CCD Photometry of the occultation of star TYC 2521-00170-1 (UCAC4 631-047700) by asteroid (814) Tauris on March 19, 2018 UT

By Tony George, Joe Garlitz and Allan Morton

Abstract

We present a double positive CCD observation and data reduction results of the occultation of star TYC 2521-00170-1 (Vmag = 9.04) by asteroid (814) Tauris (Vmag = 14.4) on March 19, 2018 UT. The observation was made at Elgin, Oregon USA. A miss observation occurred in Rexburg, Idaho USA. Possible interpretations of the double positive are: separated binary asteroid; contact binary asteroid with observation chord over gap, or asteroid with large-deep crater. The complete disappearance of the star during both positive occultations precludes possibility that a double star was occulted. Further observation of this asteroid is recommended to determine the source of the double positive.

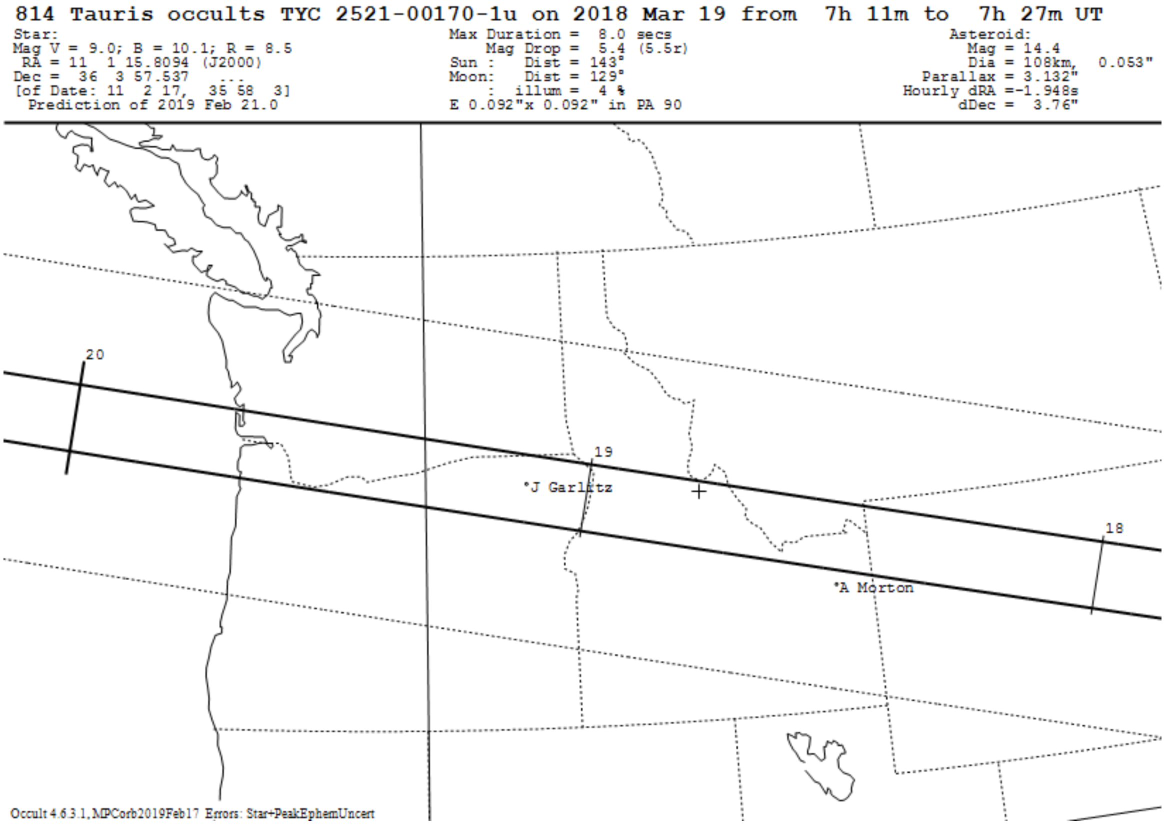
1. Introduction

In observing asteroidal occultations, the most common method is to capture the event by video using sensitive low-light video cameras. However, there are two methods of recording an asteroid occultation event using an astronomical grade CCD camera. The first is using a high cadence series of images analogous to a video recording. The second method is known as a drift scan, wherein, just prior to the predicted event, the telescope tracking is stopped, and the CCD camera shutter is opened. The field stars and the target star are thus recorded as streak trails as they cross the field of view at the sidereal rate due to the earth's rotation. The timing for opening the shutter and closing the shutter are precisely measured. The shutter timing and the sidereal rate of stars drifting across the field provides the information needed to calculate the occultation parameters. This observation of the March 19, 2018 occultation by (814) Tauris as presented here was by the drift scan method.

