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NEW SPECTROSCOPY OF MULTIPLE STARS RR LYNCIS AND HT VIRGINIS

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In this paper we present radial velocity measurements as a result of new spectroscopic observations of RR Lyncis and HT Virginis. Both systems are worth to be the objects of a long-term monitoring. The observations made during a long period of time reveal the apsidal motion and the movements around the center of mass of the systems. Long-term measurements enable us to measure the light-time effect in the eclipsing binaries as well. Data were collected using the Poznań Spectroscopic Telescope (PST1) at Borowiec station (Baranowski et al. 2009) covering a range of wavelength $4280 - 7500$ Å. The telescope is equipped with an echelle spectrograph thermally stabilized to 0.1°C. The data were calibrated with ThAr (Thorium-Argon) lamp. Data reduction was performed with IRAF[1] (Image Reduction and Analysis Facility) `echelle` package based scripts. The one-dimensional cross-correlation technique (Cross Correlation Function) was used to determine radial velocities of components with IRAF FXCOR task.

RR Lyncis

RR Lyn is listed in SIMBAD database as an eclipsing binary of Algol type with V magnitude of $5\overset{\text{m}}{.}54$, color index $(B-V) = 0\overset{\text{m}}{.}22$ and with equatorial coordinates $\text{RA}_{2000} = 06^{\text{h}}26^{\text{m}}26^{\text{s}}$, $\text{Dec}_{2000} = +56°17'06''$. It is one of the the nearest eclipsing binaries in the northern sky at the distance of 73.5 ± 2.8 pc (Khaliullin et al. 2001).

First spectroscopic observations of RR Lyncis were made in 1915 by Harper (1915) while the first light curve was presented by Huffer (1931). Spectroscopic orbits for the object were derived by Popper (1971) and Kondo (1976). In 2001 Khaliullin et al. carried out accurate WBVR photoelectric photometry of RR Lyn and obtained light curves of the eclipsing system (Khaliullin et al. 2001). Khaliullin and Khaliullina (2002) detected quasi-periodic co-phased oscillations of times of the primary and secondary minima of

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RR Lyn, based on photoelectric observations which were published during the previous 70 years. The presence of a third body with an estimated mass of $M < 0.9\ M_{\odot}$ was suggested as an explanation. The latest spectroscopic measurements (Tomkin & Fekel 2006) do not confirm the presence of a third component in the system.

The following ephemeris was derived based on high-precision $WBVR$ photoelectric measurements and other published photoelectric timings of minima of RR Lyn (Khaliullin et al. 2001):

$$\text{Min. I} = \text{HJD}2444988.49594(30) + 9\overset{\text{d}}{.}9450738(7) \times E.$$

The light curve obtained by Khaliullin et al. (2001) was typical of detached binaries of Algol type. The spectral types obtained from $WBVR$ photometry for eclipsing binary components are A6 IV for primary component and F0 V for the second one.

Our spectroscopic data (15 nights) were acquired in April 2010 and during the period between January and June 2011. The exposure times were 600 − 1800 s. The cross-correlation function for RR Lyn shows the presence of two components (Figure 1). Two narrow peaks are connected with the eclipsing pair. The results of measurements are presented in Table 1. The radial velocities for component 2 measured in certain phases (near 0 and 0.5) were impossible to derive due to the blending of CCF (Cross-Correlation Function) peaks. The results for component 1 in corresponding phases are also affected by blending.

