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# Observations of occultation of HIP 66446 by (423) Diotima on 2001 March 15 from India - Detection of a companion to the star

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**Abstract.** Observations of the occultation of the star HIP 66446 by (423) Diotima on 2001 March 15 made by the team at the Vainu Bappu Observatory and three mobile teams at Ganeshgudi, Londa and the CES Field Research Station at Sirsi are presented. We make a preliminary estimate of 186 km × 149 km for the projected size of the asteroid. The immersion and emersion events occurred in two stages revealing the binary nature of the star for the first time. The derived integrated brightness ratio of the stars from the two step immersion and the emersion events is found to be $1.33 \pm 0.27$. The projected separation between the two components along the track, *i.e.* along the direction $115^o$ from North, is found to be 28 km or $0.018 \pm 0.002$ arcsec.

*Keywords* : Asteroid occultation – Diotima – Binary star

## 1. Introduction

Occultation of HIP 66446 (SAO 120035) by (423) Diotima on 2001 March 15, was first predicted by Goffin (2000). The predictions were updated by Federspiel (2001a) using his orbit calculations of the asteroid using 59 astrometric positions by USNO, TMO (solution 1) and 198 positions by CAMC, Bordeaux, USNO, TMO (solution 2). This

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**Table 1.** The star HIP 66446

| $m_v$ | B-V | V-I | Variability | Parallax |
|---|---|---|---|---|
| 8.7405<br>± 0.0016 | 0.463<br>± 0.015 | 0.53<br>± 0.02 | 8.72 – 8.77 | 8.47 mas |

event was considered important as the target star was relatively bright and the occultation track crossed heavily populated areas crossing Malaysia, India, Middle east, S.Italy and S.France. We present here the observations made by the team at the Vainu Bappu Observatory, and the three mobile teams stationed at Ganeshgudi, Londa and at CES Field Research Station at Sirsi. The asteroid (423) Diotima is a C class dark asteroid with a diameter of 209 km from IRAS measurements (Bowell et al. 1979, Tedesco, 1989). Di Martino and Cacciatori (1984) first obtained a rotational period of $4^h.62 \pm 0^h.03$ and an amplitude of $0^m.18 \pm 0^m.01$ for this asteroid. Zellner, Tholen and Tedesco (1985) carried out reflection spectroscopy of Diotima through eight narrow band filters in the wavelength range 0.34Å - 1.04Å and found the spectrum to resemble a typical C type asteroid. The rotation axis and the axes ratio were estimated by Zappala and Di Martino (1986) using the Amplitude-Magnitude method. Their results indicate a/b=1.14 and b/c=1.5, where $a \geq b \geq c$. Dunham and Dywer (2000) used three chords of the occultation event by this asteroid on 2000 January 7 and derived a size of 240 km × 166 km.

Details of the star HIP 66446 according to the Hipparcos and Tycho Catalogues [1] is given in Table 1. No duplicity of this star is recorded.

## 2. Observations

### 2.1 Observations from the Vainu Bappu Observatory (VBO)

The observations at VBO were carried out at the cassegrain focus of the 102 cm reflector using a dry ice cooled Ge As Hamamatsu R943-02 photo multiplier tube and a locally built PC based pulse counting unit (Srinivasan, Nagaraja Naidu, Vasundhara, 1993). The event was also monitored visually at the 8 inch guide telescope. The software was earlier compiled on a PC(286) with a lower version of the operating system and run on the Window based system of a PC(486), as a background job. The timings of the data points had a delay and an uncertainty in the sampling interval because of this mismatch in the operating systems. The delay and the sampling intervals were determined by using the starting and ending times of the observing run and the visual timing of the events. Hence the event timings have an uncertainty of ±0.5 sec. The sky conditions were non photometric and there were unusual fluctuations in the star counts which could be due to malfunctioning of the PMT or due to pick-up in the pulse counting system. The counts

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[1] ESA, 1997, The Hipparcos and Tycho Catalogues, ESA SP-1200,

