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Comparative Study of JKTEBOP and TAP Codes for the Light Curve Analysis of the Extra-Solar Planetary Systems

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Abstract— *The physical and orbital parameters of the extra-solar planetary systems can be estimated using the two publicly available codes: JKTEBOP (Southworth et al. 2004a,b)[15-16] and TAP (Gazak et al. 2012)[4]. We present the comparative study of the physical and orbital parameters derived for the extra-solar planetary systems using these two codes. For our analysis, we have taken one transit light curve of extra-solar planetary system TrES-5 observed by us. In addition to this, the light curves of other extra-solar planetary systems such as Qatar-1, WASP- 5, WASP-10, WASP-24, WASP-67, TrES-3, and GJ-1214 are also taken from the literature. The light curves are separately analyzed using these two codes by employing the same initial parameters. We find that the estimated parameters derived from these codes show good agreement. However, we could not confirm the results reported by Hoyer et a. (2012)[7] and Turner et al. (2013)[5] that JKTEBOP underestimates the errors in the fitted parameters than those estimated in TAP.*

Keywords— *stars: extra-solar planetary systems — stars: fundamental parameters — technique: photometry — parameter estimation codes: JKTEBOP and TAP*

1. INTRODUCTION

The discovery of first extra-solar planet opens a new field of astronomy. The first extra-solar planet transit around HD 209458 was discovered by Charbonneau at el. (2000)[2] by radial velocity method. Since then, 2691 transiting extra-solar systems have been confirmed till now. The transiting photometric method becomes a powerful technique to investigate the close-in extra-solar planets. This prives have more information about transiting extra-solar planets such as the transit depth related to the radius of two bodies (star and planet) and the transit duration related to orbital elements and primary radius.

The light curve modeling and the estimation of physical and the orbital parameters of the extra-solar planetary system can be performed by using publically available codes such as JKTEBOP and TAP. The estimation of physical and the orbital parameters and its uncertainty with high accuracy is very important to study of the extra-solar planetary system. The overestimation of modeled parameters uncertainty reduces the scientific impact of the important observation while underestimation of parameter uncertainty produces contradictory results from the multiple results which have good agreements. Hoyer et al. (2012)[7] and Turner et. al. (2013)[5] performed the JKTEBOP and TAP software to estimates the physical and orbital parameters for the WASP-5 and TrES-3 systems, respectively. They found good agreement between the estimated parameters. However, it was also pointed out by then that JKTEBOP underestimate the errors than those estimated in TAP. This results encourage us to perform the comparative study between the JKTEBOP and TAP codes by considering the light curves of various extra-solar planetary systems.

The reminder of this paper is organized as follows. In the section 2, we discussed about observational data sources taken from literature. Our observation and data reduction are described in Section 3. In Section 4 we presents the methods for analysis of transit light curves. Comparative study of two codes JKTEBOP and TAP are described in Section 5. Finally, in Section 6 we summarize and discuss our results.

2. DATA SOURCE

Table 1: Details of the Transit light Curves Data

Data Number	*Object Name*	*Data Source*
1	TrES-3	Turner et. al .(2013)[5]
2	TrES-3	Vanko et. at. (2013)[18]
3	Qatar-1	Covino et. al. (2013)[3]
4	GJ1214	Horpsoe et.al. (2013)[6]
5	WASP-5	Southworth et. al. (2009)[21]
6	WASP-67	Mancini et. al. (2014)[11]
7	WASP-10	Macijewski et. al. (2011)[9]
8	WASP-24	Southworth et. al. (2014)[17]
9	TrES-5	Observed using HCT (2016)

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We have taken nine transit light curves, which include eight transit data of different extra-solar planetary system from the literature and one transit data of TrES-5 observed by us using the 2-m Himalayan Chandra Telescope (HCT), Hanle, India. The selected extra-solar planetary system and their data number and source are given in Table-1.

