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# Absolute parameters of eclipsing binaries in Southern Hemisphere sky – II: QY Tel

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## HIGHLIGHTS

- First spectroscopic observations of QY Tel are presented.
- *V* light and radial velocity curves of QY Tel were solved.
- Physical parameters of the components were computed.
- The evolution case of QY Tel is examined.

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## ABSTRACT

This paper presents the first analysis of spectroscopic and photometric observations of the neglected southern eclipsing binary star, QY Tel. Spectroscopic observations were carried out at the South African Astronomical Observatory in 2013. New radial velocity curves from this study and *V* light curves from the All Sky Automated Survey were solved simultaneously using modern light and radial velocity curve synthesis methods. The final model describes QY Tel as a detached binary star where both component stars fill at least half of their Roche limiting lobes. The masses and radii were found to be 1.32 (± 0.06) $M_{\odot}$, 1.74 (± 0.15) $R_{\odot}$ and 1.44 (± 0.09) $M_{\odot}$, 2.70 (± 0.16) $R_{\odot}$ for the primary and secondary components of the system, respectively. The distance to QY Tel was calculated as 365 (± 40) pc, taking into account interstellar extinction. The evolution case of QY Tel is also examined. Both components of the system are evolved main-sequence stars with an age of approximately 3.2 Gy, when compared to Geneva theoretical evolution models.



## 1. Introduction

It is well known that eclipsing binary (EB) systems provide one of the most accurate tools for determining stellar masses, sizes, temperatures and other physical parameters. Algol EB systems allow the additional study of mass transfer and angular momentum transfer in binary systems, as well as the interaction of such systems with the interstellar medium through mass (and angular momentum) loss from the systems. Since a large proportion of stars are in multiple systems, the knowledge gained from EB studies is vital to understanding the evolution of real populations in the Galaxy as a whole. Over the last decade, many authors (e.g. Pavlovski et al., 2012) have demonstrated that present methods available for the analysis of EB systems achieve a level of accuracy and precision that allow for stringent tests of theoretical stellar evolutionary models. As shown by Torres et al. (2010) though, physical parameters have only been determined to high precision for a small number of systems. Therefore, there is a clear need for dedicated campaigns to obtain many precise parameters for many more EB systems.

This paper is the second in a series (Erdem et al., 2015, Paper I) that reports on the analysis – using cross-correlation techniques – of detailed radial velocity measurements of southern Algol systems (or Algol-like systems) which have not previously been studied for radial velocities, but appear to have spectroscopically separable components.

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The eclipsing nature of QY Tel (CPD -45 9404 = GSC 08360-01489 = HIP 91578, $V$=9.67 mag) was revealed in HIPPARCOS observations (ESA, 1997). Later, the system was classified by Kazarovets et al. (1999) as an Algol-type binary star. QY Tel has a spectral type of F8 and amplitude of 0.48 mag ranging from 9.64 mag to 10.12 mag in the *Hp* band (ESA, 1997). QY Tel was neglected after HIPPARCOS observations. No detailed photometric and/or spectroscopic studies of the system have so far been included in the literature. Only some estimated physical and geometrical parameters of the system were given in the eclipsing binary catalogue of Yu et al. (2006).

## 2. Spectroscopic observations and data reduction

The first spectroscopic observations of QY Tel were made at the Sutherland Station of the South African Astronomical Observatory (SAAO) in 2013. A 1.9 m telescope and grating spectrograph with SITe CCD camera were used. Grating 4 of the spectrograph, which has wavelength coverage of 410 – 510 nm with blaze peak at 460 nm and a resolution of 0.1 nm (giving $R = 4600$ for chosen wavelength range), and a slit width of 1.5 arcsec, was chosen for all observations. The SITe CCD is effectively 266 × 1798 pixels in size, and it is usable over wavelengths ranging from 0.35 $\mu$m to 1 $\mu$m. Its pixel size is 15 $\mu$m.

A total of 33 spectra for QY Tel were obtained during the weeks of 24–31 July 2013 and 1–6 August 2013. Comparison spectra of a Cu/Ar arc lamp were taken before and after each stellar image during the observations. A set of Quartz-Iodine lamp images was also taken for flat-field calibrations. The standard stars HD 693 (F8V, $V_r$ = 14.81 km/s) and HR 3383 (A1V, $V_r$ = 2.80 km/s) were observed to obtain radial velocity measurements of the components of these two binary systems. The exposure times for QY Tel were chosen as 1000 and 1500 s, depending on weather conditions. Data reduction and calibrations were carried out using standard IRAF procedures.

## 3. Modelling of radial velocities

Radial velocities (RVs) of the components of QY Tel were derived from the spectroscopic observations using the cross-correlation technique (CCT). The FXCOR task in the RV package of IRAF (Tonry and Davis, 1979; Popper and Jeong, 1994) was followed for the cross-correlation. For the process, two different spectral regions (4600 – 4800 Å and 4700 – 4950 Å) were used. However, the H$\beta$ (4861.33 Å) lines of the components of the system were chosen as the most suitable for reliable RV measurement. The Gaussian function was adopted as the best-fitting one, and the spectra of the RV standard HD693 were used as a template for deriving RVs of the components. The RV measurements, with standard errors, of components of QY Tel are given in Table 1, in which phase values of the observed times of RV measurements were calculated using the linear ephemeris in Table 2.