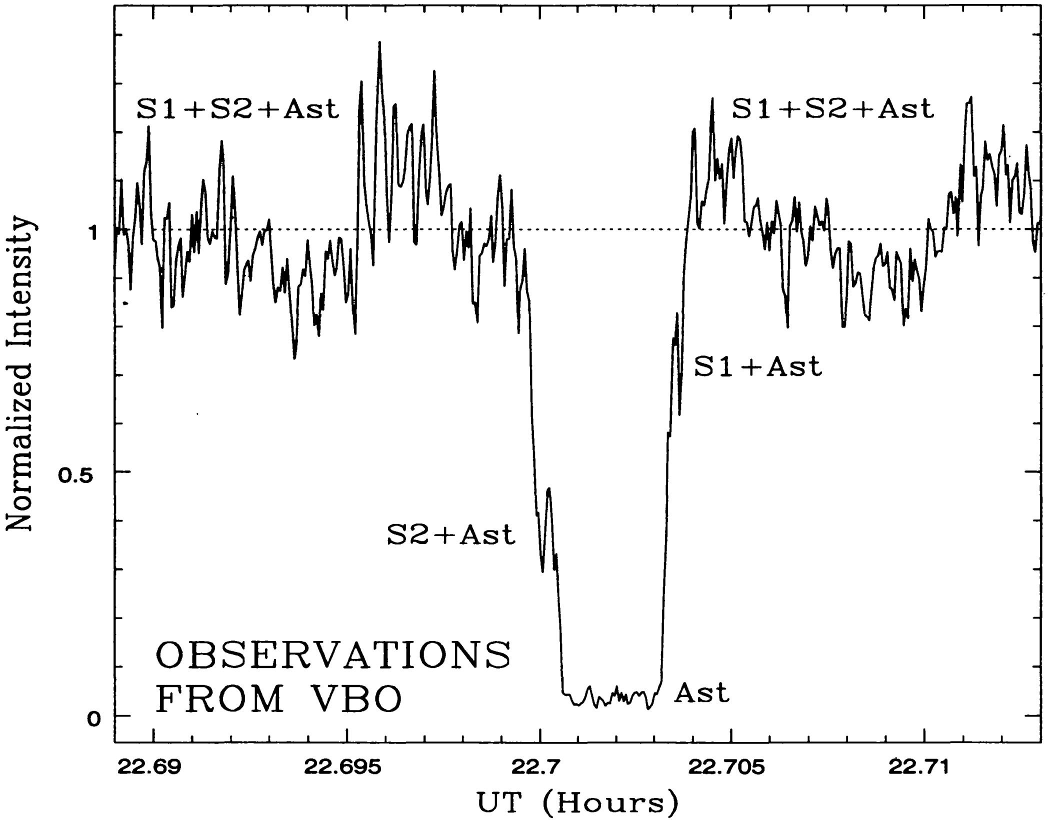

**Figure 1.** Light curve recorded at the 102 cm telescope at VBO. The normalized flux level outside the event, S1, S2, and Ast corresponds to contributions from the components A and B of the star and the asteroid respectively. The brighter component A was occulted first and about 2.8 seconds later, the fainter component B went behind the asteroid. The stars made the reappearance in the same order.

were also found to be low. Hence in order to increase the signal, the observations were carried out in integrated light. In spite of the noisy data, the light curve shown in Fig. 1 clearly shows the occultation dip. The immersion as well as the emersion events occurred in two stages indicating the binary nature of the star.

## 2.2 Observations at Ganeshgudi

The observations at Ganeshgudi were video-recorded using a CCD based web-camera attached to the eye-piece holder of a portable Schmidt-Cassegrain telescope of 14 inch aperture. Prior to the departure from Pune, the computer was synchronized using one of the atomic clock programmes. The computer clock was checked an hour before the event using a GPS clock on site. This time was automatically used for time stamping the video records, which were 20 frames per second. The timings of the event were extracted by redisplaying these frames. As the auto-contrast feature in the software was not disabled, the system was continuously adjusting the contrast of every frame and thus it is difficult to determine the time of disappearance accurately. This could also be due to the fact that the star was double (Section 5). Reappearance was however accurately determined. This mobile observing station was equipped with uninterrupted power supply for 30 minutes and 12 volt car battery to run the telescope. An effort to retrieve the photometric information to construct the light curve from the video frames is in progress.

### 2.3 Visual Observations at the CES Field Research Station

The observations at the CES FRS were carried out using a portable Schmidt-Cassegrain telescope of 8 inch aperture and a focal length of 2000 mm. An eye piece of 40 mm 1.25 barrel was used for visual timing. A stop watch was used to mark the start of the event and the lap button on the stop watch was used to find the duration of the event. The stop watch was stopped at a known time a few minutes later noting the display on the GPS receiver. The star light did not diminish abruptly as one expects in case of occultation of a single star by an atmosphere-less body like an asteroid. The observers instead noticed a gradual fall in light. During emersion, the star re-appeared faster but not instantaneously.

### 2.4 Visual Observations from Londa

This station which is north of Ganeshgudi had a 6 inch telescope. But the thick clouds rolled in just before the event giving no chance to the observers to shift the observing location.