2. Prediction of Occultation by 814 Tauris

The prediction data we used for the observation was published by Steve Preston.[1] . The occultation was predicted to occur on March 19, 2018 with a local time predicted at 07:19:08. The star, TYC 2521-00170-1, V magnitude at 9.04, and the asteroid (814) Tauris, V magnitude of 14.4 gave a predicted combined V magnitude of 9.03. The predicted V magnitude drop was 5.37. The event sky elevation was at 80 degrees and the azimuth was 195 degrees, very favorable for measuring this occultation. The probability of the event occurring at the observer's location was 74.9%, with a maximum occultation duration of 8.1 seconds. **See Figure 1**, a path map for details of this event generated by Occult4 [2].

Figure 1



3. Location and Equipment

The double positive observation of the Tauris event was made by Joe Garlitz at Elgin, Oregon USA located at Latitude 45:34:22.33 North and -117:55:15.7 Longitude at elevation of 810 meters. The telescope was a standard Newtonian with an aperture of 30.5 cm and a focal length of 152 cm. The CCD camera used was an SBIG ST402 which uses a Kodak KAF-0402ME chip having a 756 x 510 array of 9.0-micron pixels.

4. Method of Observation

The drift scan procedure for recording this occultation was straight forward. The target star was acquired before the event and set to the East edge of the image frame. With the camera shutter closed and knowing the time it takes for the target star to drift halfway across the image field, the telescope tracking was stopped at a time just prior to this amount (32 seconds before the predicted center of the event). Immediately after stopping the tracking the shutter was opened for a timed 60 second exposure. Finally, at a time just before the star would drift out of the camera frame, the shutter was closed. The CCD image recorded the trail of the target and field stars as they drifted across the camera field of view. The beginning of the trail was marked by the timing of the shutter opening and the end of the trail was marked by the closing of the shutter.

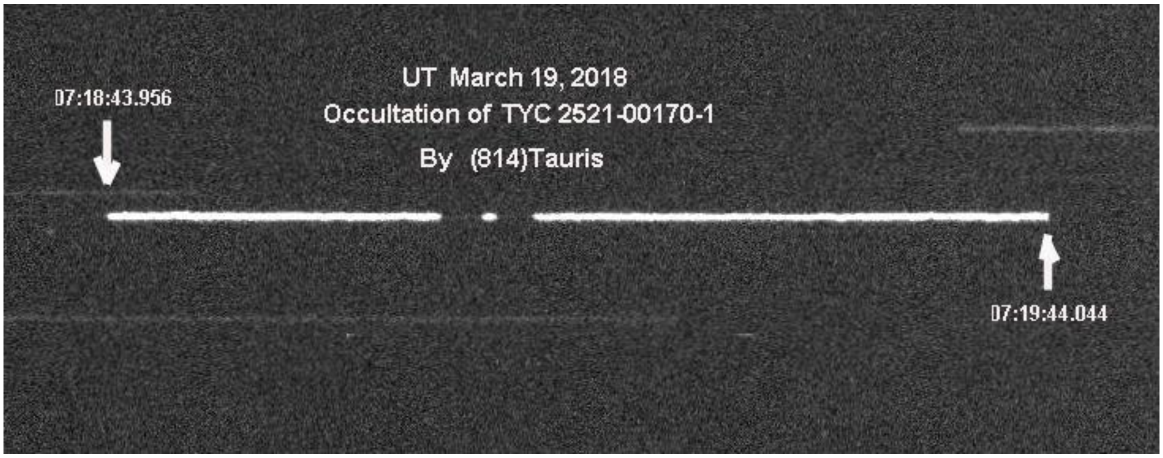
5. Timing

Timing of the shutter operation was made using a Garmin 18xusb GPS unit through an add-in feature for the SBIG CCDOps5 camera software. The camera software used the GPS timing signal to precisely mark the shutter opening and closing. The shutter operation times were recorded in the image fits header. Measuring the length of the drift trail in pixels and dividing this length by the time between the shutter opening and closing calibrates the drift trail in pixels per second and conversely seconds per pixel. The time at which the shutter opened marks the absolute UT time of the start of the drift trail. This provided the timing reference for the measurement of the occulted star drift scan trail.

