

UNIVERSITY GRANTS COMMISSION
BAHADUR SHAH ZAFAR MARG NEW
DELHI – 110 002

PROFORMA FOR SUBMISSION OF INFORMATION AT THE TIME OF
SENDING THE FINAL REPORT OF THE WORK DONE ON THE PROJECT

1. Title of the Project: **Investigating Close-in Extra-solar Planets through Photometric Follow-up of their Transits**
2. NAME AND ADDRESS OF THE PRINCIPAL INVESTIGATOR: **Dr. Parijat Thakur, Department of Pure and Applied Physics, Guru Ghasidas Vishwavidyalaya, Koni, Bilaspur - 495009, Chhattisgarh**
3. NAME AND ADDRESS OF THE INSTITUTION: **Guru Ghasidas Vishwavidyalaya, Bilaspur (C.G.)**
4. UGC APPROVAL LETTER NO. AND DATE: (i) F. No. -43-521/2014(SR) Dated 28 Sep, 2015
(ii) F. No. -43-521/2014(SR) Dated 28 Oct, 2017
5. DATE OF IMPLEMENTATION: **01/07/2015**
6. TENURE OF THE PROJECT: **01/07/2015 to 30/06/2018**
7. TOTAL GRANT ALLOCATED: **Rs.10,02,500/-**
8. TOTAL GRANT RECEIVED: **Rs.8,16,680/-**
9. FINAL EXPENDITURE: **Rs. 7,72,273/-**
10. TITLE OF THE PROJECT: **Investigating Close-in Extra-solar Planets through Photometric Follow-up of their Transits**
11. OBJECTIVES OF THE PROJECT: The main objectives of the proposed research project are summarized in the following items:
 1. Determination of the improved estimates of the planetary, stellar, and orbital parameters through high-precision and high cadence photometry of the transiting extra-solar planetary systems and comparison with previous studies.
 2. Estimation of the refine ephemeris for the orbital periods and mid-transit times required for the future transit observations of the extra-solar planetary systems.

3. Based on the obtained transits, we would determine the the mid-transit times and with following analysis of the transit timing variations (TTVs), we would discuss the possible presence of the additional planet (perturber) in the extra-solar planetary systems.
4. We would also try to estimate the upper-mass of additional low-mass planet as a function of orbital period ratio of transiting extra-solar planet and the additional planet.

Finally, based on the outcome of our presently proposed research project, we would prepare the report and research papers.

12. WHETHER OBJECTIVES WERE ACHIEVED:

Yes, major portion of our objectives are achieved as several photometric follow-up observations of transiting extra-solar planetary systems such as Qatar-1, TrES-3, and WASP-12 have been carried out with the 2-m Himalayan Chandra Telescope (HCT) at the Indian Astronomical Observatory (IAO), Hanle and the 1.3-m J. C. Bhattacharya Telescope at the Vainu Bappu Observatory (VBO), Kavalur of the Indian Institute of Astrophysics (IIA) Bangalore, India. Based on the findings of transit timing variation analysis of extra-solar planet Qatar-1b, our paper entitled "**Investigating Extra-solar Planetary System Qatar-1 through Transit Observations**" has been published in the international peer-review journal of **Bulletin de la Société Royale des Sciences de Liège**. In addition to this, we have investigated the presence of additional planets, the orbital decay and the apsidal precession phenomena in the TrES-3 system by considering 83 mid-transit times, which include 12 mid-transit times derived from the analysis of new transit light curves observed by us and the remaining 71 were derived from the transit light curves taken from the literature. Based on the outcome of the work on TrES-3 system, our research paper entitled "**Probing Transit Timing Variation and its Possible Origin with 12 New Transits of TrES-3b**" has been published in the **Astronomical Journal (AJ, impact factor 5.838)**. Besides this, the photometric follow-up observations of the transits of several extra-solar solar planets such as WASP-12b and TrES-5b are still in progress as their sufficient number of full transit events could not be observed due to bad weathers.

13. ACHIEVEMENTS FROM THE PROJECT:

The results of the proposed works have been published in the Astronomical Journal (AJ), which is a journal of American Astronomical Society (AAS) with Impact Factor of 5.838. While pursuing UGC-MRP project, the research facilities have been developed, as well as the well trained and skilled Project Fellow in the area of extra-solar planetary science has been produced. Even after

completion of this project on June 30, 2018, the research work in the field of extra-solar planetary system is still being carried out, as the Project Fellow (Mr. Vineet Kumar Mannaday) of UGC-MRP project has registered himself for Ph. D. programme in the Guru Ghasidas Vishwavidyalaya, Bilaspur (C.G.). Moreover, the research facilities developed in our department through this project helped several students to complete their master level project in this new and burning field of extra-solar planetary science.

