. 1994). Wide-slit observations of the slit comparison star were made to correct our spectra from slit losses and from differential atmospheric dispersion effects.

All the data reduction was done using standard IRAF\(^1\) reduction procedures. The images were bias subtracted and corrected from flat fields. The spectra were then extracted using an optimal extraction algorithm (Horne 1986), and calibrated in wavelength and flux. The spectra in the red range were also corrected from telluric absorption effects in the vicinity of \( \text{H}_\alpha \) line, using a scaled telluric absorption template with the same spectral resolution.

3. RESULTS

3.1. Spectral Features

We present in Figure 1 the average spectra in the red region, covering \( \text{H}_\alpha \) and \( \text{He}_\text{I} \) \( \lambda 6678 \) lines, and in the blue region, covering the \( \text{H}_\beta \), \( \text{H}_\gamma \), and \( \text{He}_\text{II} \) \( \lambda 4686 \) lines. The Balmer and \( \text{He}_\text{I} \) lines seem double peaked, while the \( \text{He}_\text{II} \) line appears single peaked, with extended wings. Only the most intense lines can be used for Doppler tomography. We can see that near \( \text{He}_\text{II} \) there is a blend of \( \text{C}_\text{III} \) and \( \text{N}_\text{III} \) lines. Unfortunately, the blending between them is too severe and prevents the Doppler mapping of these lines. No absorption lines from the secondary could be detected.

\(^1\) IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

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TABLE 1
JOURNAL OF OBSERVATIONS

| Observation Date | Telescope (m) | \( \lambda_\text{c} \) (Å) | Exposure Time (s) | Number of Spectra | Number of Cycles |
|------------------|---------------|-----------------|------------------|------------------|-----------------|
| 2001 Jan 17 ...... | 1.60 LNA      | 6560            | 100              | 24               | 0.3             |
| 2001 Jan 18 ...... | 1.60 LNA      | 6560            | 100              | 114              | 1.6             |
| 2001 Mar 22 ...... | 1.60 LNA      | 6560            | 70               | 41               | 0.3             |
| 2002 Jan 21 ...... | 1.52 ESO      | 4550            | 180              | 74               | 1.6             |
| 2002 Jan 22 ...... | 1.52 ESO      | 4550            | 180              | 78               | 1.5             |
| 2002 Mar 16 ...... | 1.52 ESO      | 4550            | 180              | 50               | 1.3             |
| 2002 Mar 17 ...... | 1.52 ESO      | 4550            | 180              | 78               | 1.6             |
| 2003 Mar 31 ...... | 1.60 LNA      | 4600            | 160              | 14               | 0.2             |
| 2003 Apr 1 ......  | 1.60 LNA      | 4600            | 160              | 12               | 0.6             |
| 2003 Apr 2 ......  | 1.60 LNA      | 4600            | 160              | 82               | 1.4             |
| 2003 Apr 3 ......  | 1.60 LNA      | 4600            | 160              | 20               | 0.9             |
3.2. Line Profile and Radial Velocity Study

We can see in Figure 1 that the He \( \text{II} \) line is blended with the C \( \text{III/NI} \) complex, but this blending does not significantly compromise the He \( \text{II} \) blue wing profile, so we can simply limit the maximum velocity used in He \( \text{II} \) radial velocity study to avoid the nearby lines. The maximum velocity was fixed at 1000 km s\(^{-1}\).

The spectra were binned in phase boxes, using the orbital period proposed by Kubiak (1984) and our spectroscopic conjunction phase (see Fig. 4). From the phase diagrams, it can be seen that the lines do not present a large oscillation around the rest wavelength, indicating primary’s low radial velocity semiamplitude. For the line wings, we can see that the oscillation around the rest wavelength becomes more noticeable. No emission is found above 1200 km s\(^{-1}\).

The H\( \alpha \) line profile does not show a clear single-peaked profile at any orbital phase (Fig. 2). The H\( \alpha \) line presents a more intense emission near \( \phi = 0 \). The He \( \text{I} \) line is also more intense near phase \( \phi = 0 \), has a more structured shape than the H\( \alpha \) line, and also shows emission at larger velocities. For H\( \beta \), H\( \gamma \), and He \( \text{II} \), an increase of the line intensity is found near phase 0.6. The phase-sampling of our data was verified, confirming that this intensity increase could not be caused by an irregular phase coverage.

The He \( \text{I} \) and He \( \text{II} \) (Fig. 3) phase diagrams have different shapes, but it is important to recall that they were observed at different epochs. The H\( \alpha \) phase diagram is slightly different from those of H\( \beta \) and H\( \gamma \), which were also derived from data taken at different dates.

