Asteroidal Occultations: The unique case of Regulus

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We show the preliminary results of a mission to Vibo Valentia (Calabria, Italy) to measure the Regulus' occultation by the asteroid 166 Rhodope on October 19, 2005. Asteroidal profile, stellar diameter and orbital definition are discussed showing preliminary “first hand” results made also from other observers across Europe. The accuracy of such observations is enough for measuring relativistic effects in the orbit.

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I. HISTORICAL REVIEW

The importance of stellar occultations in planetary investigation is well known. For example Uranus' occultation of star SAO 158687 made possible the discovery of its planetary rings through the symmetry of secondary occultations with respect to the main one [1].

Asteroidal occultations have been predicted and observed since 1958 [2], but only with the development of ephemerides programs for personal computers the predictions and international coordinated observational campaign of such events become possible. In 2004 an occultation of a first magnitude star has been discovered in calculating ephemerides: the brightest star of Leo, Regulus, was going to be occulted by asteroid 166 Rhodope on October 19, 2005 [3]. Until today only faint stars have been protagonist of such events [4]. Besides the mutual occultations of planets observed by Kepler with his master Michael Maestlin in 1590-1591 (Venus over Mars, and Mars over Jupiter) there are no news of such peculiar observations in the history.

II. PROBABILITY OF A FIRST MAGNITUDE STAR’S ASTEROIDAL OCCULTATION

Due to the small cross section of asteroids and stellar diameters, occultations of first magnitude stars are much more rare than total solar eclipses, and their totality paths are much narrower. For a typical asteroidal radius of 30 km, at a 2 A.U. distance, the angular diameter is 40 arcsec (milli arcseconds), its parallax being 4 arcsec. Considering observation sites spread along the Earth’s diameter an asteroid spans 8 arcsec on the celestial sphere, and its profile covers background stars with an areal velocity of 0.32 arcsec²/s, if the relative orbital velocity is 30 km/s, 10⁴ of such asteroids over the zodiacal band area ~ 10¹² arcsec² (i.e. ~ 12/88 of the whole sky area) in 3.6 · 10⁵ s or 114 years. With ~ 20 first magnitude stars in the zodiacal band, we expect one of such occultations visible on the Earth each 6 years. Next event will be in 2014, again Regulus (which is fairly close to the ecliptic) occulted by 163 Eridrone and visible in North America and in 2023 Betelgeuse will be occulted by 319 Leona on a line from Cuba to Sicily[3]. Those data confirm the previous order-of-magnitude estimate.

III. REGULUS OCCULTATION

Regulus is the brightest star of Leo: a B8 giant rapidly rotating star [5]. It lies almost exactly on the ecliptic. On October 19, 2005 at the moment of the occultation the elongation from the Sun was 36°. Assuming Earth and Asteroid on circular orbits on the same plane, the vectorial composition of orbital velocities yield a relative motion of Rhodope with speed v⊥ ~ 34 km/s perpendicular to the line of sight (see Fig. 1).

On the ground the velocity of the asteroidal shadow and its shape, which section is cylindrical, depends on the inclination of Earth’s surface with respect to the line of sight Earth-Regulus. Regardless on the shadow dimension, the true section of the asteroid at a given distance from the centerline can be obtained multiplying the time of occultation by the relative velocity of the asteroid perpendicular to the line of sight. From ephemerides [6] the exact value of v⊥ = 29.6 km/s. Knowing the durations of occultations in different sites it is possible to recover the shape of the asteroid.

A. Shape of the asteroid

For assessing the asteroidal shape we need other observations besides our one. We collected video recorded observations from IOTA members (International Occultation Timing Association) available at Euraster website[7] on October 28, 2005 (see table I). Each observation is provided with position and UT synchronization.

Of each observation we calculated the distance from the centerline calculated by Andrej Plekhanov

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FIG. 1: Geometry of solar system with Earth and Rhodope’s orbits

<table>
<thead>
<tr>
<th>Observers</th>
<th>Lat / Long [°]</th>
<th>projected c.l. distance (km)</th>
<th>( t_{\text{occ}} ) (s)/semi-lengths (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>W. Nobel</td>
<td>38.54 / -1.85</td>
<td>8.09 S</td>
<td>1.94 ± 0.04 / 28.72 ± 0.59</td>
</tr>
<tr>
<td>C. Sigismendi</td>
<td>38.68 / 16.10</td>
<td>8.80 S</td>
<td>1.96 ± 0.04/29.02 ± 0.59</td>
</tr>
<tr>
<td>D. Tröse &amp; D. Montagnese</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R. Guscalves</td>
<td>37.92 / -8.24</td>
<td>28.83 S</td>
<td>0.96 ± 0.04/14.15 ± 0.50</td>
</tr>
<tr>
<td>A. Ayiosanitis</td>
<td>38.30 / 23.74</td>
<td>8.29 S</td>
<td>1.95 ± 0.05/28.88 ± 0.74</td>
</tr>
<tr>
<td>D. Dunham</td>
<td>38.06 / -6.24</td>
<td>30.27 S</td>
<td>0.50 ± 0.1/7.37 ± 1.48</td>
</tr>
<tr>
<td>O. Farago</td>
<td>38.50 / -3.50</td>
<td>3.48 S</td>
<td>2.02 ± 0.02 / 29.83 ± 0.30</td>
</tr>
<tr>
<td>D. Nye</td>
<td>38.17 / -8.49</td>
<td>2.29 S</td>
<td>2.03 ± 0.04/29.92 ± 0.59</td>
</tr>
<tr>
<td>D. Dunham</td>
<td>37.96 / -6.23</td>
<td>41.09 S</td>
<td>no occ.</td>
</tr>
<tr>
<td>A. Montesino</td>
<td>38.57 / -5.84</td>
<td>18.71 N</td>
<td>no occ.</td>
</tr>
<tr>
<td>T. L. Gomez (visual)</td>
<td>38.65 / -3.41</td>
<td>10.91 N</td>
<td>0.8 ± 0.2 / 11.81 ± 2.95</td>
</tr>
<tr>
<td>M. Iglesias (visual)</td>
<td>38.62 / -3.68</td>
<td>9.66 N</td>
<td>0.5 ± 0.2 / 7.38 ± 2.95</td>
</tr>
</tbody>
</table>

