New eccentric eclipsing binary in triple system: SY Phe

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Abstract

Analyzing available photometry from Hipparcos, ASAS, Pi of the sky and Super WASP, we found that the system SY Phe is a detached eclipsing binary with similar components and orbital period about 5.27089 day. It has a slightly eccentric orbit, however the apsidal motion is probably very slow. The system undergoes an additional photometric variation on longer time scales superimposed on the eclipsing light curve. It also contains one distant component, hence the third light was also considered.

Key words: stars: binaries: eclipsing, stars: individual: SY Phe, stars: fundamental parameters

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1 Introduction

The system SY Phe (= HD 9283 = HIP 7024) was discovered as a variable by Hoffmeister (1949). Later, Hoffmeister (1958) noted that the Algol-type curve is of BO Cep-type, and the additional variability is discussed. The Hipparcos satellite (Perryman et al., 1997) reveals two clearly-shaped eclipses and found the period about 5.27140 day. The photometric amplitude is about 0.5 mag. It is therefore remarkable that SY Phe is still classified as a ”Variable Star with rapid variations”, according to Simbad, or GCVS (Samus et al., 2012).

Spectral type of the system was firstly derived as F8 by Spencer & Jackson (1936), while Hoffmeister (1958) gave the type F4. Later Houk (1978) noted

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the type F3/F5V. According to the Tycho data (Høg et al., 1997) the photometric index is $B_T - V_T = 0.512$ mag, and van Leeuwen (2007) derived the parallax of the system $\pi = 4.69 \pm 1.49$ mas.

However, the system consists of two visual components separated about 4" on the sky. According to the Washington Double Star Catalog (hereafter WDS1, Mason et al. 2001), the astrometric observations of this double do not show any significant change of the position angle. Therefore, the pair is only weakly gravitationally bounded and its semi-major axis is rather large. The Hipparcos observations indicate that the eclipsing variable is the A component (the brighter one).

2 Period analysis of the system

The system was observed by several automatic and robotized telescopes and surveys. Besides the old Hipparcos data, there exist also some photometry of SY Phe obtained by the ASAS survey (Pojmanski, 2002), ”Pi of the sky” (Burd et al., 2005), and Super WASP (Pollacco et al., 2006). For the photometry see Fig 1. All of these observations were used for deriving the times of minima of SY Phe. Both primary and secondary minima were derived, see Table 1. Some of the minima have relatively large uncertainty, however if we plot these minima times in the $O - C$ diagram (see Fig. 2), there is clearly
seen the eccentric orbit of the system. Primary and secondary minima are well-separated, but the analysis of apsidal motion is still difficult.

The method of apsidal motion analysis was described elsewhere, e.g. Giménez & García-Pelayo (1983), Giménez & Bastero (1995). All of the minima times given in Table 1 were used for the analysis. Unfortunately, the set of our data is still very limited and leads to many different results. From these different solutions, we chose to present here two, which have the lowest rms of the fit. These are given in Table 2. As one can see, the change of argument of periastron is still rather small and one cannot easily derive the correct solution. However, the very fast apsidal motion of about 17 years is less probable due to the typical longer apsidal periods in systems of this type. On the other hand, the Solution II (see Table 2) presents so slow apsidal motion, that the value of \( \dot{\omega} = \frac{d\omega}{dt} \) is even so low that the apsidal period \( U \) grows to many thousand years. The time spread of epochs of photometry is still too short yet, hence new precise observations are therefore needed to confirm this hypothesis with higher conclusiveness.

3 Light curve analysis of the system

For the light curve analysis, there arises several problems with the available data: the photometry from the ”Pi of the sky” survey is unfiltered, and the ASAS data have only poor coverage. Relatively best data coverage is provided by the SWASP data, but these are not obtained in any standard photometric filter. The filter used here is a special broadband filter covering a passband from 400 to 700 nm. Therefore, for the use of these data in our light curve

![Fig. 2. O-C diagram of times of minima derived from available photometry. The black points stand for the primary minima, while the blue open circles stand for the secondary ones. The two different apsidal motion solutions are plotted as solid curves (Solution I), and dashed curves (II).](image)
Table 1
The heliocentric minima times used for the analysis.

