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RESEARCH NOTE: THE OCCULTATION OF 1 VULPECULAE BY PALLAS

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RESUMEN

Se presentan y se discuten procedimientos de observación y tiempos de la ocultación de 1 Vulpeculae por el asteroide Palas. La ocultación fue observada utilizando los telescopios de 84- y 150-cm del Observatorio Astronómico Nacional en San Pedro Mártir, B.C. También se presentan cantidades medidas para la binaria espectroscópica 1 Vul, se estiman los errores de observación y se indican prospectos futuros para este tipo de observación.

ABSTRACT

Observing procedures and timings of the occultation of 1 Vulpeculae by the asteroid Pallas, observed with the 150-cm and 84-cm telescopes of the Observatorio Astronómico Nacional at San Pedro Mártir, are given and discussed. Measured quantities for the spectroscopic binary 1 Vul are also presented. Our observing errors are estimated, and prospects for further observations of this type indicated.

Key words: OCCULTATION – ASTEROIDS

On the night of May 29, 1983 occurred a rare astronomical event, the occultation of the bright star 1 Vulpeculae by the second largest asteroid Pallas, that was observed extensively in the southern United States and northern Mexico. This event had been predicted by Taylor (1981), Wasserman, Bowell, and Millis (1981) and by Dunham (1983*a*) and widely publicized by Dunham (1983*a*), Dunham and Maley (1983) and others, leading to the most complete coverage of an asteroidal occultation yet (Dunham 1983*b*).

Precise, coordinated observations of such occultations can provide fundamental information concerning asteroids and concerning the occulted star. First, well-placed observers across the occultation path allow an accurate determination of the shape and diameter of an asteroid, which can be used to check and to calibrate indirect methods for measuring asteroidal diameters, such as the radiometric and polarimetric techniques. Also, a known size plus photometry of the asteroid will give geometric albedoes, or plus a known mass, such as for Pallas, will give the mean density. Albedoes and mean densities are very important for studying compositions and distributions within the asteroid belt.

A previous occultation by Pallas of SAO 85009 (Wasserman *et al.* 1979) had given a mean diameter of 538 ± 12 km, a profile of Pallas which was slightly elliptical, a mean density of 2.8 ± 0.5 g cm^{-3} and a visual geometric albedo of 0.103 ± 0.005. The current occultation will allow a refinement of these values with the measurement of a different profile.

Second, the coordinators of this Pallas occultation placed considerable importance upon the search for satellites of the asteroid. Viewpoints concerning asteroidal satellites vary greatly. Binzel and Van Flandern (1979) conclude that such satellites must be "numerous and commonplace", while Reitsema (1979) urges caution against such a conclusion pointing out that most secondary "occultations" are unconfirmed and can be explained by instrumental or atmospheric effects. However, for Pallas not only do photoelectric and visual observations of three occultation events during the 1970's (Dunham and Maley 1983; Binzel and Van Flandern 1979) provide evidence for a satellite, but also the binary star observers van den Bos and Finsen (reported by Innes 1926) once saw Pallas as a "close double star", and Hege and collaborators (1980*a*, *b*) using speckle interferometry conclude that Pallas has a large secondary approximately 720 km from the main body. Careful, redundant photoelectric observations spaced across an occultation path can give definitive answers concerning asteroidal satellites (Reitsema 1979).

Finally, when the occulted star is a spectroscopic binary, as for 1 Vul, photoelectric observations can provide data concerning the separation, position angle, and difference in magnitude between the components. When many such observations are combined, inaccuracies produced by asteroidal topography average out leading to more precise values for the separation and position angle. Also, high-speed photoelectric measurements may allow the determination of the components' diameters.

Dunham's (1983*a*) first path for the May 29th event showed the San Pedro Mártir observatory to be near the center. A later revised path (Dunham and Maley 1983) placed our observatory near the northern limit where important information concerning the size and northern cap of the asteroid could be obtained.

The 84- and 150-cm telescopes, the 5C and 8C photometers, and the DC amplifiers 4 and 1, respectively, were used for the observations. We decided to make redundant photoelectric observations to confirm any secondary occultations and to avoid confusion in the interpretations as shown in the note of Clark and Milone (1973) for a previous Pallas occultation and as discussed by Reitsema (1979). Obviously, with two telescopes so close together we cannot distinguish spurious secondary "occultations" produced by atmospheric phenomena, but we can recognize instrumental problems.