14. SUMMARY OF THE FINDINGS: (IN 500 WORDS)

Outcomes based on Qatar-1 system:

We explored the existence of additional planet in the extra-solar planetary system Qatar-1 through analyzing the transit timing variation (TTV) of Qatar-1b. For this study, total 38 transit light curves are considered among which three high precision light curves are obtained in R band with the 2-m Himalayan Chandra Telescope (HCT) of the Indian Astronomical Observatory, Hanle, India during June 30, 2016 to September 10, 2016 and the remaining 35 are taken from the literature, as well as from the Exoplanet Transit Database (ETD). The orbital parameters of this system with the precise mid-transit times are determined homogeneously by analyzing the transit light curves with the Transit Analysis Package (TAP). Using the best fitted values of mid-transit times, we derive new ephemeris for the orbital period and mid-transit time of Qatar-1b through which the timing residuals (O-C data) were obtained and examined the presence of possible TTV signal in this system. From our study, we do not find any indication of TTV in the Qatar-1 system, which allows us to conclude that the additional planet may not be present in the Qatar-1 system. Based on these findings, our paper entitled "**Investigating Extra-solar Planetary System Qatar-1 through Transit Observations**" (Thakur & Mannaday et al. 2018) has been published in the international peer-review journal of **Bulletin de la Société Royale des Sciences de Liège**.

Since it is required to collect long-term precision transit light curves of extra-solar planet for the precise TTVs study, 18 new transit light curves have been observed using the observing facilities across the globe available to our collaborator Prof. Ing-Guey Jiang, National Tsing-Hua University, Taiwan. By combining these light curves with the above 38 and many more from literature, the further TTV has been examined including the orbital decay of Qatar-1b. Based on the finding of this part of work, our manuscript entitled "**Are There Transit Timing Variations for**

the Exoplanet Qatar-1b?" (Su et al.) has been submitted to the **Astronomical Journal (AJ)**, which is now under review.

Outcomes based on TrES-3 system:

We observed 12 new transits of hot-Jupiter extra-solar planet TrES-3b using the 2-m HCT, the 1.3-m Devasthal Fast Optical telescope of ARIES, Nainital, India and the 1.25-m telescope (AZT-11) of Crimean Astrophysical Observatory (CrAO), Nauchny, Crimea to probe the transit timing variation (TTV). By combining the mid-transit times determined from these 12 transit data with those re-estimated through uniform procedure from 71 transit data available in the literature, we derive new linear ephemeris for orbital period and mid-transit time, which are consistent with those reported previously in the literature. The timing residuals of the linear ephemeris model suggests the possibility of TTV in the TrES-3 system. However, the computed frequency analysis shows that the possible TTV is unlikely to be periodic, indicating the absence of an additional body in this system. To explore the other possible origins of TTV, the orbital decay and apsidal precession ephemeris models are fitted to the transit time data. We find the decay rate of TrES-3b to be -4.1 ± 3.1 ms/yr, and the corresponding estimated modified stellar tidal quality factor of $Q_* \sim 1.11 \times 10^5$ is consistent with the theoretically predicted values for the stars hosting the hot-Jupiters. The shift in the transit arrival time of TrES-3b after 11 years is expected to be $T_{\text{shift}} \sim 69.55$ s, which is consistent with the rms of the timing residuals. Besides, we find that the apsidal precession ephemeris model is statistically less probable than the other considered ephemeris models. To rule in or out this phenomenon in the TrES-3 system, the observation of secondary eclipse would be required. Although the linear ephemeris model appears to be the most plausible model to represent the transit time data, the possibility of the orbital decay cannot be completely ruled out in the TrES-3 system because of following reasons: (i) the T_{shift} is consistent with the rms of the timing residuals and (ii) the values of χ^2_{red} and BIC are not significantly different between the linear and orbital decay ephemeris models. To confirm this, further high-precision and high-cadence follow-up observation of transits of TrES-3b would be required. Based on these outcomes, our paper entitled "**Probing Transit Timing Variation and its Origin with 12 New Transit of TrES-3b**" (Mannaday & Thakur et al. 2020) has been published in the **Astronomical Journal (AJ)**.