In order to calculate the orbital parameters from RV data derived from the CCT, the ELEMDR77 program, developed by T. Pribulla (private communication), was used. After several iterations, the ELEMDR77 program gave a value close to zero for the eccentricity, $e$, within uncertainties. A circular orbit for the system was therefore adopted in the further analysis. During the iterations, the orbital period ($P_{orb}$) of QY Tel was fixed to be 2.488926 days (from Pojmanski and Maciejewski, 2004). The adjusted parameters were the velocity amplitudes ($K_1$ and $K_2$) of the components and the conjunction time ($T_0$). Finally, the best-fitting orbital elements of QY Tel are given in Table 2, and the corresponding best theoretical fits to the radial velocity curves are shown in Fig. 1.

**Table 1**
RV measurements, with standard errors, of components of QY Tel.

| Time HJD | Phase | $RV_1$ (km/s) | $\sigma_1$ (km/s) | $RV_2$ (km/s) | $\sigma_2$ (km/s) |
|---|---|---|---|---|---|
| 2456509.3751 | 0.010 | – | – | 14.3 | 4.7 |
| 2456504.5512 | 0.072 | – | – | 46.5 | 10.5 |
| 2456504.5613 | 0.076 | – | – | 53.5 | 12.1 |
| 2456507.2825 | 0.169 | -97.5 | 15.1 | 98.3 | 5.2 |
| 2456507.2974 | 0.175 | -100.4 | 15.1 | 99.3 | 4.9 |
| 2456507.3149 | 0.182 | -101.1 | 14.6 | 102.6 | 4.7 |
| 2456507.5222 | 0.266 | -106.8 | 12.4 | 115.4 | 4.3 |
| 2456507.5376 | 0.272 | -110.9 | 12.9 | 112.3 | 4.6 |
| 2456507.5553 | 0.279 | -112.7 | 13.7 | 107.1 | 4.7 |
| 2456505.3480 | 0.392 | -59.8 | 14.1 | 69.4 | 5.1 |
| 2456505.3600 | 0.397 | -60.2 | 11.8 | 64.6 | 5.9 |
| 2456510.3546 | 0.404 | -59.4 | 16.9 | 64.1 | 6.0 |
| 2456510.3737 | 0.411 | -47.9 | 13.9 | 60.7 | 5.7 |
| 2456508.3853 | 0.612 | 81.0 | 15.2 | -48.5 | 4.8 |
| 2456508.5218 | 0.667 | 108.0 | 14.0 | -83.3 | 4.7 |
| 2456508.5358 | 0.673 | 108.9 | 16.2 | -86.8 | 4.4 |
| 2456503.5627 | 0.675 | 106.7 | 21.2 | -85.2 | 8.0 |
| 2456503.5663 | 0.676 | 114.9 | 22.1 | -83.7 | 9.9 |
| 2456503.5742 | 0.679 | 110.8 | 16.2 | -85.3 | 5.3 |
| 2456508.5528 | 0.680 | 105.1 | 14.6 | -91.8 | 5.2 |
| 2456503.5912 | 0.686 | 110.4 | 17.9 | -87.4 | 6.5 |
| 2456503.6120 | 0.694 | 113.6 | 16.8 | -89.6 | 5.4 |
| 2456503.6296 | 0.702 | 111.5 | 17.2 | -95.4 | 6.0 |
| 2456506.2947 | 0.772 | 122.1 | 15.1 | -99.1 | 5.3 |
| 2456506.3088 | 0.778 | 121.5 | 13.5 | -100.3 | 5.0 |
| 2456506.4120 | 0.819 | 108.0 | 11.3 | -93.4 | 5.1 |
| 2456506.4331 | 0.828 | 105.0 | 12.7 | -91.2 | 4.1 |
| 2456506.4548 | 0.837 | 93.3 | 15.3 | -94.8 | 4.6 |
| 2456506.5324 | 0.868 | 89.7 | 11.5 | -71.1 | 5.4 |
| 2456506.5502 | 0.875 | 87.6 | 9.2 | -71.6 | 4.9 |
| 2456506.5692 | 0.883 | 83.2 | 8.2 | -70.1 | 5.5 |

**Table 2**
Spectroscopic orbital parameters of QY Tel.

| Parameter | Value |
|---|---|
| $P_{orb}$ (days) | 2.488926 (fixed) |
| $T_0$ (HJD) | 2451957.1046 (± 0.0036) |
| $V_\gamma$ (km/s) | 5.59 (± 0.57) |
| $q$ | 1.093 (± 0.007) |
| $K_1$ (km/s) | 114.82 (± 0.95) |
| $K_2$ (km/s) | 105.02 (± 0.57) |
| $a_1 \sin i$ (AU) | 0.0263 (± 0.0002) |
| $a_2 \sin i$ (AU) | 0.0240 (± 0.0002) |
| $M_1 \sin^3 i$ ($M_\odot$) | 1.309 (± 0.026) |
| $M_2 \sin^3 i$ ($M_\odot$) | 1.431 (± 0.027) |

## 4. Simultaneous solution of the light and radial velocity curves

To obtain absolute parameters of QY Tel, the ASAS $V$ light curve (from Pojmanski and Maciejewski, 2004) and our RV curves of the system were solved simultaneously. The Wilson-Devinney (W-D) code (Wilson and Devinney, 1971) was used in the solution.

During the analysis, the adopted and fixed parameters were as follows. To estimate the effective temperature of primary component of QY Tel, the value of its mass, as derived from our RV curves solution in Section 3, was used. Then, based on the mass of the primary component, the spectral type was assigned as F6V using the calibration of spectral type and physical parameters from Drilling et al. (2000) – in their Table 15.8. Thus, the value of 6550 (± 200) K was adopted for the effective temperature of primary component, using the calibration of spectral type, colour and effective temperature from Drilling et al. (2000) – in their Table 15.7. The square-root limb-darkening law was assumed and limb-darkening coefficients were taken from Claret and Bloemen (2011) and Claret et al. (2013) according to the filter wavelengths used and effective temperatures of the components. The