3. OBSERVATION AND DATA REDUCTION

In this study, we have monitored one transit event of TrES-5b on Sept. 30, 2016 using the 2-m HCT Telescope. This transit observation was taken with the HFOSC (Himalayan Faint Object Spectrograph and Camera) instrument mounted on the *2-m HCT*. The transit event was observed using a single R-band filter with exposure time of 60 second.

The HCT CCD images of TrES-5 system were calibrated using the standard *IRAF* procedures such as trimming, dark and bias subtractions, and flat field division. After pre- processing, the aperture photometry was performed on the TrES-5 and the nearby comparison stars using ***'phot'*** task within *IRAF*. Using the flux of TrES-5 and the comparison stars, we carried out the differential photometry to plot the light curve for TrES-5 system.

4. ANALYSIS OF THE LIGHT CURVES

We have modelled the light curves of all the extra-solar planetary systems mentioned in Table-1 using TAP and JKTEBOP individually. The procedure given in Hoyer et al. (2012)[7] to choose initial parameters was adopted. While running both the codes, the same initial parameters were considered for each extra-solar planetary system. The initial parameter values are taken from the concerned papers listed in Table-1.

4.1 Analysis of Light Curves using Jktebop Code

JKTEBOP was originally developed from the EBOP model. The Transit Analysis Package as described in Gazak et al. (2012)[4] has been used for our light curves analysis. The TAP employs MCMC technique and the model of Mandel & Agol (2002)[10] to fit the light curves of the transiting extra-solar planetary systems. This model derived for a simple two-body star-planet system. Hence, for each *TAP* run, we obtain most likely orbital parameters separately for each epoch. However, before using *TAP*, relative flux is normalized so that the *OOT* values are closed to unity. We individually modeled each light curve of the extra-solar planetary system. To run the TAP, the initial parameters values of the extra-solar planetary systems were taken from the references mentioned in Table-1. TAP fits the same parameters as JKTEBOP does except for $R_p/a+R_*/a$. Instead of $R_p/a+R_*/a$, it fits a/R_*. In each run of TAP. the orbital inclination (i), ratio of planet to star radius (R_P/R_*), mid-transit time (T_O) were assumed to be free, whereas a/R_* and P were fixed. The values of eccentricity of orbit, e, and longitude of periastron, ω, were set to zero.

5. COMPARATIVE STUDY OF THE RESULTS FROM JKTEBOP AND TAP CODE

The best fitted parameters values of orbital inclination (i), planet to star radii ratio (R_p/R_*), Mid-Transit time (T_O) of all the nine transit events are calculated using the JKTEBOP and TAP codes. The parameter values estimated from these two codes are plotted in left panels of Fig. 1. As the slope of plots in the left panels are nearly equal to one, it indicates that the estimated parameters using these two codes shows good agreement. In order to examine this agreement more carefully, we have used the method of Altman and Bland et al. (1983)[1] and plotted the graph between differences against the average values of a particular parameters obtained using the these two codes in right panels of Fig. 1. It is clear from right panels of Fig. 1 that all the points are within 2σ (i.e. 95% confidence level), which allows us to confirm that the estimated parameter values using these two codes are in good agreement.

