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A Multiple Star System: IU Aurigae

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Abstract

The early-type system IU Aur is a semi-detached close binary system with an orbital period of 1.81 days, containing two massive stars. The *O - C* diagram of the binary has been analyzed with the least - squares method by using all available times of minima. It is known that the orbital period of IU Aur system displays a periodic change. This change has been explained interms of the gravitational effect of a third companion on the binay star. As a result of the analysis, the physical parameters of the probable third body have been recalculated using the new data which is gravitationally bound to the binary star. Eclipsing binary revolves around a third-body with a mass of about $M_3 > 10\ M_\odot$ in a highly eccentric orbit.

Keywords: multiple system, period analysis, gravitational waves, IU Aur.

Çoklu Bir Yıldız Sistemi: IU Aurigae

Özet

Erken – tür yarı ayrık örten çift sistem olan IU Aur'ın yörünge periyodu 1.81 gün olup sistemde büyük kütleli iki bileşen bulunmaktadır. Literatürdeki bütün minimumlar kullanılarak En Küçük Kareler metodu ile bu çift sistemin *O - C* dönem analizi yapıldı. IU Aur sisteminin yörünge periyodunun periyodik bir değişim gösterdiği bilinmektedir. Bu değişim çift yıldıza bağlı üçüncü bir bileşenin kütle çekimi (gravitasyonel) etkisinden kaynaklandığını ifade etmektedir. Analizler sonucunda çift yıldıza çekimsel olarak bağlı olası üçüncü cismin fiziksel parametreleri yeni veriler kullanılarak yeniden hesaplandı. Çift sistemin etrafında dönmekte olan büyük eksantrik (basık) yörüngeye sahip olan üçüncü cismin kütlesi yaklaşık olarak $M_3 > 10\ M_\odot$ bulundu.

Anahtar Sözcükler: Çoklu sistem, dönem analizi, kütle çekim dalgaları, IU Aur.

1. Introduction

IU Aur (HIP 25565; SAO 58059; TYC 2411-1941-1; HD; 35652, $\alpha = 5^h\ 27^m\ 52^s$,$\delta = 34^0\ 46'\ 58''$ (SIMBAD Database)) is a gravitationally bound third component of a semi-detached early - type eclipsing binary of spectral type (O9.5 V+B0.5 IV-V) with an orbital period of $1^d.8114745$ (Özdemir, 2003). It is one of the very few systems with accurately defined light

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time effect. It was identified as a variable star by Mayer (1965).
IU Aur has been subject to various studies, which are referenced in a study by Mayer (1987), who solved UBV light curves measured at four different epochs between 1964 and 1984. In the later Liu et al (1988) published results from an analysis of UBV light curves obtained at McDonald Observatory between 1984 - 1987. In all these studies a third light contribution was between approximately 20% (Eaton, 1978). Subsequent photometric measurements of IU Aur by Ohmori (1989) and Mayer et al. (1991) revealed a reversal in the change of eclipse minimum depths. Preliminary velocity amplitudes of 307 and 220 km s^{-1} published by Mammano et al. (1977) with spectroscopic observations determined that IU Aur is a massive early type system for following component features:

Component 1 **:** sp. B0, $M_1 = 17.4\ M_\odot$ $R_1 = 5.0\ R_\odot$
Component 2 **:** sp. B0.5, $M_2 = 11.8 M_\odot$ $R_2 = 8.5\ R_\odot$

was obtained by Mammano (1977). Özdemir et al. (2003) made the period analysis of the system in terms of the light - travel time effect (hereafter LTE) because of the presence of a third body in the system. He found that the cyclic sinusoidal *O* - *C* variation was changing with period of 293.3 days (0.80 yr) with a minimum of 14.2 $M_\odot$ for the third body masses.

In the present study the orbital parameters of the third body were refined by an analysis of all accurate minimum times collected from literature using the minima times from 1965 to 2012, which were taken from the database of *O* - *C* Gateway (Paschke and Brát, 2006).

