Capturing a rare Occultation Event

A Course Project Report

Submitted by
Aakash Shandilya
215120031

Submitted to
Prof. Varun Bhalerao

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1 Problem Statement

On March 1, 2023, an asteroid named (866) Fatme, which is an 11.2 mag star and 84.4 km in diameter, passed in front of a star in the constellation Virgo. This event caused the combined light of the asteroid and the star to decrease by 4.01 mag to 15.14, which is the magnitude of the asteroid, for 29.680 seconds. We were lucky because the GROWTH India Telescope at Hanle observatory[1] was approximately 26 km from the event centre, which is well within 1 σ error distance. The occultation started at 3:39:51 AM local time and lasted 20±5seconds. We used Photometric Analysis to predict the size of the asteroid. However, since we only had one fixed telescope observing the event and we don't have any other observation data from anywhere else on the Earth, we can only make predictions about the size of the asteroid in the direction it was moving. These types of events are rare and can be helpful in learning about asteroids.

We can use the duration of the occultation to calculate the length of the asteroid. And when several observers record the same event from different positions on Earth, we can also estimate the shape of the asteroid. There are about 400,000 asteroids that we know of, and they range in size from a few hundred kilometers to a few meters. Studying these asteroids can provide us with useful information, which can help us take action if they pose a threat to Earth in the future.

2 Observation

Since the time window of the event was very small, a lot of planning was required. One of the major issues that we could face was that the time window in which the occultation occurs could be missed while observing. We decided that the observations could not be made using the automatic ToO based observations because of the following reasons,

- The exposure time we needed was very small as we needed to make sufficient number of observations in the small 20-30 second time window to make a proper light curve and observe the dip. But reducing the exposure time also reduced the limiting magnitude which could result in it going below the magnitude of our target, and hence we would lose the sight of our target.

- So we decided to reduce the read out time so that we have as long of an exposure time as possible. The first thing we did was to reduce the image size to 1000x1000 pixels instead of the 4000x4000 pixels used in the automatic ToO based observations. But to do this we precisely have to point the telescope at the RA and DEC of the star so the it is at the centre of the sensor. The readout time was further reduced using 4 port readout instead of using the standard single port readout. In single port readout, used in the automatic ToO based observations, all of the charge accumulated in the pixels in the CCD are read out sequentially through a single output channel. Whereas, the CCD is divided into quadrants and the each quadrant is read out separately through a dedicated output channel. This allows for faster readout speeds and higher frame rates compared to single-port readout, as the charge accumulated in the pixels is read out in parallel through four channels. To further reduce the read out time the exposure was taken as Kinetic Series of 150 over a 12 minute window starting at UTC 21:59:28 where a series of 150 small exposures were taken and there was no write operation in between until the whole series is completed. Not doing write operations during the observation saves the time taken in disk operations.

We used the website asteroidoccultation.com to get the approximate time for the occultation event which gave us an hour long window of the complete trajectory over the earth. To get a more precise time window, we checked the minorplanetcenter.net website for the then-current position of asteroid and when it was expected to occult the star. Due to it's very low velocity and the positional precision, we were only able to find a 10 minute long window where we should center our observations. Another thing that we tried was to use cloud.occultwatcher.com website where

Astronomers at different locations could collaborate to make observations and then share their data, unfortunately, no other data could be acquired from there.

At the start of the night, we took flats and bias images in the same 4-port readout mode. The actual observations started at UTC 21:59:28 and a series stacked of images were acquired.

3 Processing and Analysis

3.1 Image Reduction

From the 150 kinetic exposures we took a total of 10 images within which the occultation occurred. We then performed Bias subtraction and flat fielding on the selected images to get the reduced images.

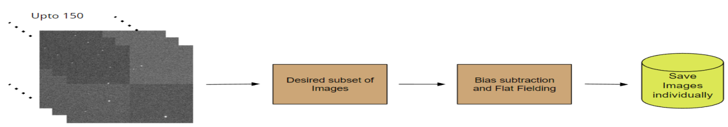

Figure 1: The Image reduction process we followed

3.2 Photometry

There were very less stars in our field of view because the exposure time was very small and also because the image size was too small to record large number of stars. Due to this lack of stars in the image, astrometry could not be performed on it. This meant that we could not calculate the actual magnitude of the star but we only need the dip in magnitude to analyze the occultation, and hence we went for relative photometry. We chose a bright reference star and calculated it's instrumental magnitude and source star's instrumental magnitude using Aperture Photometry Tool. It would be obvious that when the occultation occurs the flux of the source star falls by some amount and the flux from the reference star remains the same throughout. The variability of the Reference star was not taken into account because the time period in which the magnitudes were calculated was of the order of a few minutes.

