TYC 0152-00753-1 Duplicity Discovery from Occultation by the Asteroid (392) Wilhelmina

Breno Loureiro Giacchini
Seção de Ocultações, Rede de Astronomia Observacional – REA-Brasil, Belo Horizonte, MG, Brazil
breno@ceamig.org.br

Tony George
International Occultation Timing Association – IOTA, Scottsdale, AZ, USA

Julio Spagnotto
Observatorio El Catalejo (I48), Santa Rosa, La Pampa, Argentina

Aldo Javier Wilberger
Santa Rosa, La Pampa, Argentina

Abstract: During the occultation of TYC 0152-00753-1 by the asteroid (392) Wilhelmina observed on 2018 January 29 in Argentina, evidence of a double star was found – a close component with separation of 3 ± 2 mas, position angle 3 ± 10 deg and magnitude difference of 0.7 ± 0.3.

Introduction

On 2018 January 29 the main belt asteroid (392) Wilhelmina occulted the star TYC 152-00753-1 (UCAC4 461-023559). This event was predicted by Steve Preston on behalf of the International Occultation Timing Association during routine prediction of asteroid occultations of bright stars (Preston, 2018). (392) Wilhelmina has mean diameter D = 60 ± 6 km (Alí-Lagoa *et al*., 2018). According to the JPL Horizon System, at the moment of the occultation its apparent angular diameter was δ = 0.043" and its magnitude was M_{ast} = 14.17. The maximum predicted duration was 7.0 s (see Figure 1 for the predicted trajectory of the shadow and the circumstances of the event).

The star TYC 152-00753-1 (HD 49203) is listed in the Tycho-2 catalog as an 8.46 VT-mag star. The Gaia DR2 catalog (Gaia Collaboration *et al., 2016, 2018)* records this star under the identifier 3126362567994357376, with G-Mag = 8.4265 ± 0.0012. This star is not listed in the Washington Double Star (WDS) catalog, and it was not observed during an occultation before the event reported in the present work (Herald *et al*., 2018).

Observation

The occultation was observed in Argentina in two different sites, in the cities of Alta Italia and General Pico, province of La Pampa. The position of each observing station, the names of the observers and the details of the equipment used are displayed in the Table 1.

In General Pico the observation was carried out with a QHY5L-II-M camera which was set to take a sequence of images with a cycle of 0.1 s and negligible read-out time. The initial time of each exposure was recorded in the header of the FITS images and was calibrated by the software *Dimension4*, which uses a Network Time Protocol. Inspection of the acquired data shows, nonetheless, that there were periods (which could last for up to 2 s) during which no image was recorded; this was possibly caused by a computer memory conflict. Moreover, the times listed in the FITS headers suggest that the cycle was not constant during observation, as the time interval between images could vary by about 20% of the exposure time. In our opinion this apparent irregularity in the cycle does not mean an oscillation in the exposure time itself, as the fluxes of the stars in the field did not vary abnormally during the ob-

