New Astronomy 49 (2016) 13–16

Contents lists available at ScienceDirect

New Astronomy

journal homepage: www.elsevier.com/locate/newast

First period investigation of detached binary star AM Tau

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HIGHLIGHTS

- We obtained several new CCD times of light minimum.
- We first ever analyzed the periodic variations of AM Tau.
- The secular period decrease may result from enhanced stellar wind.
- Two cyclic oscillations may reveal AM Tau a quadruple system.

ARTICLE INFO

Article history:
Received 17 March 2016
Revised 11 May 2016
Accepted 12 May 2016
Available online 18 May 2016

Keywords:
Stars: binaries: close
Stars: binaries: eclipsing
Stars: individual (AM Tau)

ABSTRACT

AM Tau is a detached eclipsing binary with the secondary component more evolved than the primary one. The period changes of this neglected eclipsing binary are analyzed based on four times of primary minimum obtained between 2007 and 2016 together with those collected from the literature. It is detected that the general trend of the O-C curve shows a downward parabolic variation, which reveals a continuous period decrease at a rate of $dP/dt = -9.0 \times 10^{-7}(\pm 0.2)$ d yr^{-1}, meanwhile, the system undergoes two cyclic oscillations with periods of 24.1 and 8.8 years. The continuous decrease in the orbital period may be caused by angular momentum loss (AML) via an enhanced stellar wind of the evolved secondary star. The two cyclic variations in the O-C diagram are interpreted by the light travel-time effect via the presence of two additional stellar companions with masses estimated as $M_3 \sin i_3 \sim 1.36\,M_\odot$ and $M_4 \sin i_4 \sim 0.33\,M_\odot$. Their orbital separations are about 14 and 8 AU, respectively, and the orbital periods are almost in 3 : 1 resonance orbits.

1. Introduction

The eclipsing binary AM Tau was first detected photographically as an Algol type variable by Hoffmeister in 1934. Subsequently, Jensch (1934) determined its visual brightness as $10.^{m}37 \sim 12.^{m}3$. According to the General Catalogue of Variable Stars (GCVS, http://www.sai.msu.su/groups/cluster/gcvs/), its spectral class is B8 and the orbital period is 2.043926 days. Its light variation belongs to EA-type. The physical model and absolute parameters of this system were reported by Brancewize and Dworak (1980). Their results imply that AM Tau is a detached system with a mass ratio of 0.42 and the mass of the primary component as $5.05\,M_\odot$. Its secondary component is more evolved than the primary one, like in the Algol system. Times of light minimum of this target were observed and published by many researchers, i.e., Szafraniec (1976), Sippel et al. (1998), Diethelm (2003); 2004), Agerer and Hübscher (2003), Nelson (2004), Molïk (2007), Brát et al. (2007), Samolyk (2008) and Hübscher et al. (2010) etc. Although some of them noticed that the orbital period of this system is variable, no detailed period study is available.

In order to investigate the changes of its orbital period, we have chosen it as our object to observe since 2007. In the present paper, we collected all available minimum dates of AM Tau. Combined with our new timings, the period variations of this system are analyzed and discussed in detail.

2. New CCD photometric observations

New CCD photometric observations of AM Tau ($\alpha_{2000} = 05:52:21.4$ and $\delta_{2000} = 16:17:01$) were obtained several times with different telescopes of Yunnan Observatories in 2007, 2012 and 2016. They are described as follows:

1. On January 23, 2007, the observations were carried out by the PI 1024 TKB CCD photometric system attached to the 1.0-meter

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http://dx.doi.org/10.1016/j.newast.2016.05.003

Table 1
Our new CCD times of light minimum for AM Tau.

JD. Hel.	Error	Min.	Filter	Tel.
2454124.0011	± 0.0003	I	V	1 m
2456274.2048	± 0.0002	I	NRI	60 cm
2456276.2491	± 0.0001	I	NRI	60 cm
2457433.0991	± 0.0001	I	RI	60 cm

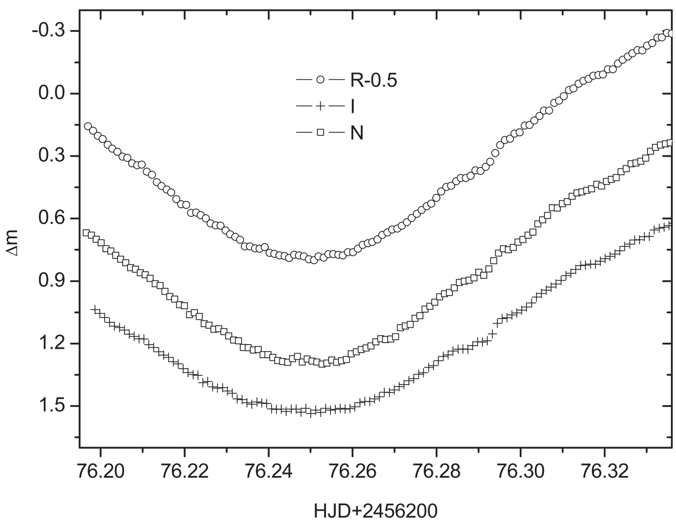

Fig. 1. The $N(RI)_c$ bands CCD observations obtained on December 14, 2012 with 60 cm telescope in YNAO.

Cassegrain reflecting telescope. The effective field of view is $6'.5 \times 6'.5$. During the observation, a Johnson's V filter was used.

2. Other observations made on December 12 and 14, 2012 and February 14, 2016 were carried out by the DW 436 2K CCD photometric system attached to the 60 cm Cassegrain reflecting telescope. Its field of view at the Cassegrain focus is about $12' \times 12'$. The $N(RI)_c$ filters were used.