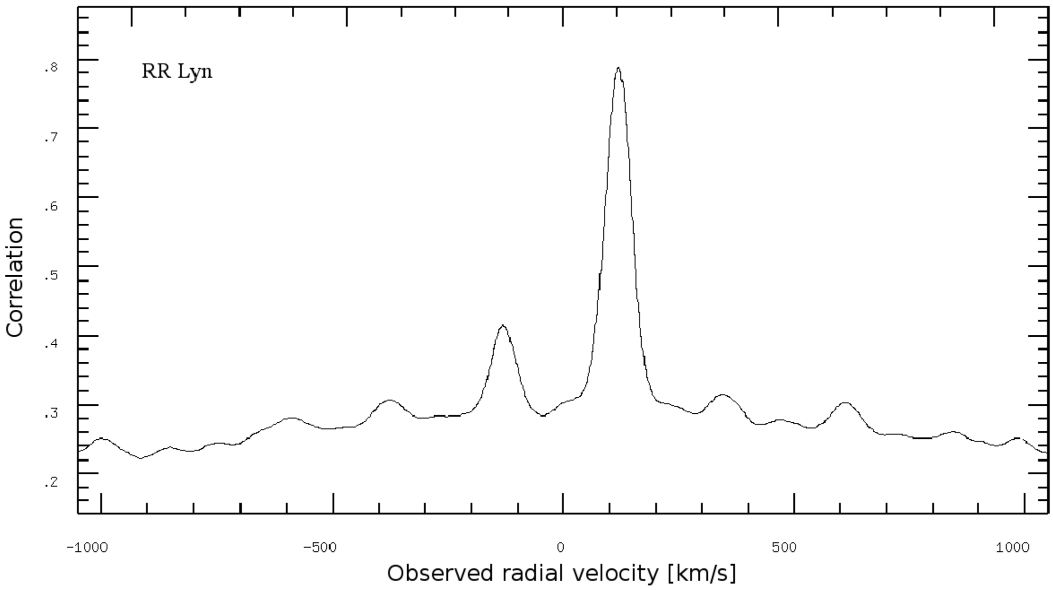

Figure 1. The cross-correlation function for RR Lyn. There are two peaks of the eclipsing pair.

We used the PHOEBE code (Prša & Zwitter 2005) based on the Wilson-Devinney method (Wilson & Devinney 1971) in order to derive preliminary solution for the system parameters from this radial velocities. We used Tomkin & Fekel (2006) values for inclination and surface potential (fixed parameters). The measurements made during phases of the minimal radial velocities were not taken into account during modeling due to the blending effect. The radial velocity solution for RR Lyn is well defined (Figure 2) because of the narrow shape of the peaks which are well separated in CCF. The dispersion of data is equal to $\sigma = 0.36\,\mathrm{km/s}$. The results from the radial velocity curve modelling (Table 2) are the preliminary solution. We present the preliminary solution in order to provide a reader with the orders of magnitude of the results obtained using our measurements.

The spectroscopic data we obtained is shifted with respect to the ephemeris ($ph_{\mathrm{shift}} = -0.004 \pm 0.003$). The ephemeris might have been affected by the light-time effect.

Table 1. Heliocentric radial velocity measurements for two eclipsing components of RR Lyn - PST1. (The values given in the table are plotted in the chart in Fig. 2.)

HJD −2455000	RV_1 [km/s]	RV_2 [km/s]	HJD −2455000	RV_1 [km/s]	RV_2 [km/s]
304.38946	−74.0	73.0	624.41394	−10.7	−*
304.39930	−75.7	−**	624.43784	−10.1	−*
304.42738	−73.0	73.3	629.35782	−3.2	−*
305.35812	−42.2	33.4	629.38278	−4.2	−*
305.38691	−41.0	31.4	629.42699	−5.9	−*
605.35305	21.9	−50.8	629.45110	−6.7	−*
605.37696	22.7	−52.1	629.47628	−7.4	−*
605.40829	23.6	−53.9	629.49952	−8.1	−*
605.43169	24.4	−54.7	650.36610	−45.1	35.4
614.25972	−17.0	−*	650.38209	−45.7	36.5
614.28042	−16.3	−*	705.37704	36.9	−71.1
614.30271	−15.6	−*	705.39313	37.3	−71.9
616.27191	44.2	−80.9	707.34378	43.5	−80.3
616.28857	44.6	−80.9	707.35998	43.6	−80.3
616.30449	44.8	−81.0	707.38418	42.8	−80.3
621.31289	−73.0	70.2	707.40148	42.9	−79.8
621.33188	−73.3	71.1	716.37329	50.1	−87.5
624.36039	−12.2	−*	716.38878	50.1	−87.3
624.38715	−11.3	−*			

* - There is no RV value derived in this phase due to the blending of CCF peaks,
** - no values due to higher dispersion of the measurements.