## 3. Computation of the chords

Table 2 gives the longitude, latitude and altitude of the observing stations. The observed times of immersion and emersion are given in columns 4 and 5 respectively. The chords across the asteroid on the sky plane as seen from different stations were calculated using the asteroid positions computed by Federspiel (2001b) and the star positions from the TYCHO2 Catalogues (Høg et al. 2000). Due to paucity of sufficient number of chords, a detailed evaluation of the shape and size of the asteroid is beyond the scope of the present work. We make use of the pole solutions P1 given by $\lambda_0 = 170^o$ and $\beta_0 = 63^o$ and P2 given by $\lambda_0 = 345^o$ and $\beta_0 = 31^o$ derived by Zappala and Di Martino (1986), where $\lambda_0$ and $\beta_0$ are the ecliptic longitude and latitude of the pole direction with respect to the equinox of 1950. The projected pole directions of P1 and P2 on the sky plane are

**Table 2.** Geographic location of the sites and observed timings for the first component

| Site | Longitude Latitude | Altitude meters | Immersion UT | Emersion UT | Comments |
|---|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) | (6) |
| VBO | 78° 49′.33 E<br>12° 34′.64 N | 725 | 22 41 59.2 | 22 42 16.0 | Visual Timings[1]<br>±0.5 s |
| Ganeshgudi | 74° 31′.789 E<br>15° 17′.158 N | 600 | 22 42 48.55 | 22 43 04.95 | Extracted from video frames[2] |
| CES FRS | 74° 50′.618 E<br>14° 37′.959 N | 616 | 22 42 45.09 | 22 43 01.24 | Visual Timings[3]<br>$\pm(\Delta T/2)$ |
| Londa | 74° 29′.127 E<br>15° 26′.745 N | 620 | Clouded | out | Visual |

1. Used GPS display
2. As the auto-contrast of the CCD camera was not disabled, there may be uncertainty in the time of Immersion. The time of Emersion should be precise to 0.05 s.
3. $\Delta T$ = 2.8s =average separation between events of the two stellar components.

shown along OP1 and OP2 in Fig. 2. These directions were calculated using equations by (Rhode and Sinclair 1992). The fitted elliptical projection of the asteroid was obtained by visually examining the best fitting ellipse by considering P1 or P2 as the possible short axes (Zappala and Di Martino 1981) and by adjusting the 1) length of the long axis, 2) projected ratio of long to short axes of the asteroid and 3) an along the track shift of the asteroid position. This shift along the track is to account for the residual correction of the asteroid's orbital longitude or the component of the error in the star's position along the track. Correction for the error in the star's position in the lateral direction or error in the orbital latitude of the asteroid is much more difficult to determine as it requires several chords distributed North and South of the track. Due to limited number of chords, a least square solution was not attempted. Such an analysis can best be made by combining all the available data covering a wide number of sites across the occultation track. Using the present data set it is found that the pole solution P2 (Zappala and Di Martino 1986), appear to give a better fit to the fitted outline of the asteroid compared to their P1 solution. We make a preliminary estimate of 180 km × 153 km for the projected size of the asteroid. The centre of the asteroid had to be shifted 26 km along the track towards East in order to obtain the fit. This indicates a delay of 2.5 sec in the observed times compared to the predictions.

## 4. Duplicity of the star

During an asteroid occultation, the starlight undergoes an abrupt fall during immersion and an abrupt recovery at emersion. In the case of a binary asteroid, the star light will recover after occultation by one component and again disappear behind the other