2. *O* - *C* diagram analysis for light time effect (LTE)

The minimum times of IU Aur were collected from different previously reported sources in the literature. The interval of the available minima times of IU Aur covers the last 47 years from 1965 to the end of 2012. All available minima times were collected from their original sources in the literature. Minima times contain a data set of 150 photoelectric and 28 CCD (Charge Coupled Device) minima times in Table 1. The solution parameters and their standard errors, which were used to obtain the theoretical *O* - *C* curve, are provided in Table 2.

Table 1. Summary of dataset

Star	Data Interval	Photoelectric/CCD	Total
IU Aur	1965 - 2012	150/28	178

The *O* - *C* values were computed using the following linear light elements given by database of O-C Gateway (2006):

$$\underline{\text{Min. I}} = \text{HJD } 2450737.451 + 1^{d}.8114753 \times E.$$

As ploted in Figure 1, this ephemeris can only indicate the general trend of the (*O* - *C*) diagram.

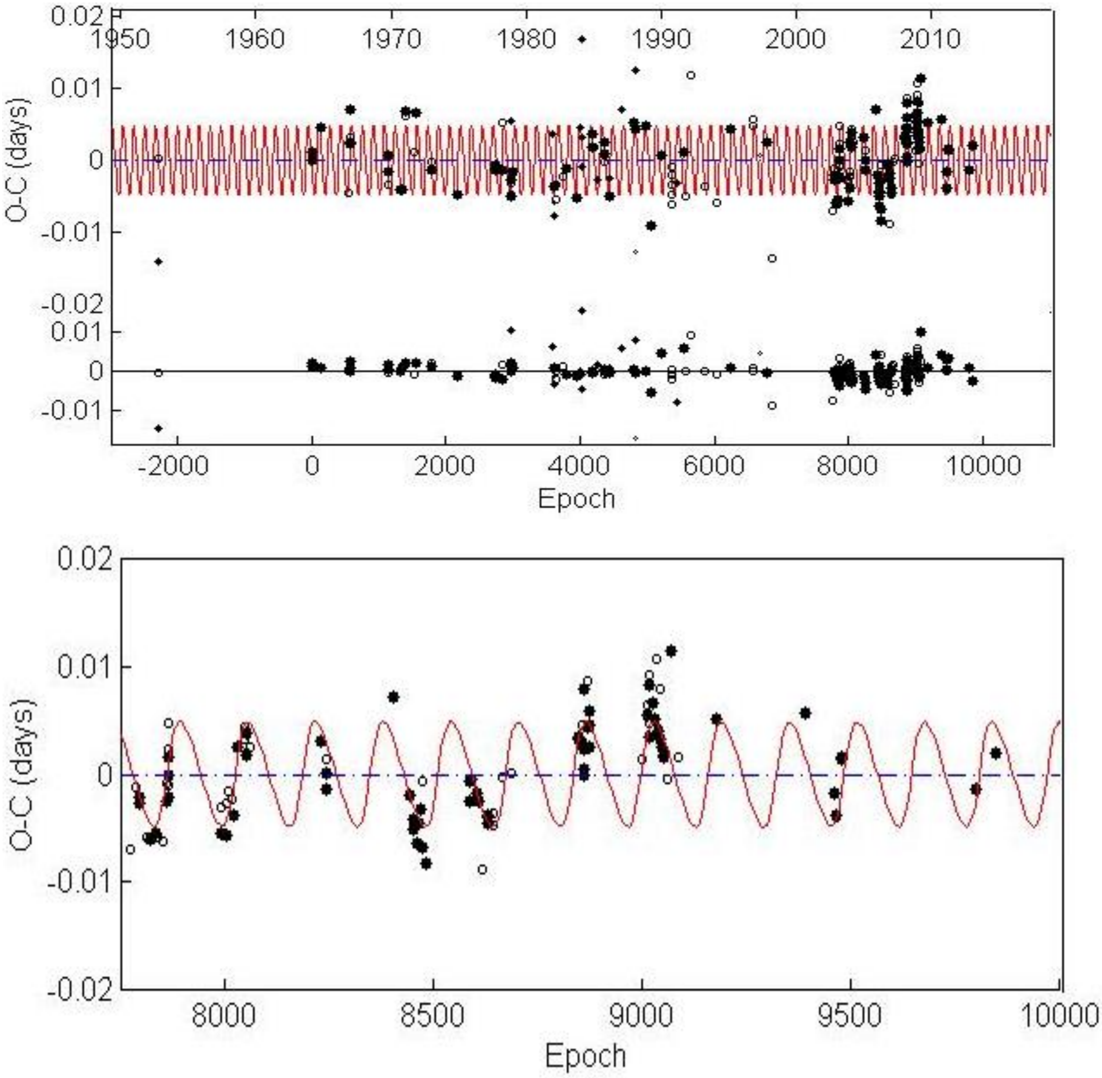

Figure 1 Top panel: The *O* - *C* differences for IU Aur, phased with the period of 293.85. Note that the curve deviaties significantly from sinusoid. Filled circles correspond to primary minima I, and open circles correspond to secondary minima II.
Lower panel: Part of the *O* – *C* diagram representing the best fit curve among from 2000 to 2012.

Table 2. The third body orbit of IU Aur compared with the previous study of Özdemir et al. (2003).

Parameter	Unit	Present study	Özdemir et al. (2003)
T	HJD	2438448.405374 ± 0.000954	2450737.451
P	day	1.81147457 ± 0.00000014	1.8114753
T_0	HJD	2437987.891 ± 23.386	2438010
A	day	0.0048749 ± 0.0004612	0.00522
P_{12}	day	294.0516 ± 0.2303	293.3
P_{12}	year	0.8051 ± 0.0006	0.8022
e'		0.3857 ± 0.1871	0.615
ω'	^{o}	0.0 ± 25.6	2.7
a'_{12}sin	AU	0.9148 ± 0.0865	0.89
f(m)	$M_\odot$	1.1891225 ± 0.0369112	
M_3 (90)	$M_\odot$	12.76 ± 0.25	14.2
M_3 (60)	$M_\odot$	15.33 ± 0.31	
M_3 (30)	$M_\odot$	33.29 ± 0.81	