6. Data Processing and Reduction:

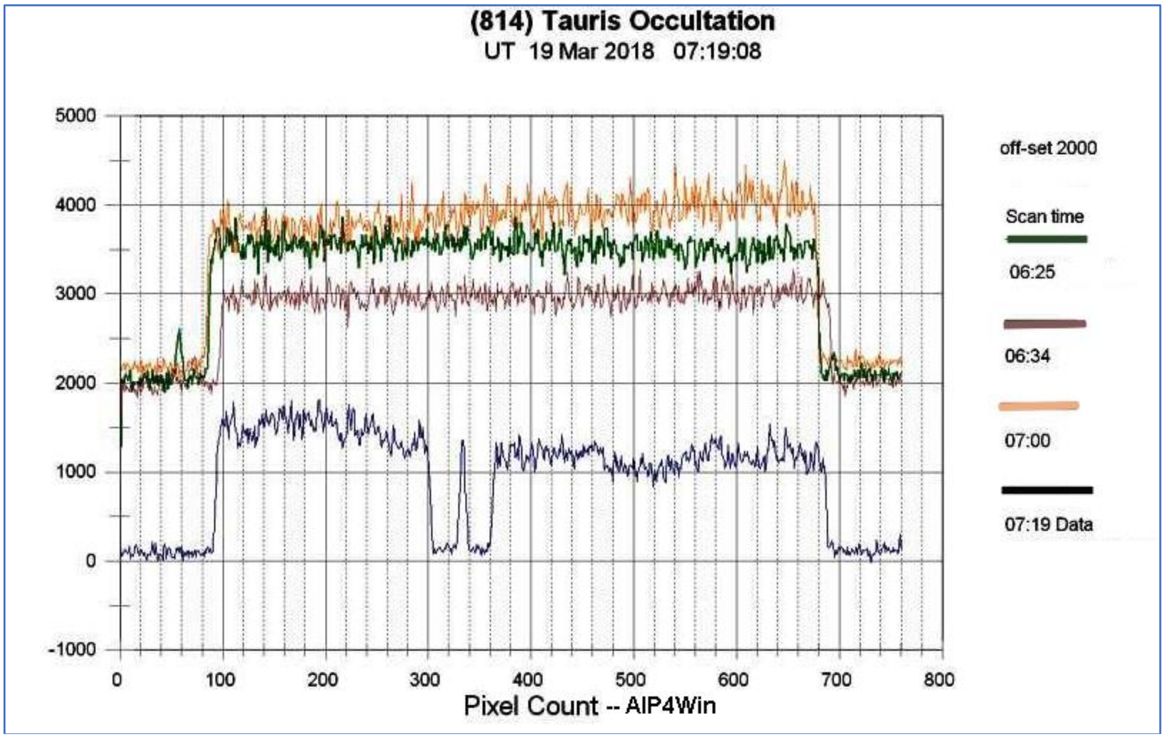
The event data consisted of a single CCD image; see **Figure 2.** The image was dark and flat field calibrated and the precise times of the camera shutter opening and closing were read from the fits header of the image.

Figure 2



The length of the star's drift trail was then measured in pixels and the brightness of the trail along its length was measured using the spectroscopy tool in AIP4Win[3]. A drift trail and a star's spectrum are analogous linear light traces. As a result the AIP4Win tool works as well for measuring the brightness variations of the drift trail as it does for measuring a spectrum. The measured "spectrum" file was saved as a .csv file for analysis; see **Figure 3.**

Figure 3



The original .csv file was not in a format that could be analyzed with occulation timing analysis tools, so the data was transcribed into a .csv format normally produced by Limovie [4] The Limovie format .csv file was then analyzed using R-OTE[5]. ROTE is only capable of analyzing one 'event' at a time. So the light curve was split into two segments, with one 'event' in each segment. The AIP4Win analysis of the drift trail creates multiple data points in the disappearance (D) and reappearance (R). This is normal for a drift scan analysis. For each segment, ROTE fitted a square wave to the light curve using maximum likelihood statistics. The D and R times reported conform to the point in the transition that represents the 50% brightness level. Error bars were generated using a Monte Carlo analysis of a synthetic square wave, with noise equivalent to the event added. The light curves analyzed on ROTE are shown in **Figure 4** and **Figure 5.**