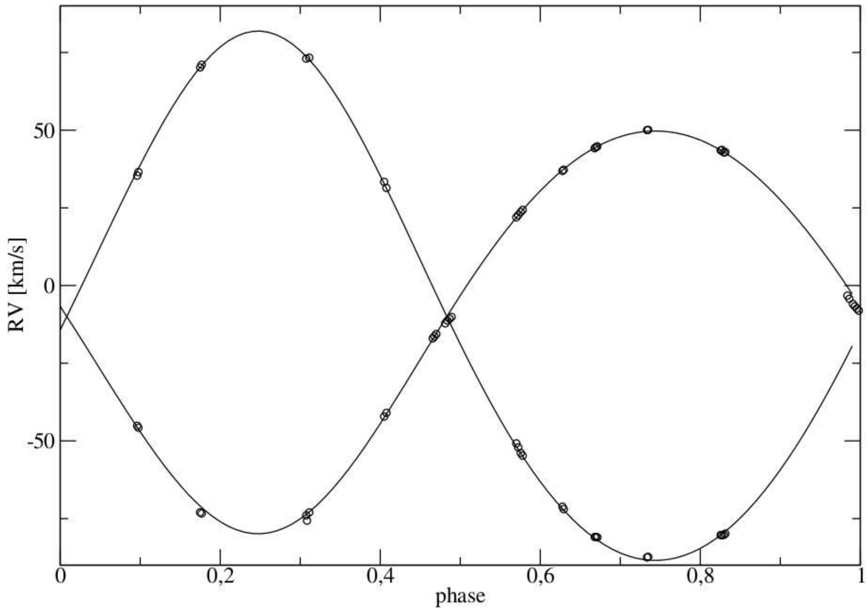

Figure 2. Radial velocity measurements (PST1) for two components of the eclipsing pair RR Lyn. The solid line presents the synthetic curve based on the derived model.

Table 2. Preliminary solution for the eclipsing pair RR Lyn and formal errors outputted by the PHOEBE code.

Parameter	Value
HJD_0	2455629.530±0.004
P (days)	9.9453±0.0002
a ($R_\odot$)	29.55±0.04
e	0.087±0.002
ω (rad)	3.17±0.02
V_γ (km s^{-1})	-10.06±0.08
q	0.769±0.002
i^* (deg)	87.45 (fixed)
$\Omega^*_{R_1}$	12.176 (fixed)
$\Omega^*_{R_2}$	15.570 (fixed)

* - fixed values based on results of Tomkin & Fekel (2006).

HT Virginis

HT Vir is listed in SIMBAD database as an eclipsing binary of W UMa type. The visual magnitude of the object is $7\overset{m}{.}16$, color index is $(B-V) = 0\overset{m}{.}54$ and the equatorial coordinates are $\mathrm{RA}_{2000} = 13^h46^m07^s$, $\mathrm{Dec}_{2000} = +05°06'56''$.

The first photometric measurements of this object were made by Walker & Chambliss (1985). The spectroscopic measurements published by Lu et al. (2001) showed that HT Vir is a quadruple system with a contact binary (HT Vir B - eclipsing pair of SB2 type) and a component HT Vir A which is actually also a binary of SBI type. The analysis of the data from the Hipparcos indicated the separation between the component HT Vir B and HT Vir A equal to 0.56 arcsec (Fabricius & Makarov 2000).

The orbital period of the contact binary is 0.407670 d and the period of single-lined binary is 32.45 d (Lu et al. 2001). Zola et al. (2005) obtained BVR photometric measurements of HT Vir B. The light curve is typical of W UMa-type stars. Lu et al. derived F8 V spectral type for HT Vir B.