The linear regression of these data shows the systematic differences from the linear variation in the current *O - C* curve with the cycle sinus oscillatory variation. For the LTE analysis, the least squares method with statistical weights in a MATLAB code written by Zasche et al. (2009) was used, which is based on mathematical method given by Irwin (1952, 1959). The cycle variation analysis allows us to derive the orbital parameters of the third body using the eq.1 proposed by Irwin (1952, 1959);

$$(O - C)= \left[T_0 + P_{orb}\ \mathrm{X}\ E + \frac{A}{\sqrt{1-e^2cos^2\omega'}}\left\{\frac{1-e'^2}{1+e'cosv'}\sin(v'+\omega') + e'\sin\omega'\right\}\right] \qquad \textbf{Eq.1}$$

where e', ω', and v' are the eccentricity, longitude of the periastron and true anomaly of the third - body orbit, respectively. The observed semi - amplitude (*A*) of the light - travel time curve (in days) is given in eq.2 :

$$A=\frac{a'_{12}\sin i'}{173.15}\sqrt{1-e^2cos^2\omega'} \qquad \textbf{Eq.2}$$

3. Conclusion

Orbital - period study of the semi – detached eclipsing binary IU Aur, show that the light - travel time effect is present. The analysis of the *O - C* diagram shows that the orbital period of IU Aur changes with a sinusoidal shape superimposed on the linear structure after HJD2434301.926. Assuming the presence of unseen third body that is gravitationally bound to the eclipsing binary and the light - travel time effect as the cause of the observed cyclic sinusoidal variation in the *O - C* diagram, the parameters of the third - body orbit were computed. The analysis of CCD and photoelectric times of minimum light for this system has shown that a sinusoidal variation can give a good description of the general trend of the Fig 1a. curve and Fig1b. curve part of the *O – C* diagram representing the best fit curve among the data points. The analysis of *O – C* curve suggest an eccentricity of $e = 0.38 \pm 0.18$ for the third body orbit, and the third body mass function suggests a minimum mass of 12.76 $M_\odot \pm$ 0.25. The periodic change with 294.05 ± 0.23 days can be explained interms of the light-time effect. In consistency of the unobservable large mass of the third body indicate the possibility that it may either be a black hole or a binary.

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