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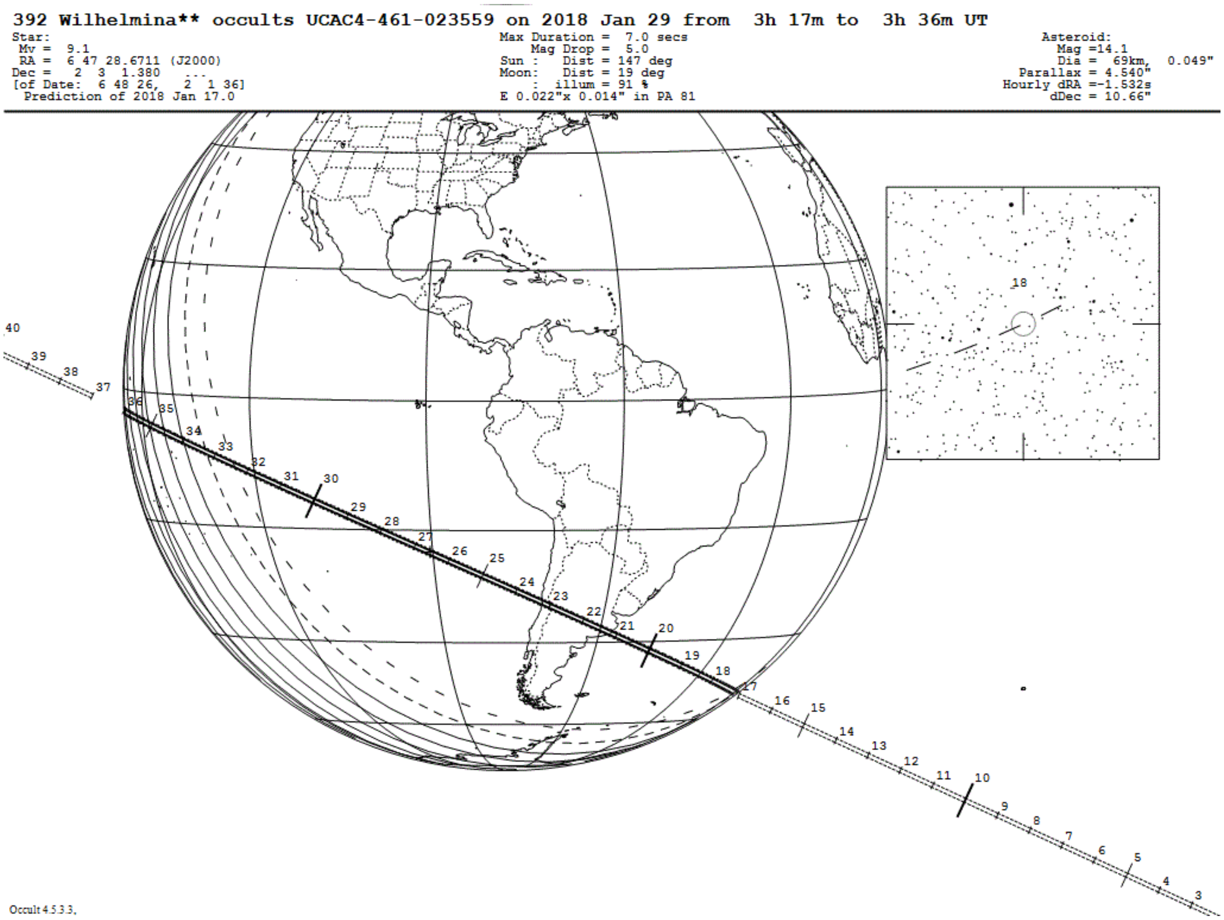

Figure 1: Predicted path and occultation details (Preston, 2018).

servation. Indeed, before the occultation the flux oscillation spans an interval of about 6% of the average flux. Hence, in our analysis we consider that the aforementioned variation in the cycle is due to the synchronization between *Dimension4* and the capture software. Accordingly, we assume an *a priori* uncertainty of 0.02 s on the times reported in the FITS header.

The sequence of images obtained by Wilberger at General Pico was analyzed using the Tangra software (Pavlov, 2018) to produce a light curve (Figure 2). The main feature of the resultant light curve is the presence of two flux drops during the disappearance of the star. The short step event lasted for 0.29 ± 0.02 s and it is evidence of the duplicity of the star. Unfortunately, it was not possible to verify the occurrence of the secondary event during the reappearance, inasmuch as it happened during a gap of 2.17 s when no image was taken (see Figure 2), a result of the aforementioned memory conflict. It is also important to point out that the remaining flux when both stars were occulted is compatible to a