Figure 4

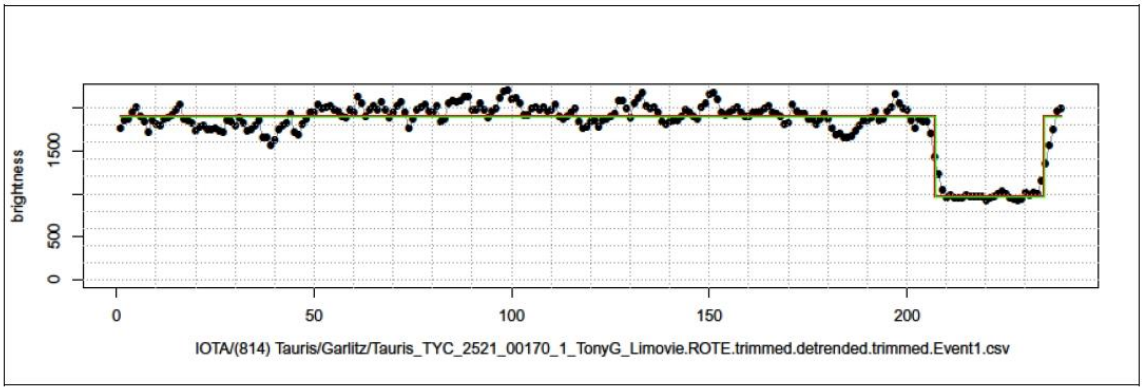
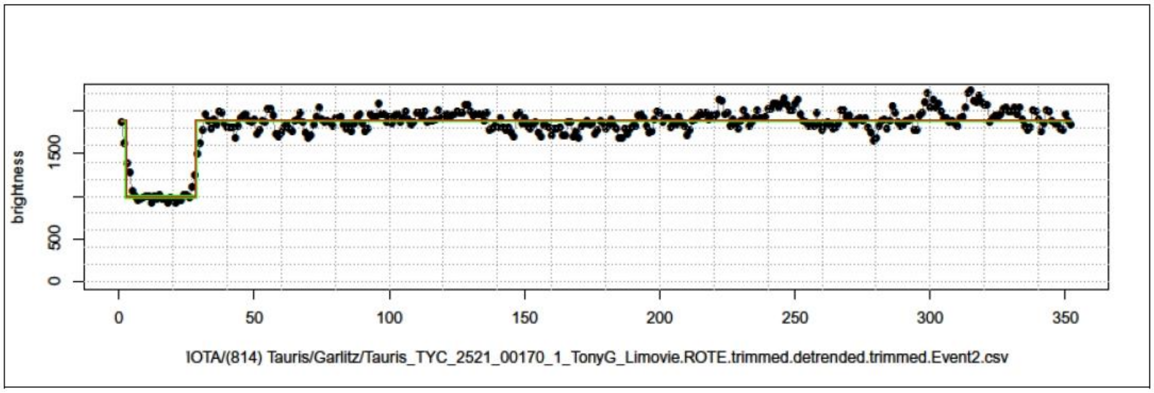


Figure 5



7. Results

The analysis of the event timing was made by Tony George using ROTE as described. From the time stamp in the header of the FIT file, the UT times for the event, was as follows:

Time UT = 07 18 43.956 [start of exposure, no flux drop]
Time UT = 07 19 44.044 [end of exposure, no flux drop]
The data point rate = 0.1011804 sec per data point.