| HJD        | Error  | Type | Filter | Source         |
|------------|--------|------|--------|----------------|
| 2400000+   |        |      |        |                |
| 48470.71478| 0.00269| Prim | Hp     | Hipparcos      |
| 48473.34287| 0.00527| Sec  | Hp     | Hipparcos      |
| 52471.31528| 0.00258| Prim | V      | ASAS           |
| 52473.93542| 0.00685| Sec  | V      | ASAS           |
| 53541.30923| 0.00158| Prim | V      | ASAS           |
| 53543.92347| 0.02567| Sec  | V      | ASAS           |
| 53709.98250| 0.00564| Prim | -      | Pi of the sky  |
| 53712.58972| 0.01718| Sec  | -      | Pi of the sky  |
| 53907.61660| 0.00210| Sec  | SWASP  | SWASP          |
| 53936.62590| 0.00017| Prim | SWASP  | SWASP          |
| 53965.59620| 0.00044| Sec  | SWASP  | SWASP          |
| 53981.40956| 0.00065| Sec  | SWASP  | SWASP          |
| 54002.49111| 0.00225| Sec  | SWASP  | SWASP          |
| 54031.49955| 0.00176| Prim | SWASP  | SWASP          |
| 54047.31409| 0.00066| Prim | SWASP  | SWASP          |
| 54297.66860| 0.00205| Sec  | SWASP  | SWASP          |
| 54334.55734| 0.00427| Sec  | SWASP  | SWASP          |
| 54342.48405| 0.00078| Prim | SWASP  | SWASP          |
| 54363.56689| 0.00044| Prim | SWASP  | SWASP          |
| 54379.38040| 0.00023| Prim | SWASP  | SWASP          |
| 54416.27834| 0.00245| Prim | SWASP  | SWASP          |
| 54437.35735| 0.00290| Prim | SWASP  | SWASP          |
| 54439.97948| 0.00158| Sec  | SWASP  | SWASP          |
| 54611.29793| 0.00127| Prim | -      | Pi of the sky  |
| 54613.91990| 0.00132| Sec  | -      | Pi of the sky  |
| 54632.38124| 0.00295| Prim | V      | ASAS           |

analysis, we used the filter with the most similar transmission curve, which is the $V_T$ filter of Tycho experiment onboard of the Hipparcos satellite. The PHOEBE programme (see e.g. Prša & Zwitter 2005), based on the Wilson-Devinney algorithm (Wilson & Devinney 1971), was used for the analysis.

Due to missing information about the stars, and having only the light curve in one filter, some of the parameters have to be fixed. At first, the ”Detached binary” mode (in Wilson & Devinney mode 2) was assumed for computing. The value of the mass ratio $q$ was set to 1. The limb-darkening coefficients were interpolated from van Hamme’s tables (see van Hamme 1993), the linear cosine law was used. The values of the gravity brightening and bolometric albedo
Table 2
The parameters of the apsidal motion.

| Parameter | Value - Solution I       | Value - Solution II      |
|-----------|--------------------------|--------------------------|
| HJD0      | 2454163.2646 ± 0.0021    | 2454163.2642 ± 0.0020    |
| P [day]   | 5.27088632 ± 0.00000631  | 5.27088780 ± 0.00000636  |
| ε         | 0.0072 ± 0.0012          | 0.0168 ± 0.0059          |
| ω₀ [deg]  | 217.5 ± 1.3              | 251.6 ± 0.9              |
| ω̇ [deg/cycle] | 0.306 ± 0.013         | < 0.0001                 |
| U [yr]    | 17.1 ± 0.8               | > 10000                  |
| Pₚ [day]  | 5.27533454 ± 0.00000632  | 5.27088779 ± 0.00000636  |

Table 3
The light-curve parameters of SY Phe, as derived from our analysis.