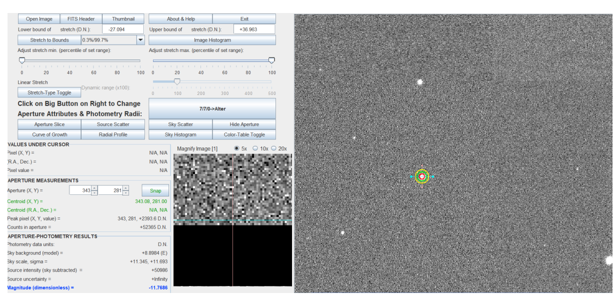

Figure 2: Aperture Photometry tool

4 Calculations

Using data from APT, we plotted the lightcurves for the source and reference star for their instrumental magnitude and then subtracted them to plot another lighcurve showing the mag difference

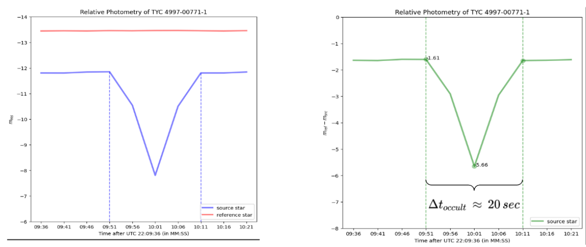

Figure 3: (a) Instrumental magnitude for source star and reference star. (b) magnitude difference of the source star and reference star, i.e. $m_{\text{ref}} - m_{\text{source}}$

From the figure we observe that the lightcurve shows a dip for an interval of 20 seconds. Notice that this interval has an uncertainty equal to our sampling rate which is 5 seconds. Hence the total occultation time is Δt_{occult} = 20sec ± 5sec

$$\left.\begin{array}{l} \text{v}_{\text{ra}} = 0.001\text{''}/\text{sec} \\ \text{v}_{\text{dec}} = 0.001\text{''}/\text{sec} \end{array}\right. \implies v_{\text{net}} = 0.0014\text{''}/\text{sec}$$

$$\Theta_{\text{along}} = v_{\text{net}}\Delta t_{\text{occult}} \quad \implies \Theta_{\text{along}} = 0.0028\text{''} \pm 0.0007\text{''}$$

We know the distance of the asteroid from Earth, which is d = 2.6599 au

$$s_{\text{along}} = d \times \Theta_{\text{along}} \quad \implies s_{\text{along}} = 2.6599\text{au}\,(0.0028\text{''} \pm 0.0007\text{''}) \quad \implies s_{\text{along}} = 54.4\text{km} \pm 13.5\text{km}$$

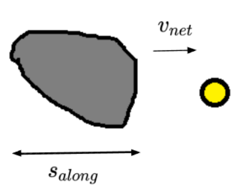

Figure 4: A visual representation of v_{net} and s_{along}

5 Results and Summary

We found out that the length of the asteroid along the direction of travel is 54.4km ± 13.5km, which is very close to the actual maximum measured diameter of this asteroid, 84.4 km. Hence we can say that this measurement was the diameter of the asteroid. All of this was performed using simple photometric analysis.

Usually, these kinds of studies are performed in collaborations so that we have observations from different points on Earth[2], which can then help us determine the actual shape of the asteroid as we will have its various dimensions. But we did not have the opportunity this time. However, we could still infer a lot of given the amount of information we had. The most difficult part of this project was not the analysis of the data and the calculation, but it was the observation. It required a lot of planning as we could not simply use the automatic ToO based observation pipeline. We had to actively collaborate with the team at Hanle to access the Andor application from the Windows PC and then configure it for our specific purposes. We learnt a lot of new methods of observations such as taking images using 4 port readout, using a smaller portion of the sensor and not the entire sensor to capture the image and taking images as a kinetic series and then saving all of them at once in a single fits file. All of this was done just to make sure that we do not decrease the limiting magnitude below asteroids magnitude. Because of very small number of stars in our image we had to locate for the source star manually by comparing the nearby stars to a larger image from the internet that had astrometry done on it.

We realised that these events are covered more often by amateur astronomers with their mobile telescopes. It is also very beneficial if multiple collaborative observations are made as it increases the confidence about the size and shape of the object calculated from the observations.

References

[1] Eric C Bellm, Shrinivas R Kulkarni, Matthew J Graham, Richard Dekany, Roger M Smith, Reed Riddle, Frank J Masci, George Helou, Thomas A Prince, Scott M Adams, et al. The zwicky transient facility: system overview, performance, and first results. *Publications of the Astronomical Society of the Pacific*, 131(995):018002, 2018.

[2] Nicholas Kaiser, Herve Aussel, Barry E Burke, Hans Boesgaard, Ken Chambers, Mark Richard Chun, James N Heasley, Klaus-Werner Hodapp, Bobby Hunt, Robert Jedicke, et al. Pan-starrs: a large synoptic survey telescope array. In *Survey and Other Telescope Technologies and Discoveries*, volume 4836, pages 154–164. SPIE, 2002.