Table 1: Observation sites, observers and equipment

Site	Longitude Latitude Elevation	Telescope: aperture, type, *f*-ratio Camera Observing method	Observer
General Pico	63°44'34.2" W 35°40'01.2" S 141 m	20 cm, Newtonian, *f*/5 QHY5L-II-M Sequential images	A. J. Wilberger
Alta Italia	64°06'53.0" W 35°19'57.0" S 167 m	20 cm, Newtonian, *f*/5 Meade DSI I CCD drift-scan	J. Spagnotto

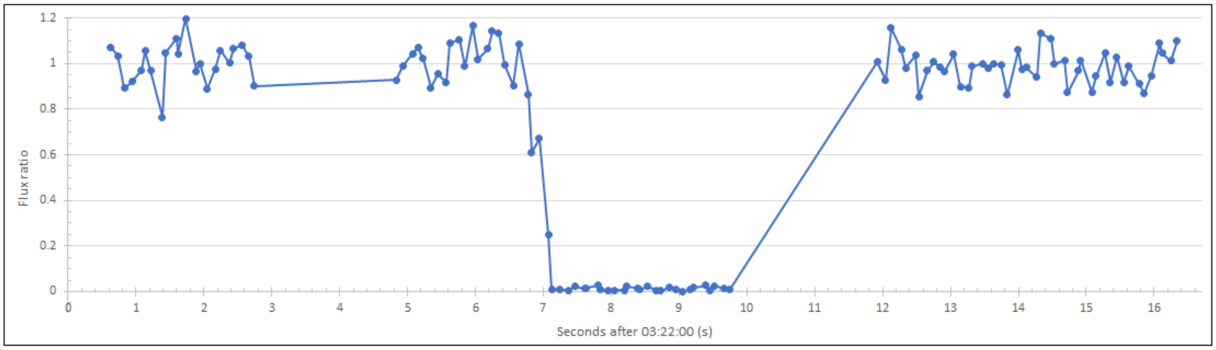

Figure 2. Combined star plus asteroid light curve after 03:22:00, in General Pico. The light curve was normalized to the average flux corresponding to the period in which both stars were visible.

magnitude variation of 5 ± 2 with respect to the initial (combined) magnitude, in agreement to the predicted variation.

Observation at Alta Italia was carried out by the drift-scan technique. A single exposure of 40 s was taken, during which the target drifted through the field since the clock-driven mechanism had been turned off. The light curve resultant from the drift-scan image obtained by Spagnotto is depicted in Figure 3. It is, actually, an intensity profile, from which the background average before and after the occultation has been subtracted. From the flux during the occultation it follows that the presence of a non-occulted companion at most 3 magnitudes fainter is ruled out. In addition, the profile shows no clear evidence of a secondary event. However, the variation of flux for each event was gradual, spanning about 7 pixels and yielding a smooth profile. This feature is typical in this technique and it is consequence of the smearing of the star light among more than one pixel. The effect of this moving distribution of flux, when suddenly switched off due to the occultation, is a smooth pattern, like the one in Figure 3. A secondary occultation event would be easily detectable in the "light curve" if it happened with a large separation with respect to the time scale associated to this smooth flux drop. On the other hand, if the step event is very short, then its signature may be hidden in this gradual variation. In particular, for the event under discussion the velocity of the star in the field was 9.78 pixel/s, which means that a secondary event of 0.3 s – like the one observed in General Pico – would increase the gradual dimming of the star by about 3 pixels, which may have been in the limit of detectability. During the disappearance one can note that there are two consecutive pixels with a somewhat similar flux, which may indicate a very short step event. The reappearance occurred more smoothly, which could be justified by an even shorter step.

The times of the contacts in both light curves were determined with the R-OTE software (Anderson, 2013) and the results are displayed in Table 2. Since the first star occulted is fainter than the second one, we identify them by the labels B and A, respectively.