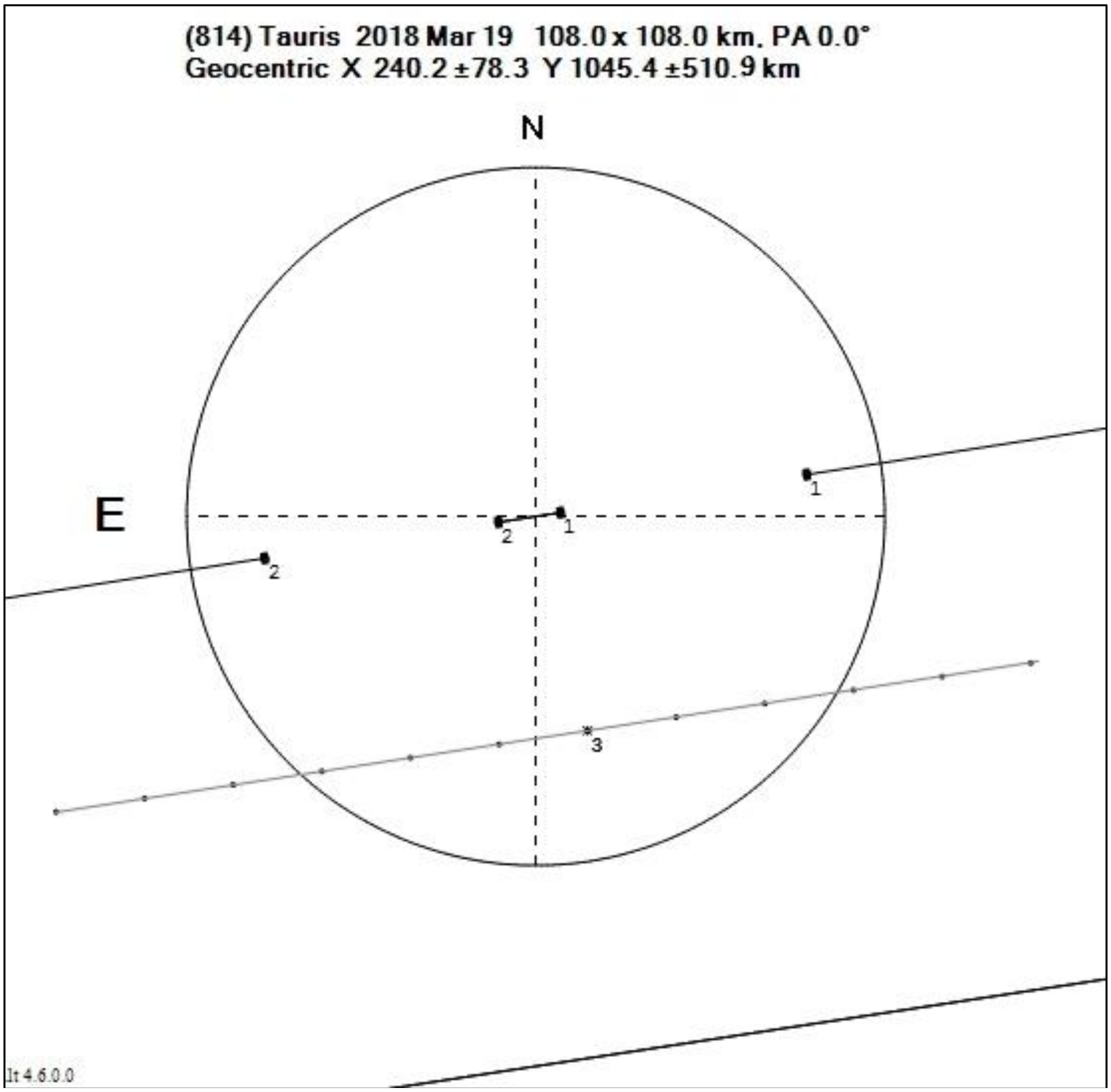
Based on the above timing, the resulting D and R times for both events were:

- First event:
  - D = 07:19:05.065
  - R = 07:19:07.849 +/- 0.02 sec (0.95 confidence level)
  - Measured magnitude drop = 0.73
- Second event:
  - D = 07:19:08.545
  - R = 07:19:11.193 +/- 0.02 sec (0.95 confidence level)
  - Measured magnitude drop = 0.70

[Note: Measured magnitude drop is for comparison of the two events and not for evaluation against the predicted magnitude drop. The measured magnitude drop depends on the subtraction of the background brightness from the light curve, which does not appear to be done in AIP4Win.]

When these observations are plotted in Occult4 on the fundamental plane defined by the apparent position of the star on the equinox of date, and the events are compared to the nominal predicted 108 km diameter of a single asteroid, we get the plot as shown in **Figure 6**.