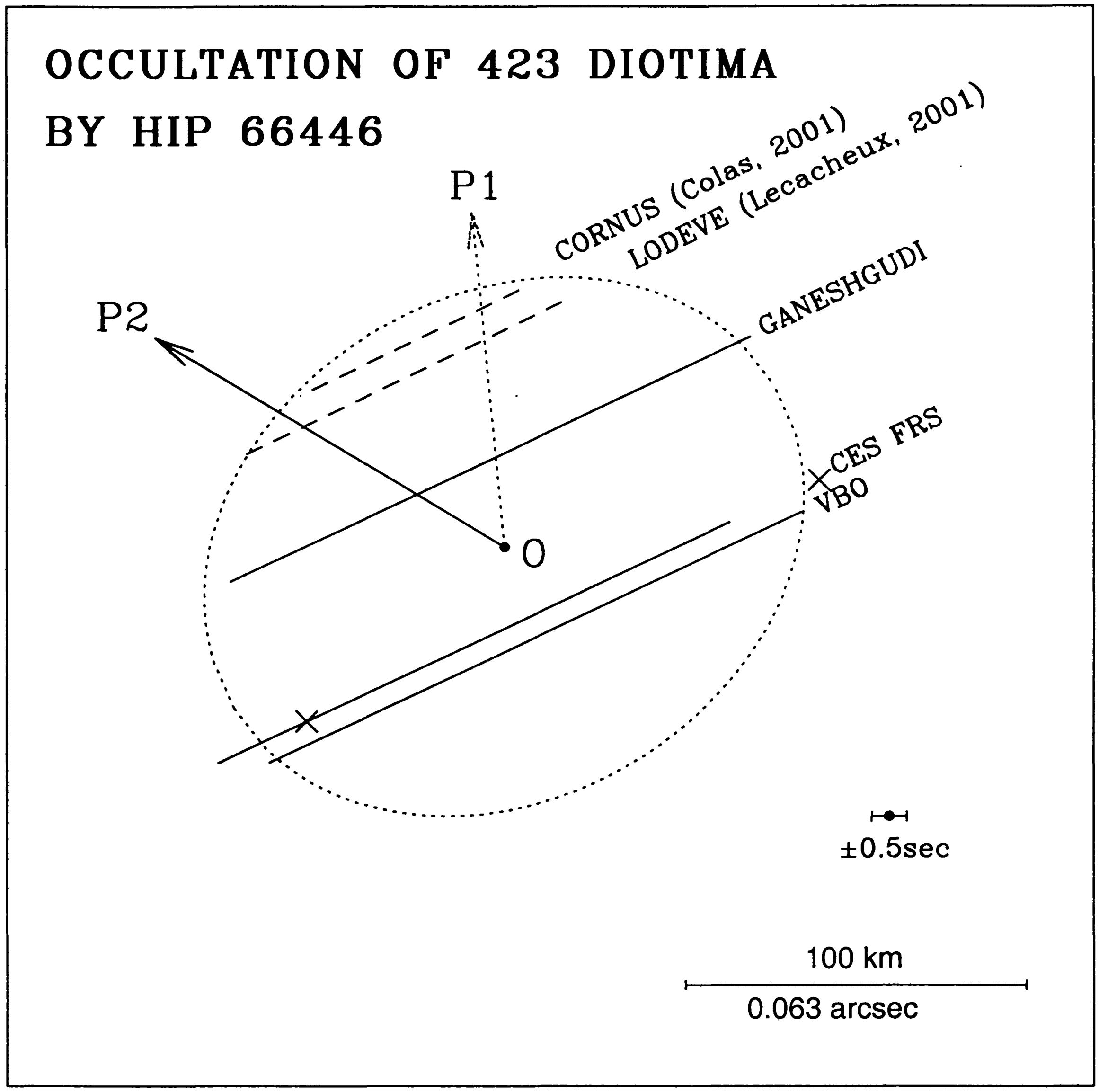

**Figure 2.** Computed chords across the asteroid projected on the sky plane as seen from the three stations (solid lines). The chords (dashed lines) corresponding to the times and durations by Colas (2001) and Lecacheux (2001) from Cornus and Lodeve respectively were also included to obtain the projected shape and orientation of the asteroid. North is up and East to left. The projected directions of the poles P1 and P2 (Zappala and Di Martino 1986) are along OP1 and OP2 respectively. The error in the size estimate of the asteroid of ±5.2 km corresponding to an error in timing of ±0.5 sec is indicated on the right.

component. Two sets of light diminutions of equal magnitude drop (total disappearance) would be expected. In the present case, the visual observers noticed a slow fall during immersion and a rapid (but not abrupt) emersion. Several visual observers from Europe also described the events as 'soft' change or slow change lasting for about 2 sec (Berthier et al., 2001). A possible double star event was therefore suspected. The two stage immersion and emersion events in the light curve from VBO (Fig.1) clearly shows the binary nature of the star. Subsequent spectroscopic observations made with the 'Aurelie' spectrometer at Observatoire de Haute Provence confirmed the binary nature of the star (Berthier et al., 2001) without ambiguity. The eastern component which was occulted first (component A) is found to be brighter than the western component (component B). The brightness ratio in the integrated light is found to be 1.33 ± 0.27. The immersion and emersion timings in Table 2 correspond to the occultation events of component A. The average separation between the events by the two stars of 2.8 sec corresponds to an along the track linear separation of 28 km or 0.018 ± 0.002 arcsec.

## 5. Results and discussions

Unlike occultation of a single star by an asteroid where the immersion and emersion timings can be determined without ambiguity, in the present case, visual determination of the start and end of the event was complicated due to the double steps. The light curve of Fig. 1 and the sky plane positions in Fig. 2 helped in identifying the CES FRS immersion time to correspond to the component B instead of A. Similarly, the emersion time appears to correspond to the central shorter plateau after component A emerged and B was behind the asteroid. The positions of the star relative to the asteroid, as seen from this site at immersion and emersion, after applying the corrections are shown as crosses in Fig 2. These appear to agree with the elliptical outline of the asteroid better. For the other data points no shifts were applied. A more detailed analysis like the one being carried out by Berthier et al. (2001), by using all the available chords and the negative observations at the northern and southern limits will help in better constraining the shape and the long axis of the asteroid. The present observations demonstrate the binary nature of the star with a brightness ratio of 1.33 ±0.27 in integrated light.

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