Double star analysis

From the two flux drops h_1 and h_2 in the light curve obtained in General Pico it is possible to determine the difference of magnitude between the stars, which is given by

$$\Delta mag = 2.5 \log_{10} (h_1/h_2).$$

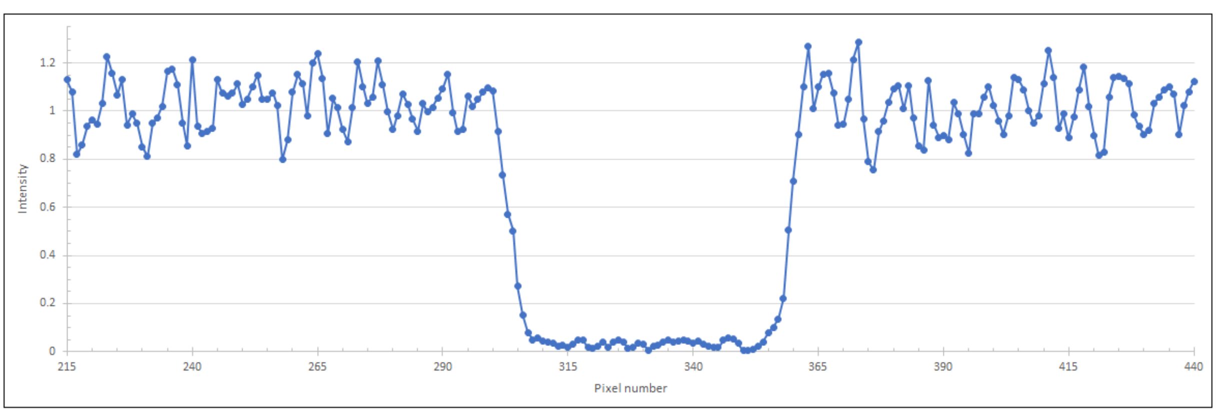

Figure 3: Normalized intensity profile from the drift-scan image in Alta Italia.

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Table 2. Times of the Observed Events.

Event	Time (UT)	
	General Pico	Alta Italia
Start of observation	$03^h18^m00^s.28$	$03^h21^m51^s.0 \pm 0.5$ s
Star B disappears	$03^h22^m06^s.82 \pm 0.02$ s	$03^h22^m09^s.4 \pm 0.5$ s
Star A disappears	$03^h22^m07^s.11 \pm 0.02$ s	
Stars A and B reappear	$03^h22^m11^s \pm 1$ s	$03^h22^m14^s.9 \pm 0.5$ s
End of observation	$03^h28^m00^s.40$	$03^h22^m31^s.0 \pm 0.5$ s

Here h_1 refers to drop caused by the first occultation and h_2 is related to the second one. It is clear that the fainter star was occulted first, as $h_1 < h_2$. It follows that the magnitude difference of the observed pair is $\Delta mag = 0.7 \pm 0.3$. Hence, considering the combined G-magnitude 8.4265 ± 0.0012 (Gaia DR2 catalog), which is similar to the visual magnitude, it follows that $M_A = 8.9 \pm 0.2$ and $M_B = 9.6 \pm 0.2$.

For the derivation of the position angle and separation we applied the method discussed in (Herald et al., 2010) and used the software Occult, version 4.6.5.1 (Herald, 2019). A solution for the asteroid elliptical profile at the moment of the occultation and the double star is defined by seven parameters. Since the images obtained in Alta Italia suggest that the secondary star was occulted in this station too, and in view of the discussion in the preceding section, we can set the events for the B star as occurring almost simultaneously to the A component, with a relative uncertainty of 0.15 s. Therefore, the four chords determine eight points in the celestial plane, allowing a single best-fit solution for the free parameters.

However, as the uncertainty in the reappearances in General Pico are very large, we omitted one of the points in the process of finding the best-fit solution, which is depicted in the Figure 4a. It turns out that there is a huge uncertainty especially for the parameters of the asteroid, because of the small number of chords and the large time error bars. In fact, we recall that with only two chords by the same star it is not even possible to find a unique solution to an elliptical profile.