The H\( \beta \)-line data were used to estimate the primary’s radial velocity semiamplitude \( K_1 \). This line was chosen because it is one of the most intense lines in our spectra, because it is not blended, and also because there are more independent observations in the blue data set than in the red set. A diagnostic diagram (Fig. 4) is built using radial velocities derived by convolving the line profiles with a double Gaussian mask (Schneider & Young 1980, hereafter SY). A mask with 50 km s\(^{-1}\) (FWHM) Gaussians was applied. Different values of the Gaussian’s half-separation were used in order to sample different projected velocities in the line profile. The Gaussian half-separation velocity \( |V| \) appears in the diagram as the horizontal axis. For each half-separation, a radial velocity curve is obtained, fitted with a periodic function, and the parameters of this fit are given in the \( y \)-axis of the panels in the diagnostic diagram. The phase scale is given by the spectroscopic inferior conjunction of the secondary; i.e., the timing for positive to negative crossing of the line wing radial velocity curves. The “best” value of \( K_1 \) found in the line wings is the one found at a minimum rms, on a plateau in the \( K_1 \) curve. In order to estimate \( K_1 \), an average of the \( K_1 \) values for velocities ranging from 466 to 605 km s\(^{-1}\) was made, obtaining \( K_1 = 37(1) \) km s\(^{-1}\). A systemic velocity \( \gamma = 1.8(2) \) km s\(^{-1}\) and a spectroscopic secondary conjunction phase \( \phi_0 = 2,452,295.7744(3) \) HJD were estimated using the same range in \( |V| \). One can see that the diagnostic diagram is well behaved; for such a large velocity range in the line wings, we have a small value of the systemic velocity, and also a small zero-phase variation.

The problem of estimating the white dwarf orbital velocity using emission lines in CVs is a classical issue. It is of course desirable that the measurement of \( K_1 \) is performed at the highest
Fig. 2.—Phase diagrams of the Hα (top), Hβ (middle), and Hγ (bottom) continuum-subtracted lines. The gray scale was set to properly show the main features in each graph. Contour lines are regularly spaced from zero to the maximum intensity.

Fig. 3.—Same as Fig. 2, but for He i λ6678 (left) and He ii λ4686 (right).

possible velocity in the wings. We simply expect that the high-velocity gradient in the disk suffer from fewer anisotropies. A plateau in the diagnostic curve is also expected if there are no anisotropies. Choosing $K_1$ from a steep diagnostic curve is much more complicated. It is possible that different authors with different signal-to-noise ratios (S/Ns) in the line wings will find different $K_1$ values. For instance, for a rising $K_1$ versus $|V|$ diagnostic curve, the observer who has the best S/N will derive the largest $K_1$ values.

The uncertainty in $K_1$ is derived from the dispersion between $K_1$ values in the diagnostic diagram plateau. The sinusoid amplitude–fitting uncertainty of individual $K_1$ points is of the same order (2 km s$^{-1}$). However, both are just formal errors. The uncertainty in $K_1$ propagates to the derived mass ranges, so
These ranges are just formal as well. They do not include the fact that measured \( K_1 \) velocities in CVs may not be the white dwarf orbital velocities. We have cross-checked our \( \text{H}\beta \) wing velocities with \( \text{H}\alpha \) measurements using the same convolution masks, and comparable results were found. Again, \( \text{H}\beta \) and \( \text{H}\alpha \) were measured at different epochs.

In the sections below, we adopt the \( K_1, \gamma, \) and phase-referenced values found here.

Another way of obtaining the primary’s radial velocity semiamplitude is from a Doppler tomogram centered at the system’s center of mass. Circular isophotes with increasing radius (or velocity modulus) were fitted to the \( \text{H}\beta \) tomogram that was constructed as described above. The inner isophotes will follow the bright features in the Doppler map, but the outer isophotes will tend to trace the intrinsic high-velocity emission in the disk. In the first panel of Figure 4, the continuous line represents the \( K_1 \) values obtained from the displacement of each isophote center y-axis origin. It is found that the value of \( K_1 \) obtained from this method is larger than that obtained from double Gaussian mask convolution for \(|v| < 700 \text{ km s}^{-1}\). They become marginally compatible with the SY plateau only at \(|v| > 700 \text{ km s}^{-1}\). This difference could be explained if we consider that in the SY method we have sampled the emission from regions with different intrinsic velocities that yields the same projected velocity inside the Gaussian mask. In the next steps, we use the value of \( K_1 \) obtained from the double Gaussian method. The SY method was preferred to the tomogram isophote fitting in the particular case of RR Pic, because \( K_1 \) is much smaller than the tomogram FWHM resolution. The presence of asymmetries in the brightness distribution at high velocities may impact the determination of isophote centers, and consequently, produce a relatively large systematic effect on \( K_1 \).