Comparison star N9KN000375 ($\alpha_{2000} = 05:52:21.8$ and $\delta_{2000} = 16:18:45.6$) and check star N9KN000371 ($\alpha_{2000} = 05:52:31.7$ and $\delta_{2000} = 16:19:01.1$) were chosen from the same field as targets. All the image reductions were done with the IRAF package. Based on our new observations, four primary times of light minimum were determined by using parabola fitting and listed in Table 1. Fig. 1 shows the data observed on December 14, 2012.

3. Orbital period variation for AM Tau

The times of light minimum of AM Tau have been compiled by means of $(O-C)$ gateway (http://var.astro.cz/ocgate/). Together with our new minima, the timings spanning close to 90 years are available. With the period given by GCVS, we use the following ephemeris to calculate the cycle E and $O-C$ values for all those times.

$$\text{Min.I} = \text{HJD}2456276.2491 + 2.^{d}043926 \times E, \quad (1)$$

The corresponding $O-C$ curve is plotted in Fig. 2 (upper panel), where the crosses stand for photographic and visual observational data, and the open circles for photoelectric and CCD observations. From Fig. 2, one can see that the $O-C$ curve shows an obviously downward parabolic change. Besides this, the photoelectric and CCD observational data with high precision reveal an cyclic change, which can not be found only by the photographic and visual observational data. This situation is similar to the case of EG Cep (Zhu et al., 2009) and EU Hya (e.g., Qian and Boonrucksar, 2003). We took a weight of 1 for photographic and visual observational data and 10 for the photoelectric and CCD observational data. Then, by means of a least-square method, the following equation was obtained:

$$\begin{aligned}(O-C) = & -0.0142(\pm0.0026) - 2.^{d}83(\pm0.08) \times 10^{-5} \times E \\ & -2.52(\pm0.06) \times 10^{-9} \times E^2 \\ & +0.^{d}0157(\pm0.0016)\sin[0.^{\circ}084 \times E + 64.^{\circ}9(\pm6.^{\circ}1)].\end{aligned} \quad (2)$$

During the calculation, two CCD and photoelectric times of the light minimum of 2451450.5810 and 2454440.8236 were discarded, because their $O-C$ values show large deviation from the general $O-C$ trend formed by other CCD and photoelectric points. The final fit is shown in the upper panel of Fig. 2 with solid line, which is the combination of a parabolic fit and a periodic fit. The quadratic term in Eq. (2) indicates that the period of AM Tau is decreasing at a rate of $dP/dt = -9.0 \times 10^{-7}(\pm0.2)$ d yr^{-1}. This kind of long-term decrease in the orbital period is often encountered for Algol-type eclipse binaries. Some other examples are Y Psc (Qian, 2000a), FH Ori (Qian, 2001a), RT Per and TX UMa(Qian, 2001b). The dashed line displayed in the upper panel of Fig. 2 represents the fit by the quadratic term in the Eq. (2).

The sinusoidal term suggests a cyclic oscillation with a period of $T_3 = 24.1$ years and a semi-amplitude of $A_3 = 0.0157(\pm0.0016)$ days. Removing the parabolic change, the $(O-C)_1$ values are displayed in the middle panel and the solid line in this panel represents the fit by the periodic term in the Eq. (2). The residuals from the Eq. (2) are plotted in the bottom panel. From this panel, one can see that the photoelectric and CCD residuals may have the second trend of periodic variation. So we try to fit these photoelectric and CCD residuals (hereafter $(O-C)_2$ residuals) and derive the following equation:

$$\begin{aligned}(O-C)_2 = & \ 0.00019(\pm0.00006) + 0.^{d}0021(\pm0.0004) \\ & \times \sin[0.^{\circ}23 \times E - 63^{\circ}(\pm10^{\circ})],\end{aligned} \quad (3)$$

which indicates that there may be another periodic variation with a small amplitude of $0.^{d}0021$ and a period of $T_4 = 8.8$ years. The corresponding fit is shown in Fig. 3.

4. Discussions and conclusions

Based on our new eclipse times together with those compiled from literature, the O-C diagram of the eclipsing binary AM Tau is constructed. We found that the general trend of the O-C curve reveals a combination of an downward parabolic variation and a cyclic oscillation. Other types of close binary stars, e.g., contact binaries V417 Aql (Qian, 2003) and GR Vir (Qian and Yang, 2004), also show this kind of complex changes. The downward parabolic change indicates a long-term continuous decrease with a rate of $dP/dt = -9.0 \times 10^{-7}(\pm0.2)$ d yr^{-1}. The period of the cyclic oscillation is about 24.1 years, while its amplitude is 0.0157 days. After both the continuous decrease and the cyclic change are subtracted from the O-C diagram, weak evidence also shows another cyclic variation with a period of 8.8 years in those residuals. However, more high-accuracy eclipse times are required to check its presence.

The most plausible mechanism to explain the cyclic changes in the O-C diagram is the light-travel time effect via the presence of a third bodies (e.g., Liao and Qian, 2010). The mechanism was used to explain the cyclic changes in the O-C diagram of W UMa-type contact binaries (e.g., Zhu et al., 2011; 2013a; 2013b). This method has also been applied to search for black hole candidates orbiting close binary stars (e.g., Qian et al., 2008). As for AM Tau, two cyclic period variations may suggest two additional bodies orbiting around the central pair. When a total mass of $M_t = 7.2 M_{\odot}$ for the