Both telescopes were well balanced, and the movements carefully adjusted for the extreme eastern position of the occultation. Large (1 cm) diaphrams were used in both photometers, and the finder telescopes were well aligned and used as guide telescopes during the occultation to avoid losing the star. All electronics were adjusted for maximum speed of response. The tube-type D.C. amplifier number 1, which is normally somewhat slow in order to average out sky noise, was reset to give better than a 0.1 s instantaneous response and approximately a 0.7 s response to full signal. The values were obtained prior to the occultation by manually "chopping" the standard lamp of the 8C photometer using its shutter. The transistor D.C. amplifier number 4 was even faster. The chart recorders were used at 20 cm min^{-1}, and the printers at maximum print rate gave approximately 3.6 print s^{-1} at the 84-cm telescope and approximately 3.0 print s^{-1} at the 150-cm. An integration time of 0.1 s, with a dead time of approximately 0.02 s, was used. The printer-clocks were connected to a 60-cycle supply that normally gives better than a 1 s precision over a twelve-hour observing run, and the chart recorders were voltage-regulated to maintain a constant speed of paper advance. *V* filters were used in both photometers, and we attempted to observe 1 Vul for ten minutes both before and after the predicted time of occultation to look for secondary events; however, due to technical problems observations at the 84-cm telescope began only four minutes prior to the occultation.

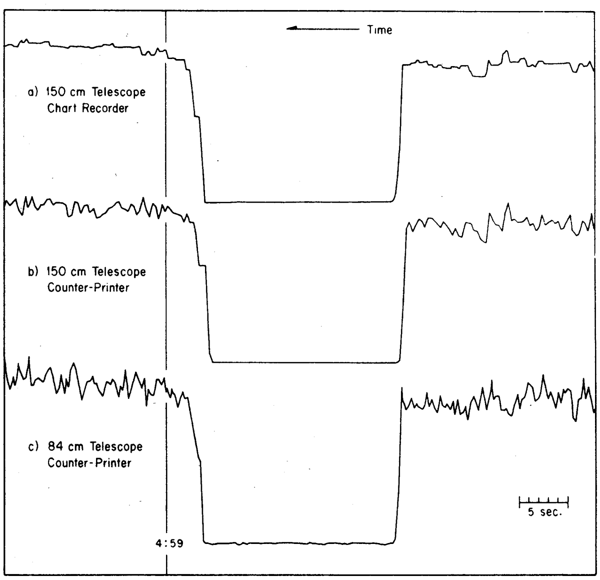

Fig. 1. Part of the photoelectric data for the occultation of May 29, 1983. We were measuring the combined light of 1 Vulpeculae ($V \sim 4.8$) and of Pallas ($V \sim 9.7$), and during the occultation the signal dropped to nearly that of the sky. The counter-printer data has been plotted to the same scale as the chart-recorder data, and 1 s intervals indicated. The time marks for U.T. 4:59:00 are only approximate. a) Chart-recorder data at the 150-cm telescope. b) Counter-printer data at the 150-cm telescope. c) Counter-printer data at the 84-cm telescope.

All clocks were set by ear approximately five hours before the occultation using a strong signal from WWV10. By one hour before the occultation WWV10 had faded considerably; WWV5 was still strong but could only be received at the 84-cm telescope. At the 150-cm telescope the clocks were checked before and after the occultation, and time marks placed on the chart paper using WWV10, when audible, or using a digital watch that was set and checked at the 84-cm telescope.

In Figure 1 we show the response of one chart recorder and both counter-printers to the primary occultation. The counter-printer data have been plotted at the same scale as the chart recorder data. Due to technical problems and lack of practice, the chart recorder at the 84-cm telescope served only for differential timings. In Tables 1 and 2 we give our timings for the occultation, and the positions of the two telescopes involved. The longitudes, latitudes and altitudes are taken from the map "San Rafael H11B45" de la Comisión de Estudios del Territorio Nacional.

No secondary occultations were observed at the San Pedro Mártir Observatory. In addition, no occultations, neither primary nor secondary, were observed at our Tonantzintla Observatory (Latitude = 19° 0.1′57.9″N, Longitude = 6^h 33^m 15.32^s W, Altitude = 2150 ± 20 m) by Barral and Costero (1983) using the 1-m telescope and the fast photometer with a *V* filter and a 2.0 mm diaphragm. Barral and Costero observed from 4:56:44 to 5:18:04 U.T. and did not expect to record the primary occultation, Tonantzintla being far south of the predicted path. However, Tonantzintla did lie well within the path of Pallas' sphere of gravitational influence, and so secondary occultations due to satellites of Pallas were a distinct possibility.

At San Pedro Mártir, for both telescopes and within the response of our electronics both stars of the spectroscopic binary 1 Vul disappeared simultaneously and instantaneously at the beginning of the occultation. The

TABLE 1

TIMINGS OF THE OCCULTATION MAY 29, 1983[a]

	Chart Recorder	Counter-Printer
150-cm Telescope; Observing Interval 4:48:00 to 5:08:00 U.T.		
Beginning	4:58:33.83 ± 0.22 s U.T.	4:58:33.89 ± 0.23 s U.T.
Duration (brighter star)	21.34 ± 0.10 s	21.21 ± 0.10 s
Duration (fainter star)	22.41 ± 0.10 s	22.33 ± 0.10 s
84-cm Telescope; Observing Interval 4:54:33 to 5:08:00 U.T.		
Beginning	...	4:58:34.72 ± 0.20 s U.T.
Duration (brighter star)	21.39 ± 0.10 s	21.30 ± 0.10 s
Duration	...	21.53 ± 0.20 s to 22.78 ± 0.32 s (gradual reappearance of fainter star)

a. By "beginning" we mean the simultanous disappearance of both stellar components.