The spectra used for the measurements presented in this paper were acquired during 5 nights of observations in May 2011. The exposure time of each spectrum was 1800 s. There are three peaks in the CCF of HT Vir (Figur 3). Two peaks which are related to the eclipsing pair are broad because of fast rotation of both components. The narrow peak is connected with the third component. The results of radial velocity measurements are presented in Table 3. The RV measurements for both components of the eclipsing pair close to phases 0 and 0.5 were impossible to derive due to the blending of CCF peaks. The results for third body in these phases are affected by blending as well.

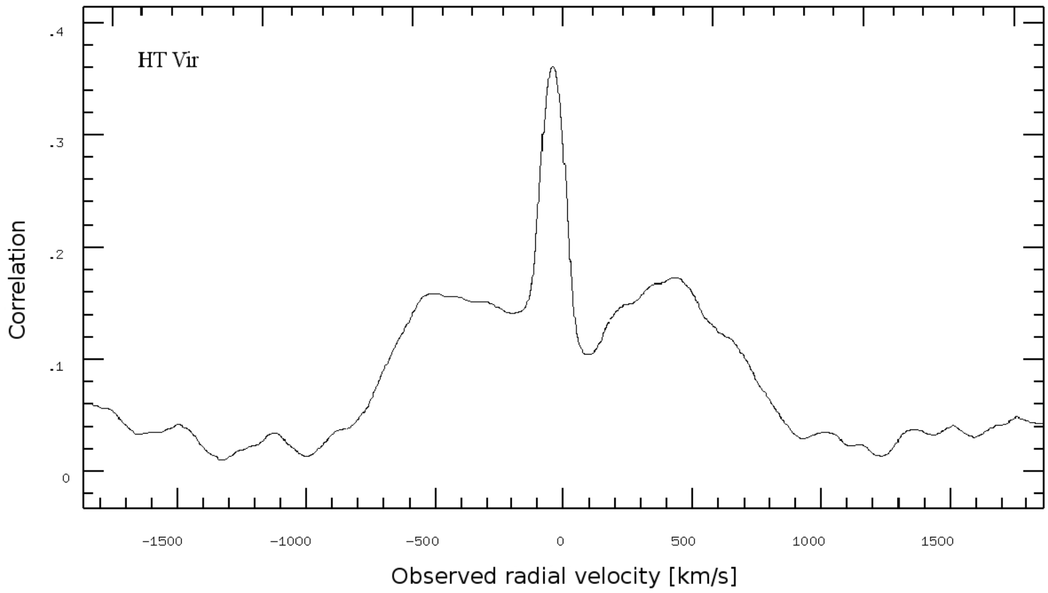

Figure 3. The cross correlation function for HT Vir. The two broad peaks of the eclipsing pair and one narrow are shown (component A).

We derived preliminary parameters of the HT Vir B system from radial velocities using PHOEBE code. As the input fixed values we used parameters of i, Ω_1 and Ω_2 from Zola et al. (2005). As a starting point for adjusting the parameter of HJD_0 we used the value $HJD_0 = 2455691.528$ of one of the measurements close to the phase 0. The adjusted radial velocity curve is shown in Figure 4. We present the parameters of the model adjusted to the radial velocities in Table 4. The large dispersion of data $\sigma = 11.0\,\mathrm{km/s}$ is due to the fast rotation of the components of the eclipsing pair which causes the broad and not well defined shape of the peaks on the CCF.

The broadening function (Rucinski 1992) method or TODCOR (Mazeh & Zucker 1992) could improve the radial velocity measurements for HT Vir. The spectra will be available at CDS for future analysis.

Table 3. Heliocentric radial velocity measurements for three components of HT Vir - PST1. (The values are plotted in the chart in Fig. 4.)