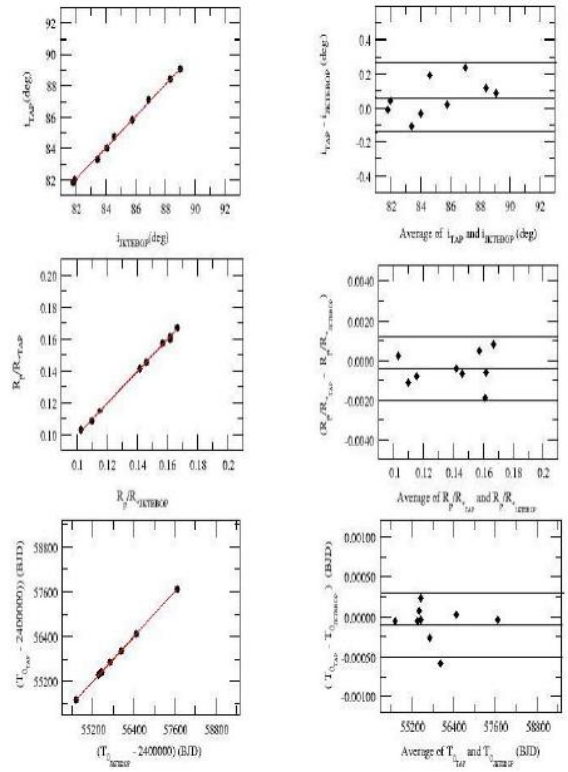

Fig. 1: The left panels: Shows parameters values estimated by TAP are taken in x-axis while parameter values estimated using JKTEBOP code are plotted in y-axis. The Right panels: Denotes the Altman & Bland plot between differences against average values of parameters estimated using JKTEBOP and TAP. The central continuous line denotes the mean difference value and the outer continuous lines denote the 95% limits of agreements (i.e. 2σ), where σ is the standard deviation in differences.

In addition to this, the differences in the uncertainties computed in planetary parameters, namely, *Rp/R**, *i* , and *To* using JKTEBOP and TAP are plotted against the data number in Fig. 2. For each planetary parameter, the difference in uncertainties is defined as the uncertainty calculated through JKTEBOP minus that estimated using TAP. From this figure, it is clear that all points lie below the zero line except for the difference in uncertainties related to Rp/R* and To for the data numbers six and seven. It has been noticed that the uncertainty in Rp/R* is larger in JKTEBOP than TAP for the data numbers six and seven, whereas that in To is found to larger only for the data number six. We found that out of nine data sets, the results of seven data sets confirm the finding of Hoyer et al. (2012)[7] and Turner et al. (2013)[5] that estimated errors in the physical and orbital parameters are smaller in JKTEBOP than TAP. However, the results of the two data sets as discussed above indicate the opposite results than those pointed out by Hoyer et al. (2012)[7] and Turner et al. (2013)[5] that JKTEBOP underestimates the errors in the fitted parameters than those estimated in TAP.

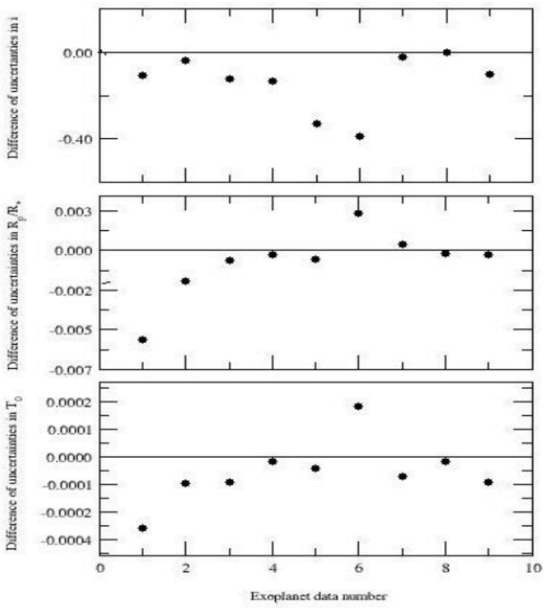

Fig. 2: From top to bottom, the differences in the estimated uncertainties in parameters i , Rp/R*, and To are plotted against the data number. The filled circles denote the difference in uncertainties derived from JKTEBOP minus those calculated using TAP. The continues line denote the zero values of the difference in uncertainties.

6. CONCLUSION

We have analyzed all the light curves individually by adopting the similar procedure as described in Hoyer et al. (2012)[7]. We found that the estimated physical and orbital parameter values show good agreement but the estimated parameter uncertainties are not always smaller in JKTEBOP than TAP.

Thus from the above results we can conclude that almost 80 % of the data results confirm the findings of Hoyer et al. (2012)[7] and Turner et al. (2013)[5] while the remaining 20% show opposite results. It is, therefore, worth mentioning here that one should be very much careful while making the conclusion that JKTEBOP underestimates the errors than TAP. In order to confirm this issue, the further analysis by including more number of data sets are required.

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