TABLE 2

POSITIONS OF THE TELESCOPES

Latitude	Longitude	Altitude[a] (m)
150-cm Telescope		
31° 02′ 40.8″ N	115° 28′ 0.3″ W	2790 ± 10
84-cm Telescope		
31° 02′ 40.9″ N	115° 27′ 56.8″ W	2795 ± 10

a. Above sea level.

reappearance was more complex and different for the two telescopes. At the 84-cm telescope the brighter star appeared instantaneously immediately after which we could see that the fainter star was reappearing gradually. At the other telescope the brighter star appeared instantaneously, and then sligthly more than one second later the fainter star reappeared quickly, perhaps not instantaneously. Although our two telescopes are separated by only approximately 100 meters, our observations show the effects of the asteroid's local topography upon the reappearance of the two components.

Our errors for the absolute timings were estimated taking several factors into account. We attributed an error of ± 0.05 to ± 0.1 s to the electronic response. Clock setting errors were estimated at ± 0.15 to ± 0.20 s, slightly higher at the 150-cm telescope due to poor radio reception. At the 150-cm telescope the internal mean error of the chart recorder timing was ± 0.05 second using twelve time marks, four before the occultation and eight after when the time intervals were most uniform. The printers gave approximately 3.0 or 3.6 print s^{-1} which correspond to uncertainty intervals of ± 0.168 or ± 0.139 s, respectively, but these were reduced by comparing the shapes of the curves in Figure 1, by considering that the integrations were 0.1 s, and by multiplying by 0.67 to give approximate single standard deviations of ± 0.08 or ± 0.06 s, respectively. The error for our differential time measurements was estimated by considering that most of the above errors will largely cancel and by comparing the four timings of Table 1.

In Table 3 we present observed quantities for 1 Vulpeculae determined by this occultation. The difference in visual magnitude between the two components of the spectroscopic binary was taken from the counter-printer data of the 150-cm telescope; at this telescope the reappearances were clearly separated, and the counter-printer responded more fully and more quickly to the full-signal change than did the chart recorder.

The position angle and separation were derived assum-

TABLE 3

THE SPECTROSCOPIC BINARY 1 VULPECULAE

Observed Quantities	
Difference in Visual Magnitude between Components	ΔV = 0.7 ± 0.1 mag
Position Angle of Fainter Star	287°
Separation between Components	0.0038″

ing a circular profile for the asteroid, simultaneous disappearance of both components, a 21.275 s occultation for the brighter star, a 1.095 s longer occultation for the fainter star, a 44.4 s duration for a full-diameter occultation (Dunham 1983*b*), and the asteroidal movement and direction given by Dunham (1983*b*). A geometrical model was drawn; our observed duration plus the maximum timing provided the relative chord of our occultation, and then the asteroidal direction plus the knowledge that the occultation occurred at the northern part of the asteroid (Dunham 1983*b*) gave the tangent angles at the points of immersion and emersion. The stars disappeared simultaneously, and the fainter star emerged last, defining its position angle. At emersion, these angles, the 1.095 second "step", and the asteroidal movement were combined geometrically to give the separation of the stellar components. The assumption of a circular profile is only approximate; the average profile measured by Wasserman *et al.* (1979) was slightly elliptical (279.5± 2.9 km and 262.7 ± 4.5 km for the semimajor and semiminor axes), but the profile of the present occultation seems "close to a circular outline" (Dunham 1983*b*). In fact, the local asteroidal topography will much more affect the derived position angle and separation than will the assumption of an average circular profile. Our own observations show evidence for local irregularities in the profile. We have not attempted to estimate the errors in the separation and position angle but they could be fairly large. The most precise values will result when our observations are combined with those of the more than 100 other observers (Dunham 1983*b*) to average out the effects of Pallas' topography.

For comparison, we estimate the semimajor axis of the true ellipse of 1 Vul's orbit to be 0.0062″ using V= 4.77, spectral types of B3IV and B4IV, P = 250 days (Dunham and Maley 1983), $M_V = -2.79$, (Allen 1973), and $M_1 + M_2 = 17.6\ M_{\odot}$ (Allen 1973). To order of magnitude this agrees with our measured separation.

In conclusion, we have obtained data useful for the study of the asteroid Pallas and the spectroscopic binary 1 Vul. For 1% precision in the diameter of Pallas, 0.5 s precision in the timings was needed (Dunham and Maley 1983), and we have exceeded this criteria by at least a factor of two. Using photometric equipment normally used for absolute photometry with timings of ± 0.1 min, we have achieved a precision of approximately ± 0.2 s for absolute timings and ± 0.1 s for relative timings. Our ultimate precision is limited by our ability to synchronize our clocks to WWV, by the print interval of our counter-printers, and by our ability to manually place time marks on the chart paper. If we were to undertake a regular occultation program, different recording equipment, such as a stereo tape recorder for the simultaneous analogue recording of the photometer signal and of the time signal, would increase our precision and reliability.

No secondary occultations were observed at either telescope.

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