A radial velocity study of RR Pic was also performed by Schmidtobreick et al. (2003), using \( \text{H}\alpha \) and \( \text{He} \lambda 6678 \) spectral lines. These authors estimated a primary radial semi-amplitude of \( K_1 \sim 170 \) km s\(^{-1}\). This value could not be confirmed by our measurements of the \( \text{H}\beta \) line wings. Schmidtobreick et al. (2003) have measured \( K_1 \) at wing velocities of \(~800 \) km s\(^{-1}\). There is almost no signal at such velocities. This can be verified by inspecting their tomograms and phase maps. In addition, both their radial velocity analysis and Doppler tomography were computed using a rather small number of independent phases (19 spectra).

### 3.3. Constraints on Stellar Masses

Considering the geometry of the system, the presence of shallow eclipses, a maximum disk radius (Paczyński 1977), and the volume radius of the secondary (Eggleton 1983), we find a possible inclination range of \( 60^\circ < i < 80^\circ \). This result is similar to that obtained by Horne (1985), considering the eclipse of the central region of the disk.
In Figure 5 we present the mass diagram for RR Pic. A lower limit of 0.2 \(M_\odot\) for the primary mass is derived from the H\(\beta\) line at FWZI. The upper limit for its mass was fixed at 1.4 \(M_\odot\). In addition, the secondary mass must be roughly equal or lower than that of the primary for a stable accretion regime. The secondary also needs to have a mass below the limit for a main-sequence secondary filling its Roche lobe (Patterson 1984).

Using broad limits on \(M_1\) (0.2 \(M_\odot\) < \(M_1\) < 1.4 \(M_\odot\)), in addition to the previously derived value \(K_1 = 37\) km s\(^{-1}\) and inclination range (60° < \(i\) < 80°), we found from the mass function that 0.09 < \(q\) < 0.2. A secondary’s radial velocity semiamplitude \(K_s\), ranging from 200 to 400 km s\(^{-1}\), is also derived.

A bootstrapping simulation (Horne et al. 1986) was performed in order to confirm the mass intervals given by the mass diagram. An inclination range of 60°–80° with a flat error distribution and a \(K_s\) value of 37(1) km s\(^{-1}\) were used in this simulation. The results of this simulation are shown in Figure 5. One can see from this same figure that the secondary must have a mass smaller than 0.15 \(M_\odot\). This indicates a low mass ratio \((q = M_2/M_1)\). From this result, one finds that the spectral type of the secondary should be near M5 if it is a main-sequence star (Allen 2000). The expression \(\tilde{\rho}_2\) is derived from Warner (1995):

\[
\tilde{\rho}_2 = 107 P_{\text{orb}}^{-2}(h) \, \text{g cm}^{-3}.
\]

The fact that the secondary has a much smaller mass than a main-sequence star suggests that the secondary may have evolved from the main sequence. One can also constrain the white dwarf mass, considering the fact that RR Pic had a moderately fast nova outburst. The white dwarf mass is probably greater than 0.6 \(M_\odot\), as expected from classical novae outburst models (Starrfield 1989). In addition, the white dwarf mass is probably not too close to the Chandrasekhar limit, since no recurrent nova outbursts have been observed in RR Pic over the last 80 yr (Webbink et al. 1987). In the next steps, we use the masses given by the center of the most probable mass region in the mass diagram, \(M_1 = 1 \, M_\odot\) and \(M_2 = 0.1 \, M_\odot\).

### 3.4. Doppler Tomography

The Doppler tomography method was applied to the brightest emission lines, obtaining Doppler maps with origins at the system’s center of mass. Before interpreting the Doppler tomograms, it is important to note that the H\(\alpha\) He I observations and the H\(\beta\) H\(\gamma\) He II data were taken at different epochs. This fact implies that tomograms from each data set should only be compared with tomograms from the same data set. The position of the secondary and the binary center of mass, as well as the primary and L1 Lagrange point, were plotted for a 90° orbital inclination. These points will be displaced in their \(y\)-values for a different orbital inclination. The self-consistency of the Doppler maps could be verified by comparing the tomogram projections with the observed spectra at the corresponding orbital phase. The projections have a good agreement with their equivalent line profiles, both in flux and in the shape of the line profile.