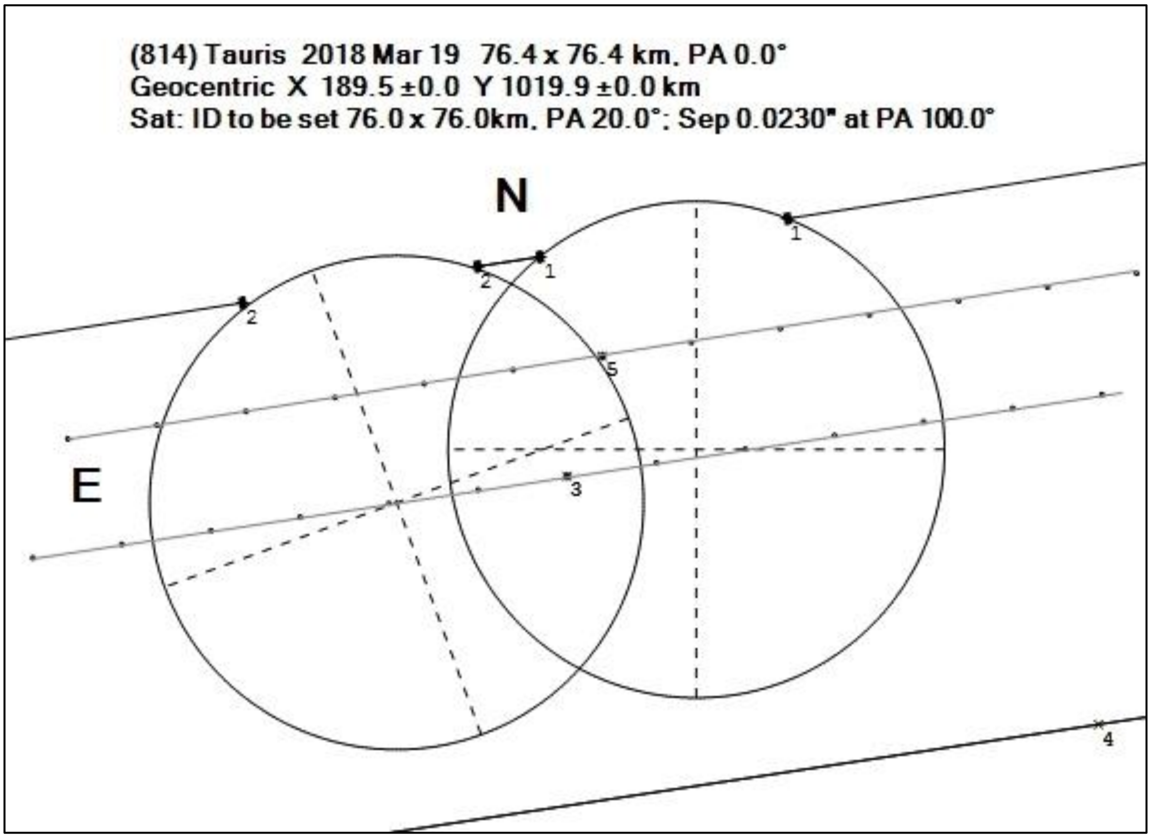
Figure 6



Clearly, neither of the double events on the Garlitz chord characterize the proper size of the asteroid. Also, the ‘miss’ chord of Allan Morton to the south of the Garlitz chord constrains positioning of any grazing event.

The double event can also be characterized by a two-body double asteroid, with one body behind the other in the line of sight. For two bodies to be large enough to create the same surface area as one single asteroid with 108 km diameter, they would have to be 76.36 km in diameter. The resulting two 76 km bodies, when fit to the Garlitz observation would appear as shown in **Figure 7.**

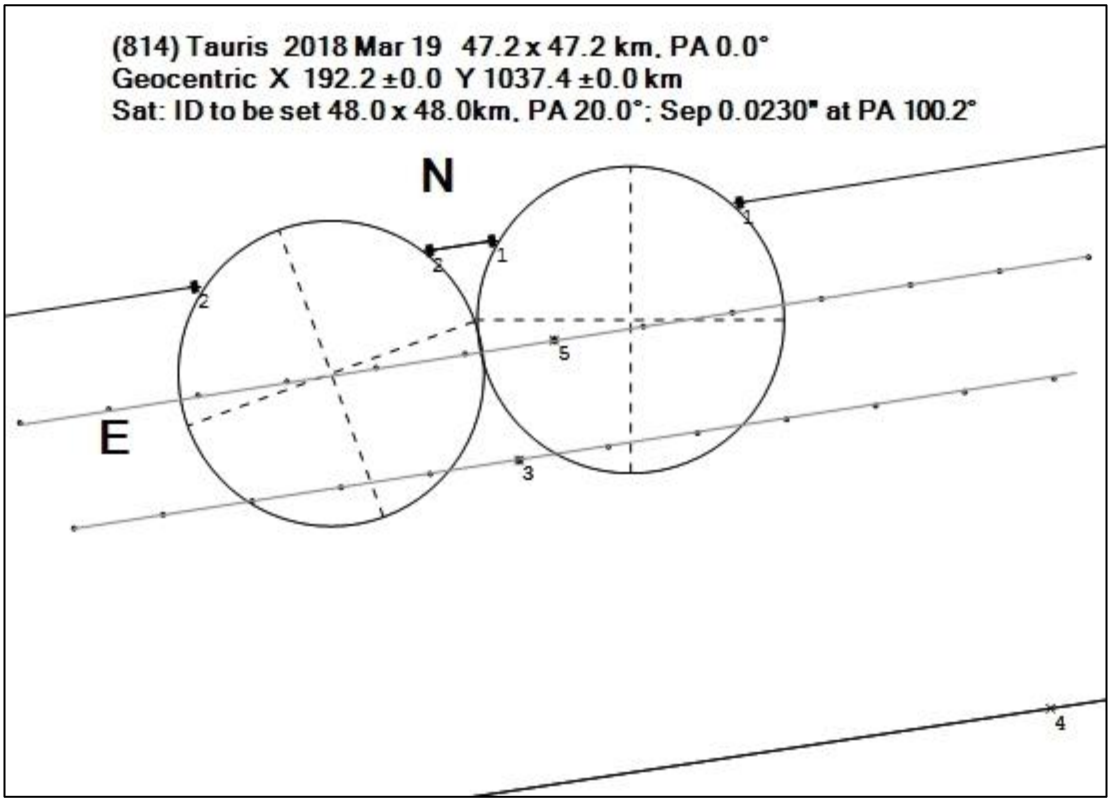
Figure 7



Note that in the two-body solution with one body behind the other, the resulting brightness of the asteroid would be reduced and the measured magnitude drop would be greater than predicted. It is also interesting to note that the area centroid of the two-body system is very close to the original path centerline (Chord 3) as well as an updated path centerline using Gaia star coordinates and updated MPCorb elements (Chord 5).

