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# High-Time-Resolution Astrophysics using the Thai 2.4-m Telescope with ULTRASPEC

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**Abstract.** The Thai National Observatory (TNO) is equipped with a 2.4-m Ritchey-Chretien telescope and the high-speed versatile ULTRASPEC camera. The instrument employs a low-noise frame-transfer EMCCD, suitable for the observation of faint objects and for high-time-resolution astrophysics. We present some of the results obtained in the first four years of operation, focusing particularly on fast photometry of lunar and stellar occultations, and follow-up efforts on a few white-dwarf binaries. Among the latter is the polar cataclysmic variable UZ For. This system displays period changes and is suspected of hosting circumbinary planets. Our high-speed photometry data show a decreasing trend in the O–C diagram of UZ For. Using our new data set, we will investigate whether the period change in this binary is due to a possible third body, or to other mechanism(s).

**Keywords.** Techniques: photometric, Stars: white dwarfs; Stars: cataclysmic variables

## 1. Introduction

Astronomy in Thailand has developed rapidly in the last eight years since the establishment of the National Astronomical Research Institute of Thailand (NARIT). One of the biggest milestones achieved by NARIT was the completion (in 2013) of the Thai National Observatory (TNO), which is the main optical facility managed by the Institute. The Observatory, located at an altitude of 2457 m in Doi Inthanon National Park, hosts a 2.4-m Ritchey-Chretien telescope, and an additional 50-cm telescope which is being used for science and public outreach. As well as the TNO, NARIT also manages four robotic telescopes in Australia, Chile, China and the US, and three Regional Observatories for the Public in the provinces of Nakhon Ratchasima, Chachoengsao and Songkhla.

The TNO and its 2.4-m telescope are equipped with three science instruments: a medium-resolution spectrograph, a 4K×4K camera, and the ULTRASPEC camera. ULTRASPEC was previously a visitor instrument on the ESO 3.6-m (Dhillon *et al.* 2008) and the NTT, but it has been fitted with a new opto-mechanical chassis and a set of re-imaging optics (see Dhillon *et al.* (2014) for details) and is to be mounted at one of the Nasmyth foci of the Thai National Telescope (TNT). The camera has been a permanent visitor instrument at the TNT since 2013.

## 2. ULTRASPEC

ULTRASPEC has a frame-transfer EMCCD with a 1K×1K imaging area, enabling it to obtain photometric data with almost zero readout time. The sub-frame mode is available with up to 4 windows, as described by Dhillon *et al.* (2014), which brings the sampling time down to a sub-second when only one window is used. In addition, Dhillon *et al.* also introduced a drift mode which was developed specifically for Lunar occultation observations with the TNT.

## 3. High-Time-Resolution Astrophysics at the TNO

The ability of the ULTRASPEC camera to reach the sub-second regime makes the instrument ideal for high-speed optical observations at the TNO. Some results of note from the current five years of operation are the white dwarf binaries studies, the search for the circumbinary planets, and lunar and stellar occultations with the TNT.

### 3.1. *White-dwarf binaries*

Photometry of white-dwarf binaries is quite challenging, owing to the rapid variations both in their light-curves and in the brightness of the systems. However, fast photometric data of these objects could be obtained with ULTRASPEC. A few systems routinely observed at the TNO are ones suspected of hosting circumbinary planets, e.g., DP Leo, UZ For and HU Aqr. Their eclipse timings are measured by fitting a sigmoid function to the light-curves during ingress and egress.

TNO data show a steep decrease in the (O–C) diagram of HU Aqr (Godziewski *et al.* 2015) and a decline in the (O–C) of UZ For (Irawati *et al.*, in prep). That implies that the models of Jovian-like companions previously proposed for those systems were not suitable as they could not explain the recent changes in the orbital period. Our current findings suggest that the variations in the (O–C) diagrams are more likely to result from intrinsic processes in the binaries, but we stress that further observations are necessary to confirm the suggestion.

Apart from those binaries, we are also studying peculiar systems known to show small eclipses in their light-curves caused by the transit of dense materials (or planetesimals) in front of the white dwarfs, such as in the case of SDSS J1021+1744 (Irawati *et al.* 2016). We used sampling times of 0.5–20 seconds to obtain photometric data of these targets. There are 16 choices of filters† for ULTRASPEC at the TNT; however, we always opted for the broadband SDSS filters ($g'$, $r'$, $i'$, $z'$), plus KG5 and clear filters, to optimise the S/N ratio. In Fig. 1, we present the light-curves of UZ For, DP Leo and SDSS J1021+1744. The data for UZ For and DP Leo were taken with exposure times of 1.8 s ($g'$) and 5.8 s (clear), respectively, while for SDSS J1021+1744 we used 3.3 s sampling with an $r'$ filter.