15. CONTRIBUTION TO THE SOCIETY: (GIVE DETAILS)

Our studies carried through this UGC-MRP research project give an extensive knowledge about the photometric observation, data reduction, transit light curve analysis, and the transit timing

variation analysis of extra-solar planetary systems. The derived best-fit physical and orbital parameters, the findings of presence or absence of additional planets, orbital decay rates, as well as the estimated modified stellar tidal quality factors in the hot-Jupiters extra-solar planetary systems (Qatar-1 and TrES-3) motivate astronomical community to better understand the formation and evolution of these systems. The scientific skills and understanding developed through this project have helped to produce manpower for working in this new and burning field of extra-solar planetary science. Besides, several post-graduate students of our department have been trained to perform photometric data reduction using Image Reduction and Analysis Facility (IRAF) using the research facilities developed with this UGC-MRP project. It is, therefore, clear that the research facilities developed through the UGC-MRP project would allow the students to pursue the research in this interesting and thrust area of extra-solar planetary science.

16. WHETHER ANY PH. D. ENROLLED/PRODUCED OUT OF THE PROJECT:

Yes! The appointed project fellow Mr. Vineet Kumar Mannaday has enrolled himself for the Ph. D. degree under the supervision of Dr. Parijat Thakur (PI of UGC-MRP) and is continuing his research work in the same area as proposed in UGC-MRP.

17. NO. OF PUBLICATIONS OUT OF THE PROJECT: **FOUR (04)**

Paper Published in International Journal:

1. ***Probing Transit Timing Variation and its Possible Origin with 12 New Transits of TrES-3b***, Vineet Kumar Mannaday, Parijat Thakur (Corresponding Author), Ing-Guey Jiang, D. K. Sahu, Y. C. Joshi, A. K. Pandey, Santosh Joshi, Ram Kesh Yadav, Li-Hsin Su, Devesh P. Sariya, Li-Chin Yeh, Evgeny Griv, David Mkrtychian, Aleksey Shlyapnikov, Vasilii Moskvina, Vladimir Ignatov, M. Vaňko, and Ç. Püsküllü, 2020, **Astronomical Journal (AJ)**, 160, 147, DOI: 10.3847/1538-3881/ab9818 (Impact Factor: 5.838)
2. ***Investigating Extra-solar Planetary System Qatar-1 through Transit Observations***, Parijat Thakur (Corresponding Author), Vineet Kumar Mannaday, Ing-Guey Jiang, D. K. Sahu, and Swadesh Chand, 2018, **Bulletin de la Société Royale des Sciences de Liège**, 87, 132, DOI: 10.25518/0037-9565.7577

Paper Published in Conference Proceedings:

1. ***Transit Timing Variations Analysis of Extra-Solar Planet Qatar-1b***, Parijat Thakur, Vineet Kumar Mannaday, Ing-Guey Jiang, D.K. Sahu, and Swadesh Chand, 2017, International Journal of Luminescence and Applications, Vol. 7, No. 3-4, Article ID: 263, p.p 527-529

2. **Comparative Study of JKTEBOP and TAP Codes for the Light Curve Analysis of the Extra-Solar Planetary Systems**, Vineet Kumar Mannaday, Parijat Thakur, Ing-Guey Jiang, D.K. Sahu, and Swadesh Chand, 2017, Vol. 7, No. 3-4, Article ID: 264, pp. 530-533

Paper under Review:

1. **Are There Transit Timing Variations for the Exoplanet Qatar-1b?**, Li-Hsin Su, Ing-Guey Jiang, Devesh P. Sariya, Chiao-Yu Lee, Li-Chin Yeh, **Vineet Kumar Mannaday, Parijat Thakur**, D. K. Sahu et al. (under review in Astronomical Journal)

Paper Submitted/ Accepted

1. **An Investigation of the Transit Timing Variations in HAT-P-12 Planetary System: Indication of Non-Sinusoidal Variations**, Devesh P. Sariya, Ing-Guey Jiang, Li-Hsin Su, Li-Chin Yeh, Tze-En Chang, V. V. Moskvina, A. A. Shlyapnikov, V. Ignatov, David Mkrtichian, Evgeny Griv, **Vineet Kumar Mannaday, Parijat Thakur**, D. K. Sahu, Swadesh Chand, D. Bisht, Zhao Sun, Jianghui Ji (submitted to RAA journal) *(Now accepted on Oct. 2020)*

Parijat Thakur

(PRINCIPAL INVESTIGATOR)

Dr. Parijat Thakur
(Seal) Principal Investigator
UGC-MRP, New Delhi
Department of Pure & Applied Physics
Guru Ghasidas Vishwavidyalaya,
Bilaspur (C.G.) 495009
(CO-INVESTIGATOR): ----NA-----

[Signature] 21.09.2020
(REGISTRAR/PRINCIPAL)
कुल सचिव / Registrar
गुरु घासीदास विश्वविद्यालय, बिलासपुर (छ.ग.)
Guru Ghasidas Vishwavidyalaya,
Bilaspur (C.G.)
(Seal)