For the above reason, in order to derive the uncertainties, we also considered solutions constrained by the oblateness of the ellipse, in view of the fact that rotation curves for (392) Wilhelmina suggest that this asteroid might have an apparent oblateness of at most 0.52, assuming an elliptical profile (Herald, 2019). Then, by varying the double star parameters and those of the asteroid, subjected by the maximum axis ratio constraint, we derived the parameters and uncertainties presented in Table 3. Some of the possible solutions are depicted in the Figure 4. It is possible to verify that more oblate solutions yield a pair with larger separation (Figure 4b) and smaller position angle (PA). On the other hand, less oblate solutions are compatible with small separations and larger PA (Figure 4c).

In what concerns the asteroid solutions, we point out that the uncertainties for the major axis and orientation are not symmetric. For the former, its lower bound is set by the length of the largest chord (Alta Italia), which is equivalent to 56 ± 3 km. For the latter, the decrease of the ellipse's position angle can only be accounted for by increasing its oblateness, hence the lower bound comes from the constraint $\varepsilon < 0.52$, where the apparent oblateness ε is defined by

$$\varepsilon = 1 - b/a,$$

with a and b being, respectively, the apparent major and minor axis.

Conclusions

The results of the occultation of TYC 0152-00753-1 by the asteroid (392) Wilhelmina on 2018 January 29 presented in this work suggest that this star is a close

Table 3: Results of limb and double star fitting to the observed data.

Asteroid parameters			Double star parameters	
Major axis (km)	Minor axis (km)	Orientation (deg)	Separation (mas)	Position angle (deg)
63^{+20}_{-5}	42 ± 11	320^{+30}_{-15}	3 ± 2	3 ± 10

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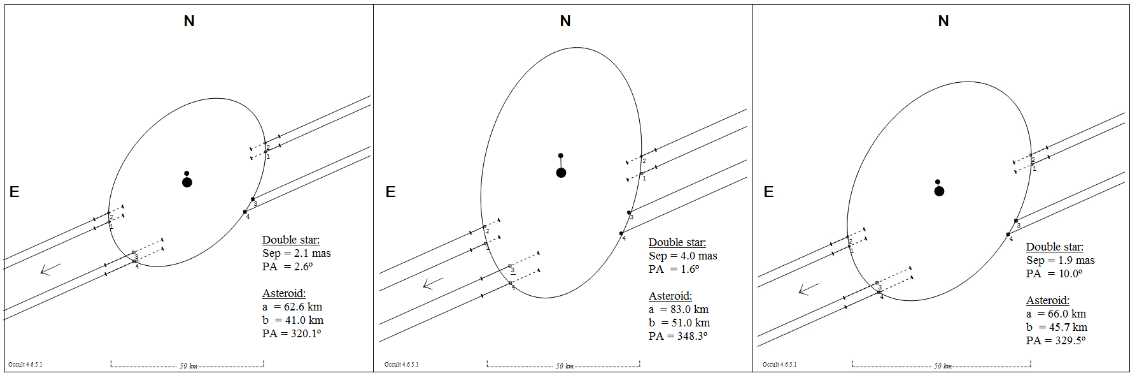

Figure 4. Limb and double star fits for the occultation chords using the times from Table 2. Chords 1 and 2 are from Alta Italia, and 3 and 4 from General Pico. The arrows indicate the direction of motion. 4a: Best fit for the asteroid and double star.

double, with separation on the order of only a few milliarcseconds. Based on the data presented in this work, the double star characteristics of the pair is:

- Star Tycho-2 0152-00753-1.
- UCAC4 461-023559.
- Gaia DR2 3126362567994357376.
- Coordinates (J2000) [Gaia DR2].
  RA 06h47m28.669s Dec +02º03'01.365"
- V-Mag A 8.9 ± 0.2.
- V-Mag B 9.6 ± 0.2.
- Separation 3 ± 2 mas.
- Position Angle 3 ± 10 deg.

Acknowledgements

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