Light curve and orbital period analysis of the eclipsing binary AT Peg

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Abstract

CCD photometric observations of the Algol-type eclipsing binary AT Peg have been obtained. The light curves are analyzed with modern techniques and new geometric and photometric elements are derived. A new orbital period analysis of the system, based on the most reliable timings of minima found in the literature, is presented and apparent period modulations are discussed with respect to the Light-Time effect (LITE) and secular changes in the system. The results of these analyses are compared and interpreted in order to obtain a coherent view of the system's behaviour.

1. Introduction

The system AT Peg (V=8.97 mag, P=1.145643 days) was discovered as a variable by Sohneller (1931) but the exact reference was not found in the literature. Since its discovery many investigators have been observed and studied the system (Cristaldi & Walter 1963; Hill & Barnes 1972; Giuricin et al. 1981; Gülmen et al. 1993; Margrave 1981; Güdür et al. 1987; Maxted et al. 1994).

The CCD light curves presented herein allow us to obtain a new photometric model of the system and calculate its absolute elements with better accuracy than previous studies and search for tertiary components around it. Moreover, the O-C diagram analysis, based on modern times of minima, provides the means to interpret the orbital period changes and suggests which mechanisms operate in the system. Moreover, since AT Peg was considered a candidate for including a δ Sct component (Soydugan et al. 2006), a frequency analysis was also performed.

2. Observations and data reduction

The system was observed during 6 nights in summer of 2010 at the Athens University Observatory, using a 20-cm Newtonian telescope equipped with the CCD camera ST-8XMEI and B and R Bessell photometric filters. Differential magnitudes were obtained with the software *MUNIWIN v.1.1.26* (Hroch 1998), while the stars SAO 127366 (V=8.3 mag) and GSC 1137-0673 (V=8.8 mag) were used as comparison and check stars, respectively.

3. Light curve analysis and absolute parameters calculation

The light curves have been analysed with the *PHOEBE v.0.29d* software (Prša & Zwitter 2005). Modes 2 (detached system) and 5 (conventional semi-detached system) were chosen for fitting applications, while the 'Multiple Subsets' procedure was used in our solution procedure. The temperature of the primary component was used as a fixed parameter (T_1=8400 K), based on the classification of Maxted et al. (1994), while the temperature of the secondary was left free. The spectroscopic mass ratio q of Maxted et al. (1994) was used as initial value, and then it was adjusted, but always kept inside the spectroscopic error. The rest parameters were either given theoretical values or they were adjusted (for details see Liakos et al. 2011). The contribution of a third light was also considered as there are indications of a third star orbiting the eclipsing pair (see next section).

Frequency analysis with the software *PERIOD04 v.1.2* (Lenz & Breger 2005) was performed on the out-of-primary eclipse residuals (observed – synthetic light curves), but no pulsations were detected.

The absolute parameters of the components were calculated and used for further study of their present evolutionary status. The synthetic and observed light curves are shown in Fig. 1, the location of the components in a theoretical Mass-Radius diagram (cf. Niarchos & Manimanis 2003) is illustrated in Fig. 2, while the derived parameters from the solution are listed in Table 1.

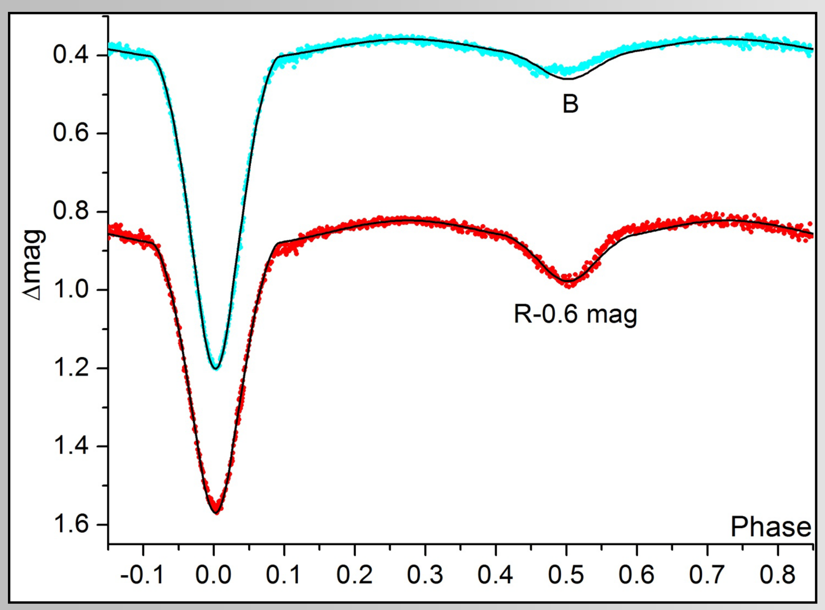

Fig. 1. Observed and synthetic light curves of AT Peg.