Another alternative could be a 'contact binary'. A contact binary would have a shape similar to that shown in **Figure 8**.

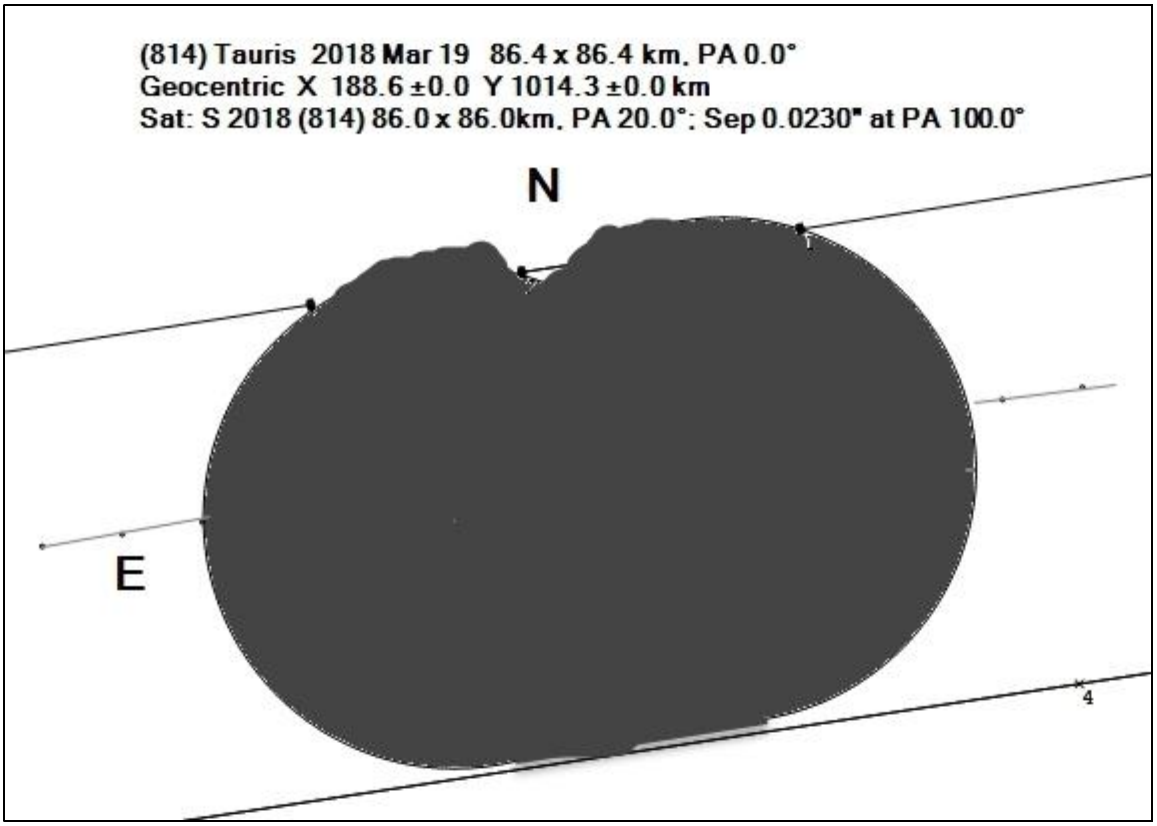
Figure 8



The contact binary solution is unlikely as both objects have a diameter of 47 km. The combined surface area of the contact binary system is 1/2.64 the surface area of a 108 km diameter object. The brightness of this system would be much lower than the 108 km diameter derived from brightness measurements.

The fourth possible explanation for the observed double event is an asteroid with a crater on one side. The plot would look similar to that shown in **Figure 9**.