### 3.2. *Stellar and lunar occultations*

The observation of stellar occultation events with the TNT+ULTRASPEC was conducted in collaboration with F. Braga Ribas (Brazil) and B. Sicardy (France). During the past four years we have successfully observed two events: the occultations of Chariklo, and of 2003AZ84 (see Fig. 2). The light-curves of those two events have been published by Berard *et al.* (2017) for Chariklo, and by Dias-Oliveira *et al.* (2017) for 2003AZ84. A few other attempts to observe occultations by Trans-Neptunian Objects unfortunately resulted in null detections, or were hindered by weather.

The fastest sampling (drift mode) was used for the lunar occultation observation (2014–2017), requiring photometry with millisecond exposure times. For the lunar occultation programme at the TNT we were able to provide the latest measurements of projected separation and angular diameters for 15 long-period binaries and giant stars, and also

† http://www.vikdhillon.staff.shef.ac.uk/ultracam/filters/filters.html

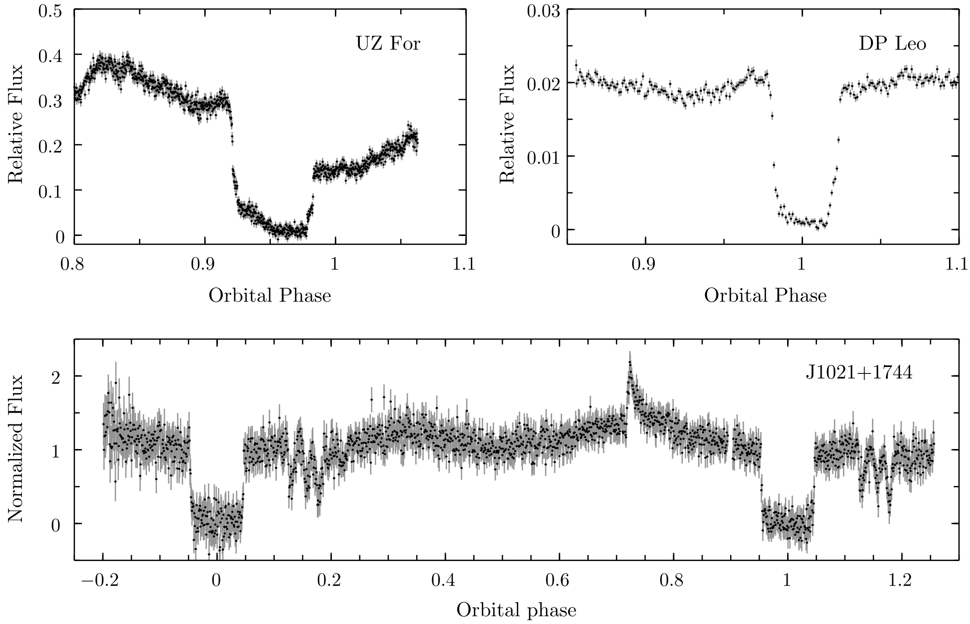


**Figure 1.** Light-curves of three eclipsing white-dwarf binaries: UZ For, DP Leo and SDSS J1021+1744, observed with the TNT+ULTRASPEC. The sampling times used were 1.8 s, 5.8 s and 3.3ṡ, respectively. We obtained the observations of UZ For in $g'$ and J1021+1744 in $r'$ filters, while for DP Leo we chose to use no filter.

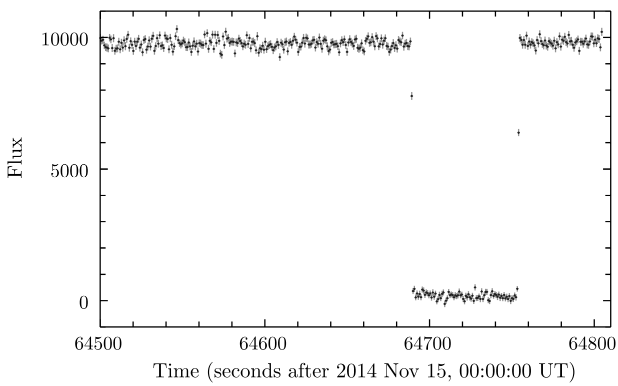


**Figure 2.** The light-curve of the occulted star (RA = + $08^h03^m51.298^s$, Dec = + $09°57'18.729''$) by Trans-Neptunian object 2003AZ84, observed from the TNO on 2014 November 15. The data were taken through a clear filter, with an exposure time of 0.8 s.

confirmation of the non-binarity detection for several sources. Those results have been reported by Richichi *et al.* (2014), Richichi *et al.* (2016), Richichi *et al.* (2017).

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