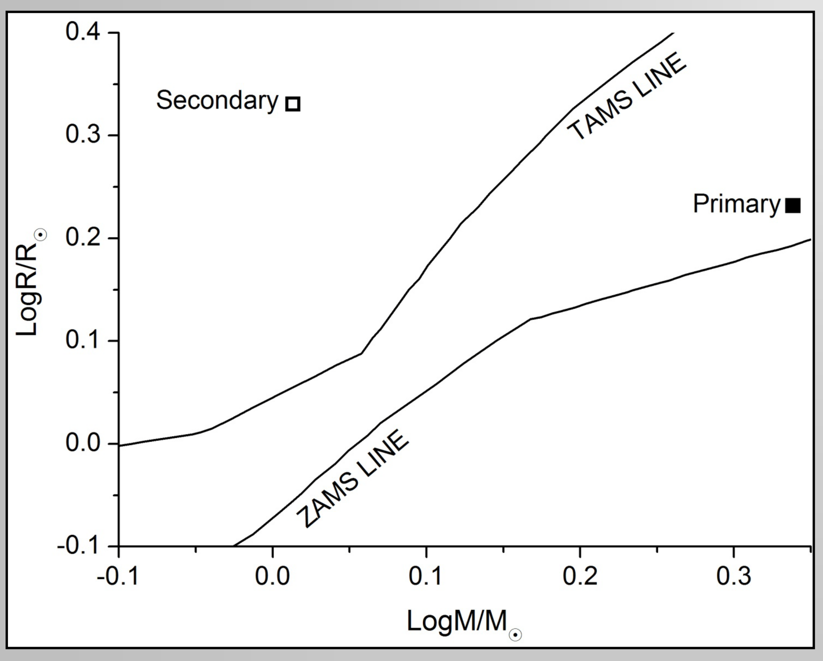

Fig. 2. The location of the components of AT Peg in the M-R diagram. Black solid lines indicate the Terminal Age Main Sequence (TAMS) and Zero Age Main Sequence (ZAMS) limits.

Table 1. Light curve solution and absolute parameters (par.) of the components

Parameter	Value	
System par.		
q	0.478 (3)	
i [deg]	77.54 (5)	
Component par.	*Primary*	*Secondary*
g	1*	0.32*
A	1*	0.5*
T [K]	8400*	5189 (7)
Ω	4.49 (1)	2.83
Filter par.	*B-Filter*	*R-Filter*
L_1/L_T	0.809 (2)	0.727 (2)
L_2/L_T	0.115 (1)	0.212 (1)
L_3/L_T	0.076 (1)	0.062 (2)
x_1	0.556	0.413
x_2	0.834	0.596
Absolute par.	*Primary*	*Secondary*
M [$M_\odot$]	2.2 (1)	1.0 (1)
R [$R_\odot$]	1.70 (3)	2.14 (3)
L [$L_\odot$]	13.0 (4)	3.0 (1)
M_{bol} [mag]	2.0 (2)	3.6 (2)
a [$R_\odot$]	2.18 (3)	4.61 (9)
log g [cm/s^2]	4.31 (3)	3.79 (3)

*assumed, $L_T=L_1+L_2+L_3$

4. Orbital period analysis

The least squares method with statistical weights in a MATLAB code (for details see Zasche et al. 2009) has been used for the analysis of the O-C diagram. The current O-C diagram of AT Peg includes 276 times of minima taken from the literature. The following ephemeris:

Min.I = HJD 2445640.459 + 1.1460901^d × E (Kreiner et al. 2001) was used to compute, initially, the O-C points these minima timings. A LITE fitting function, corresponding to a cyclic variation of the O-C points, and a parabola, assuming a mass-transferring configuration, were chosen to fit the times of minima. This fitting curve and its residuals are presented in Fig. 3, the LITE fitting is shown separately in Fig. 4, and the derived parameters are given in Table 2.