Figure 9



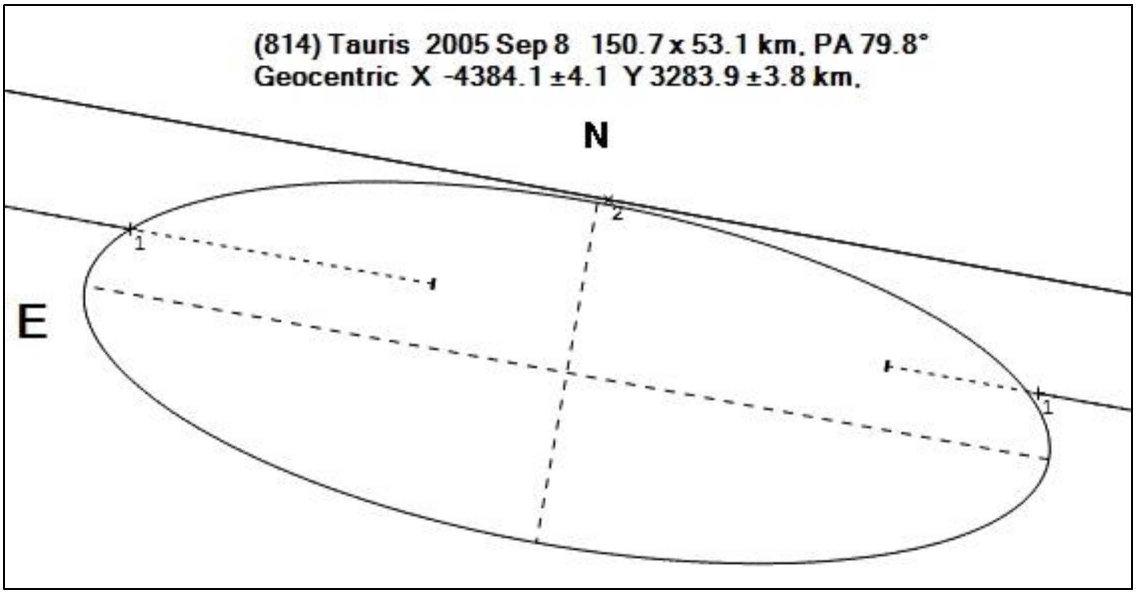
The last possible explanation for a double positive event is for a double star to have been occulted. The double components would have to be nearly equal in brightness for the ‘events to have similar measured magnitude drops. However, because the drift scan light trace shows the complete disappearance of the star during both events, this precludes the possibility that a double star was occulted.

A review of the Occult4 occultation database archive shows that (814) Tauris was observed occulting stars on four other occasions:

1999	12	15	814 Tauris	2	2
2005	9	8	814 Tauris	2	1
2015	7	26	814 Tauris	1	1
2015	7	29	814 Tauris	1	1
2018	3	19	814 Tauris	3	2

Of the four other occultation observations in the IOTA archive, none show any sign of duplicity. Only two of the other observations have multiple chords. One recorded by T Satou and F Kanno on September 8, 2005, with a positive chord and a miss, shows indications that the asteroid is elongated; see **Figure 10**.

Figure 10



The other multi-chord event by R Casas and N Kedzierski on December 15, 1999 has disparate timing results and possible geographic coordinate issues and cannot be used. The other two observations are single-chord events and do not show any sign of double events.

Conclusions

The double event observed by Garlitz coupled with the miss observed by Morton indicates that (814) Tauris is perhaps a double asteroid, contact binary, or asteroid with a large crater in the side. It is not possible to determine which of these alternatives is correct from this single observation. The double positive event was not due to the occultation of a double star. It is recommended that (814) Tauris be flagged for future observation as a possible double asteroid or contact binary. Also, it is recommended that (814) Tauris be flagged for light curve analysis and the development of a shape model.

Acknowledgments

We would like to thank;

Steve Preston for his valuable work in providing timely analysis and prediction of asteroid occultations;

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John Broughton for his clear instructions on using the drift-scan method of timing asteroid occultations and the software tools he has provided to facilitate obtaining and measure asteroid occultations.

End Notes

[1] http://www.asteroidoccultation.com/2018_03/0319_814_54492.htm

[2] Herald, D. Occult4 software, (2015) http://www.lunar-occultations.com/iota/occult4.htm

[3] Berry, R. & Burnell, J.   AIP4Win software.

[4] LIMOVIE, Light Measurement Tool for Occultation Observation using Movie Recorded written by Kazuhisa Miyashita of Japan. It is available for download from: http://www005.upp.so-net.ne.jp/k_miyash/occ02/limovie.html

[5] ROTE – R-Code Occultation Timing Extractor – Presentation at the 2013 Annual IOTA Meeting, October 4-6, 2013; Toronto, Ontario, Canada. http://www.asteroidoccultation.com/observations/NA/2013Meeting/R-OTE%202013%20IOTA%20Conference.pdf