The H\(\alpha\) tomogram (Fig. 6) presents a ring shape, as expected for an accretion disk reconstruction in which there is a low-velocity limit in the outer disk radius and an observational high-velocity limit at the inner disk. The H\(\alpha\) tomogram presents the most intense emission in the \((-V_x, +V_y)\) and \((-V_x, -V_y)\) quadrants. In contrast, the H\(\beta\) and H\(\gamma\) Doppler tomograms also present the signature of a disk, but with a weaker emission in the \((+V_x, -V_y)\) quadrant. When compared to the H\(\alpha\) map, an emission deficit in the \((+V_x, +V_y)\) quadrant is verified in the upper Balmer transitions.

The He I Doppler tomogram (Fig. 7) presents a ring shape, but it shows the inner ring radius at velocities greater than those found in the H\(\alpha\) tomogram, suggesting that the He I emission is enhanced in the inner disk region. An emission enhancement in the lower part of the tomogram is also seen. The He I Doppler tomogram is noisier than the other tomograms because the He I \(\lambda\)6678 line is much fainter than the other lines.

The He II \(\lambda\)4686 Doppler tomogram (Fig. 7) presents a dis-
Fig. 6.—Hα (top), Hβ (middle), and Hγ (bottom) Doppler tomograms. Observed velocities are quoted. The crosses indicate (top to bottom) the secondary’s center of mass, the L1 Lagrange point, the system’s center of mass, and the primary’s center of mass, using $M_1 = 1 \, M_\odot$ and $M_2 = 0.1 \, M_\odot$ (as described in § 3.3).

Distinguishing behavior when compared to Balmer and He i tomograms, showing emission at very low velocities. This low-velocity emission can be explained by the presence of a wind coming from the accretion disk, or by the emission from stationary material inside the Roche lobe. This emission could also be associated with gas spilling over the disk. The line production mechanism for such vertically extended gas distribution may be recombination, as the gas is easily irradiated by the inner disk region and boundary layer. Following this interpretation, the region of enhanced emission in the $-V_t$ region of the He ii to-
mogram could be associated with the hot spot, where the stream hits the accretion disk. An enhanced emission in this same quadrant could be also seen in the Hβ tomogram.

3.5. Accretion Disk’s Radial Emissivity Profiles

The disk radial emissivity profiles obtained from Hα, Hβ, Hγ, He i λ6678, and He ii λ4686 spectral lines are presented in Figure 8. The Doppler maps discussed above are centered in the system’s center of mass. By including the primary’s radial velocity, one can shift the Doppler tomograms to center them on the white dwarf. The radial disk emissivity profile is estimated from these tomograms by calculating the mode of the intensity over concentric rings centered on the origin. The mode was chosen as the statistical estimator, allowing us to obtain the emissivity of the disk, disregarding large emission anisotropies. Using a primary of mass $1\, M_\odot$, the Doppler tomograms were converted from velocity space to position space using a Keplerian velocity law. The radial emissivity profiles are corrected for reddening, given the color excess $E(B - V) = 0.02$ (Bruch & Engel 1994) and $R = 3.1$. The radial emissivity profile inclinations obtained are $-1.5$ for Hα and Hβ, $-1.7$ for Hγ and He ii, and $-1.9$ for He i; the error of these values is about 0.1.

The He ii radial emissivity profile shows two subsets of points with different behaviors and inclinations. The discontinuity between these two subsets is at about 500 km s$^{-1}$, so this difference could not be attributed to a blending effect with the C iii/N iv complex, since blending effects should only appear at velocities greater than 1000 km s$^{-1}$.

From Figure 8 it can be seen that the emission inclinations for Hα and Hβ lines are similar, and that the profile seems steeper for the He i and He ii emission. Note, however, that if there is a wind contribution in He ii, it will also be present in the radial emissivity profile, so this disk emission profile may be contaminated by a wind component. To convert the Doppler tomograms to position space, we assumed a Keplerian velocity law, which is not necessarily true, introducing additional errors.
in the radial emissivity curves. The emission power-law index depends on the mass of the primary, in the sense that the power law becomes steeper with increasing mass. Hence, no absolute value of the power-law index can be given. However, as the change of the power-law index with the primary’s mass must be the same for all lines, the fact that one line emission is more centrally concentrated than other line emissions is independent of the primary’s mass.