HJD -2455000	RV_1 [km/s]	RV_2 [km/s]	RV_3 [km/s]	HJD -2455000	RV_1 [km/s]	RV_2 [km/s]	RV_3 [km/s]
688.37647	−201.8	153.5	−23.6	693.37783	82.1	−128.3	−31.0
688.40044	−167.5	122.4	−23.6	693.40186	137.7	−152.6	−31.2
691.34020	99.9	−96.4	-27.1	693.43032	169.9	−187.9	−31.0
691.36410	131.1	−144.0	−27.5	693.45378	184.6	−210.9	−31.2
691.39680	165.0	−202.1	−28.5	693.47730	158.9	−166.4	−30.5
691.42198	143.2	−191.4	−28.4	703.37042	−152.5	85.9	−28.8
691.44844	142.0	−180.8	−28.5	703.39398	−174.1	99.7	−28.7
691.47214	113.4	−155.4	−28.6	703.41970	−205.7	135.8	−28.5
691.52809	−*	−*	−28.5	703.44765	−178.3	99.8	−28.8
692.34068	−*	−*	−29.5	703.47494	−183.6	143.8	−28.7
692.36357	−139.2	111.1	−29.4	703.49766	−152.4	90.7	−28.8
693.35396	−*	−*	−30.9				

*There is no RV value derived in this phase due to the blending of CCF peaks.

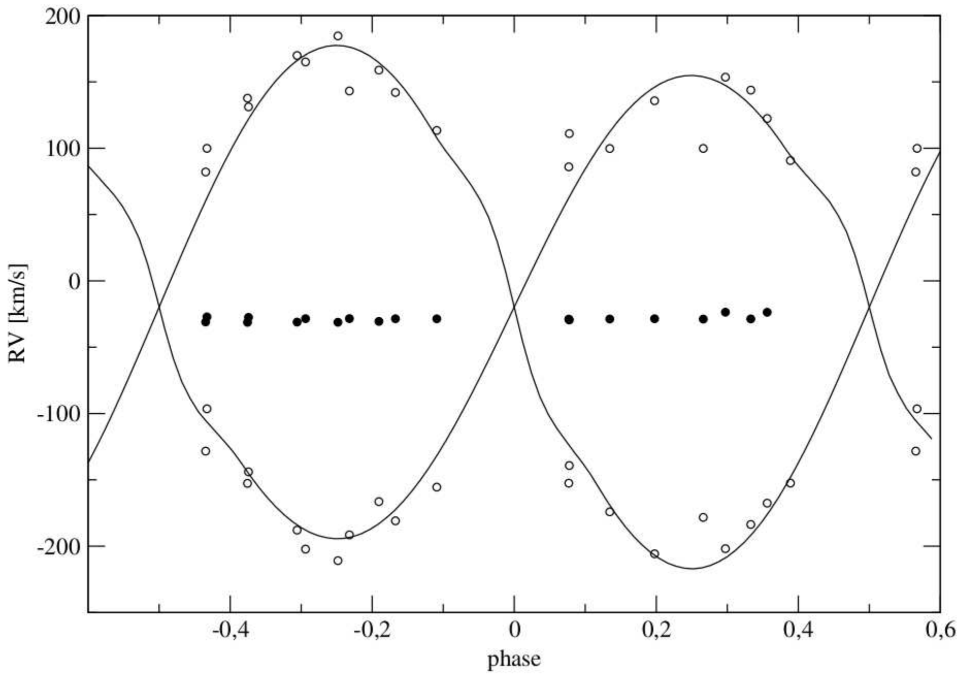

Figure 4. Radial velocity measurements for the three components of HT Vir (the eclipsing pair and third body) made by PST1 are presented in the figure. The empty circles indicate the radial velocity values of the eclipsing pair and the filled circles are connected to the third component. The solid line shows the synthetic curve based on the derived model of eclipsing pair.

Table 4. Preliminary solution for the eclipsing pair HT Vir B and formal errors outputted by the PHOEBE code.

Parameter	Value
HJD_0	2455691.511±0.002
P (days)	0.4077±0.0001
a ($R_\odot$)	3.04±0.06
V_γ (km s^{-1})	−19.6±2.8
q	1.11±0.04
i^* (deg)	84.3 (fixed)
Ω_1^*	4.067 (fixed)
Ω_2^*	4.067 (fixed)

* - PHOEBE program input values not adjust (Zola et al. 2005)

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