| Parameter | Value | Parameter | Value |
|-----------|-------|-----------|-------|
| i [deg]   | 87.0 ± 1.3 | F₁ = F₂ | 1 (fixed) |
| Ω₁       | 12.504 ± 0.059 | A₁ = A₂ | 0.5 (fixed) |
| Ω₂       | 12.754 ± 0.045 | G₁ = G₂ | 0.32 (fixed) |
| T₁ [K]    | 6890 (fixed) | Derived physical quantities: |
| T₂ [K]    | 6351 ± 260 | M₁ [M☉] | 1.36 ± 0.14 |
| L₁ [%]    | 52.1 ± 1.3 | M₂ [M☉] | 1.36 ± 0.14 |
| L₂ [%]    | 32.9 ± 1.0 | R₁ [R☉] | 1.55 ± 0.09 |
| L₃ [%]    | 15.0 ± 2.3 | R₂ [R☉] | 1.52 ± 0.08 |

Coefficients were set at their suggested values for convective atmospheres (see Lucy 1968), i.e. G₁ = G₂ = 0.32, A₁ = A₂ = 0.5. Therefore, the quantities which could be directly calculated from the light curve are the following: the relative luminosities Lᵢ, the temperature of the secondary T₂, the inclination i, and the Kopal’s modified potentials Ω₁ and Ω₂. The synchronicity parameters F₁ and F₂ were also fixed at values of 1.

Because the SWASP data have only limited angular resolution, the third component of the visual double also influences the photometry and the third light has to be considered. For the light curve analysis we used the Solution II of the apsidal motion, hence there is no need of apsidal advance of the ω angle. The ephemerides were also taken from this solution. The temperature of the primary component was fixed at a value of 6890 K (Wright et al., 2003). Here we have to emphasize once again that the temperature was only adopted on the basis of a statistical value for the considered spectral type and not from a good spectroscopic determination. The best fit we were able to reach is presented in Fig. 3. The fit is slightly worse near the primary minimum, which could suggest the primary minimum is more narrow than the secondary minimum. The parameters of the fit are given in Table 3. Regarding the values of M and R in absolute units, see below.

There can be two different explanations of the poor fit to the data. First, the orbital eccentricity of the binary should be higher, which cause the duration
Fig. 3. The light curve fit of the SWASP data from PHOEBE.

of the primary eclipse shorter, which is visible in the fit in Fig. 3. Other explanation is the fact that there are some short-periodic variations outside of the eclipses. Therefore, these variations are also presented in the eclipses and these can shift the data points a bit. The magnitude of the outside-eclipse variations is up to 0.04 mag. If these variations are physical or instrumental is still an open question. Moreover, we found that there is also a season-to-season variation of the light curve. The level of outside of eclipse brightness was changed of about 0.03 mag during the period of SWASP observations (more than 500 days).

We were trying to find some periodicity of these data after removing the light curve fit. This result is shown in Fig. 4, where a steady increase of brightness is superimposed with the sinusoidal variation with the period of about 248.6 days. Having such a long period of variations, we can only hardly identify these modulations as those making the system classified as a system "with rapid variations" as stated in Simbad. All of these findings make any analysis difficult and new more precise standard photometry in different photometric filters would be very helpful.

4 Discussion and conclusions

The first light curve and period analyses of the system SY Phe were performed. Dealing with no spectroscopy of the target, one has to consider some assumptions and many of the physical parameters are still affected by relatively large errors.
Fig. 4. The residuals of the light curve fit with respect to time. The fitted red line represents the fit with period of about 249 days and secular decrease of magnitude. Confidence level of 95% is also shown.

However, we can roughly estimate the internal structure constants for both apsidal motion solutions. Assuming the two eclipsing components have masses of about 1.36 M\(_\odot\) (spectral type F4), then the semimajor axis of the orbit is about 17.8 R\(_\odot\), which yields the values of radii of both components (see Table 3). Using these values, one can calculate the internal structure constants and compare these values with the theoretical ones, e.g. by Claret (2004). The Solution I gives log k\(_2\) value of about 0.686, while Solution II gives log k\(_2\) = -2.198. The latter value agrees well with the theoretical values by Claret (2004), assuming the F4 star is on main sequence and is about \(5 \cdot 10^8\) yr old.

The light curve solution also provides the first rough estimation about the third light from the distant component. Our result of the third light value (15% of the total light) is in excellent agreement with the \(\Delta M\) value provided by the WDS catalogue. The nature of the long-term photometric variations with period about 249 days still remains an open question. Therefore, new more detailed analysis is still needed, especially based on new spectroscopic data together with the photometric observations obtained in various photometric filters.

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