4. DISCUSSION

To date, there is no well-established photometric ephemeris for RR Pic in the literature. While the presence of a grazing eclipse seems to be confirmed, there is no published $O-C$ diagram for these eclipses. As far as we understand, the phasing adopted by Schmidtobreick et al. (2005) is based on a single feature in Warner (1986) light curves, which was interpreted as the grazing eclipse. If correct, this ephemeris would result in a spectroscopic phase offset of 0.17. Since RR Pic presents high-amplitude flickering, no fiducial phasing from grazing eclipses can be firmly established without combining several eclipse light curves and analyzing their phase residuals. Therefore, a discussion of the presence of a spectroscopic phase shift (as observed in several CVs) awaits a better definition of the eclipse ephemesis.

The secondary’s mass obtained from the mass diagram is significantly smaller than the limit given by a main-sequence star filling its Roche lobe. One interpretation that directly arises from this result is that the secondary could be more evolved than a main-sequence star. No absorption features from the secondary that could support such a hypothesis are found in our spectra. Harrison et al. (2005) performed $K$-band infrared spectroscopy of RR Pic, and they have not detected any obvious absorption features from the secondary either, so the secondary’s spectral type remains elusive.

From the radial emission profiles in Figure 8, it is possible to verify that the He $\lambda$ emission is more centrally concentrated than the Balmer and He $\beta$ emission. We can draw a preliminary conclusion by comparing the RR Pic radial emissivity profiles with other estimates in the literature. The RR Pic radial emission profiles inclinations are smaller than those of other systems. Diaz & Ribeiro (2003) found a radial emissivity profile inclination of $-2.1$ for the H$\alpha$ line and $-2.4$ for the He $\lambda 6678$ line for V841 Oph. Diaz & Hubeny (1999) found $-2.3$ for the H$\beta$ line and $-2.9$ for He $\beta$ for V347 Pup. In this study, we obtained $-1.5$ for the H$\alpha$ and H$\beta$ lines, $-1.7$ for the H$\gamma$ and He $\beta \lambda 4686$ lines, and $-1.9$ for He $\beta \lambda 6678$ line; the errors are about 0.1. From these values, we conclude that the line emission is less concentrated in RR Pic (assuming a $1 M_\odot$ white dwarf) than in V841 Oph and V347 Pup. Since the power-law index increases as the white dwarf mass decreases, in order to reach the H$\beta$ power-law index found in V347 Pup, RR Pic must have a white dwarf with approximately $0.3 M_\odot$, which seems extremely unlikely. The discontinuity found in the He $\beta$ emission profile can be regarded as evidence of non-Keplerian motion, or wind emission in the He $\beta$ line source regions.

One may ask why we do not observe the diffuse emission in the Balmer tomograms, as was observed for He $\beta$. The diffuse component is also present in Balmer lines, but for these lines the disk emission may be more intense than the diffuse component. In the case of He $\beta$, the diffuse emission produced by recombination may be dominant compared to the emission that originated in the accretion disk.

5. CONCLUSIONS

A radial velocity study of the RR Pic system was performed using extensive spectrophotometric observations. A value of $37(1)$ km s$^{-1}$ was found for the primary’s radial velocity semi-amplitude, considerably smaller than the value of about 170 km s$^{-1}$ given by Schmidtobreick et al. (2003). This small primary’s radial velocity implies a secondary star mass below 0.16 $M_\odot$. This mass estimate is approximately half of the limiting mass of a main-sequence star filling its Roche lobe, which points to an evolved companion star. The primary’s mass could not be constrained, due to the absence of photospheric lines from a secondary. Given the fact that RR Pic presents shallow eclipses, the system’s orbital inclination was constrained to an interval between 60$^\circ$ and 80$^\circ$. The mass ratio $q$ could be constrained in the wide interval between 0.09 and 0.2.

The H$\alpha$ and He $\beta$ Doppler images of RR Pic show a clear ring signature. Furthermore, the H$\beta$ and H$\gamma$ Doppler maps present ring-shaped structures, while the He $\beta$ map shows an enhanced emission at low velocities, indicating that this high-ionization line is produced in velocity field that is different from that of the disk. Radial emissivity profiles were obtained from the tomograms, indicating a more concentrated emission for the H$\gamma$ line than for the H$\alpha$ and H$\beta$ lines, and a more concentrated emission from He $\beta$ than from He $\alpha$. In addition, the RR Pic disk may present less radially concentrated emissivity profiles, compared to other novae and nova-like. However, the emission distribution in other quiescent disks should be derived in order to explore its correlation with other properties of the binary system.

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