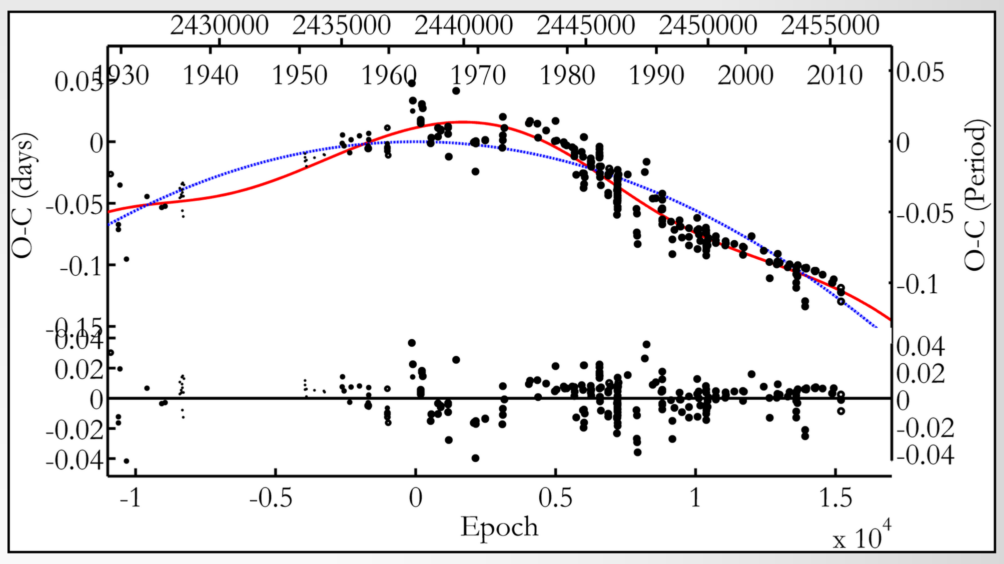

Fig. 3. Upper part: The O-C diagram of AT Peg fitted by a LITE curve and a parabola (blue line) which consist the combined fitting function (red solid line). **Lower part:** The O-C residuals after the subtraction of the total solution.

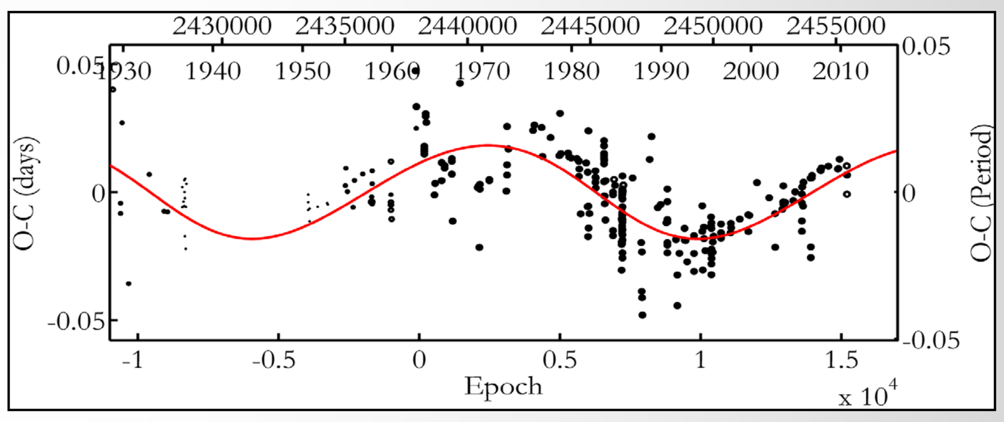

Fig. 4. The LITE fitting after pre-whitening the parabolic term.

Table 2. The O-C diagram analysis parameters

Parameter	Value
Eclipsing binary	
Min. I [HJD]	2438030.447 (1)
P [days]	1.1460905 (2)
C_2 [days/cycle]	-5.590 (1) × 10^{-10}
$\dot{P}$ [days/yr]	-3.563 (1) × 10^{-7}
LITE and third body	
P_3 [yrs]	49.7 (9)
T_0 [HJD]	2446308 (1796)
ω [deg]	204 (37)
A [days]	0.018 (1)
e	0.1 (1)
f (M_3) [$M_\odot$]	0.0129 (3)
$M_{3,min}$ [$M_\odot$]	0.57 (1)

5. Discussion and conclusions

New photometric and O-C diagram analyses of the eclipsing binary AT Peg were performed. The results were combined with those of previous spectroscopic studies and new geometric elements of the system and absolute parameters of its components were derived.

The primary component was found to be a dwarf star and close to the ZAMS limit. On the other hand the secondary is located beyond the TAMS line indicating that it is at the subgiant stage of evolution. Moreover, according to the light curve analysis, this component was found to fill its Roche lobe, therefore it may be expected to be a mass loser. Hence, according to these results AT Peg can be considered as classical Algol type system.

The period changes analysis suggests two main conclusions:

➢The light curve solution revealed a third light of ~7%, while the O-C analysis suggested a third body with a minimal mass of 0.57 $M_\odot$. Assuming a MS nature with coplanar orbit, and taking into account the mass-luminosity relation for MS stars (L~M$^{3.5}$) the expected light contribution (cf. Liakos et al. 2011) was found ~1%, which is much less than the observed one. However, if the third body orbits the eclipsing binary with an inclination of ~12° (as a MS star), or it is more evolved, then the observed additional luminosity can be justified.

➢The orbital period secular change found, contrary to what it was expected (the mass should flow from the less massive to the more massive component), resulted in a decreasing period rate. This discrepancy could be explained with a mass loss rate from the system of 6.6×10^{-7} $M_\odot$/yr, perhaps due to strong stellar winds, or with a magnetic breaking mechanism or even with systemic angular momentum loss, which superimposes the expected mass transfer (cf. Soydugan et al. 2011; Liakos et al. 2010; Ulaş et al. 2009).

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