IV. LIGHT CURVE OF THE EVENT

According to the predictions a duration of 1.09 s was expected with a magnitude drop of 14.1. Fersnel diffraction and stellar diameter effect have to be considered in such a short event. Regulus is an ellipsoidal star[5] of 1 × 2 milli arcsec, with the smaller dimension lying approximately along the ecliptic, i.e. on the asteroidal trajectory.

- **Asteroid angular velocity** A velocity \( v_\perp \sim 30 \text{km/s} \) at 3 AU of distance, implies an angular velocity of 13 mas/1 secr per s. It covers the stellar diameter in 1/13 s, i.e. 2/26 s namely 2 frames at 25 Hz videorecording. We could see only one half illuminated frame, because of the high telecamera noise.

- **Stellar diameter effect** Being occulted in 2 frames, it is possible to perceive in videorecords
the penumbral phase of the occultation, when the total flux towards us is reducing proportionally to the stellar area exposed to us. In our case, the rising phase was more clean than the dropping one, because the star appeared just in that seconds between two clouds. The rising sequence lasts two frames (see the sequence in Figures 3 and 4).

- **Fresnel diffraction** The star is nearly pointlike and at infinite, therefore wavefronts are parallel and each point is a source of spherical waves (according to the Huygens’ principle). In presence of a semi-infinite obstacle, perpendicular to the wavefronts, in the region behind the obstacle there are still zones of positive interference with some amount of light. On a screen posed at distance D behind the obstacle the luminous intensity drops to half of the unobstructed value at 0 lateral distance, and it goes to zero at the Fresnel distance \( d \sim \sqrt{DX} \). After the first zero, there are few other bumps rapidly decreasing with lateral distance. The Fresnel scale \( d \) plays a primary role in case of grazing lunar occultations, when the stellar area is covered by the Moon’s profile in long intervals of time. In these cases the pointlike Fresnel profile has to be convoluted with diameter decrease, yielding a profile much broader than the pointlike source’s case.

V. DATA

Our data show a linear decrease of the luminosity lasted more than 2 frames, as well as the rising part. From them we deduced a duration of 1.96 s for the occultation observed from Vibo Valentia’s site.

FIG. 2: 166 Rhodope preliminary profile plot with zero and northern (N in table 1) visual data. The center of the circle of radius \( r = 29.8 \) km is 2.2 km South of the predicted centerline.

FIG. 3: Some frames from Regulus’ sequence. From frame 38 to 87 we calculated the occultation of 1.96 s. The choice of those frames has been done visually examining the sequence frame per frame.

FIG. 4: Regulus’ frame sequence. The grey scale index has been calculated analyzing the video with The GIMP 2.0 graphic tool. This index ranges from 0 to 255, from black to white.
VI. GENERAL RELATIVITY AND OCCULTATIONS

With asteroidal occultations the maximum exactness of orbital data is possible, thanks to the optimal astrometry for the brightest stars. In this case many measurements allow to fix the orbit up to 1/100 s, i.e. 300 m. An accuracy of 1 part over 10⁹ is possible with the majority of video-recorded observations of this event. Our own data \( t_{\text{occ}} = 4:24:30 \) UT is affected by a rather large uncertainty of \( \pm 1 \) s due to a synchronization procedure with the IEN (Italian National Electrotechnical Institute) website [9].

Perihelion precession is about 1 arcsec per century, for Mars, corresponding to 1 part over 10⁹ of its orbit. The annual change is of 1 part over 10⁸. This consideration is enough to understand the great opportunity given by observing an first magnitude star occultation.

VII. ACKNOWLEDGMENTS

We are grateful to Danilo Montagnese. He has made possible our stay in Vibo Valentia, and gave us every kind of help in preparing and doing that unique observation. Thanks to Vittorio Vannini who helped us with video processing. All observers who have sent they reports to IOTA mailing list are implicitly thanked for their efforts in obtaining such precious data, also them who were clouded. Thanks to Raymond Dusser who indicated us some useful references.

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[4] Dunham, D.
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