THE ASTRONOMICAL JOURNAL VOLUME 99, NUMBER 5 MAY 1990

THE SIZE AND SHAPE OF (2) PALLAS FROM THE 1983 OCCULTATION OF 1 VULPECULAE

DAVID W. DUNHAM AND JOAN BIXBY DUNHAM
Computer Sciences Corporation, 10110 Aerospace Road, Lanham-Seabrook, Maryland 20706
and
International Occultation Timing Association (IOTA), 7006 Megan Lane, Greenbelt, Maryland 20770-3012

RICHARD P. BINZEL,[a] DAVID S. EVANS, MARIAN FREUH, AND GREGORY W. HENRY[b]
Department of Astronomy, University of Texas, Austin, Texas 78712

MICHAEL F. A'HEARN AND RICHARD G. SCHNURR
Astronomy Program, University of Maryland, College Park, Maryland 20742

ROBERT BETTS, HENRY HAYNES, AND RICHARD ORCUTT
Air Force Space Technology Center, Palm Bay, Florida 32907

EDWARD BOWELL, LAWRENCE H. WASSERMAN, R. A. NYE, AND HENRY L. GICLAS
Lowell Observatory, Flagstaff, Arizona 86001

CLARK R. CHAPMAN
Planetary Science Institute and The Planetary Society, Tucson, Arizona 85719

R. D. DIETZ AND C. MONCIVAIS
Department of Earth Sciences, University of Northern Colorado, Greeley, Colorado 80639

WILLIAM T. DOUGLASS, DONALD C. PARKER, AND JEFF D. BEISH
Institute for Planetary Research Observatories, South Miami, Florida 33143

JAMES O. MARTIN[c] AND DONALD R. MONGER[d]
United States Naval Observatory Time Station, Richmond, Florida 33177

WILLIAM B. HUBBARD
Department of Planetary Sciences, University of Arizona, Tucson, Arizona 85721

HAROLD J. REITSEMA
Ball Aerospace Systems Division, Boulder, Colorado 80306

ARNOLD R. KLEMOLA
University of California Observatories/Lick Observatory and Board of Studies in Astronomy and Astrophysics, University of California,
Santa Cruz, California 95064

PAUL D. LEE
Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803

BRIAN R. MCNAMARA
Department of Astronomy, University of Virginia, Charlottesville, Virginia 22903

PAUL D. MALEY
International Occultation Timing Association (IOTA), Houston, Texas 77059

PETER MANLY
International Occultation Timing Association (IOTA), Tempe, Arizona 85281

NORMAN L. MARKWORTH
Department of Physics, Stephen F. Austin State University, Nacogdoches, Texas 75962

RICHARD NOLTHENIUS[e]
Department of Astronomy, University of California, Los Angeles, California 90024

TERRY D. OSWALT, J. ALLYN SMITH, AND EDWIN F. STROTHER
Department of Physics and Space Science, Florida Institute of Technology, Melbourne, Florida 32901

HAROLD R. POVENMIRE
International Occultation Timing Association (IOTA), Indian Harbour Beach, Florida 32937

0004-6256/90/051636-27$00.90

ROBERT D. PURRINGTON AND CARLOS TRENARY
Cunningham Observatory, Tulane University, New Orleans, Louisiana 70118

GLENN H. SCHNEIDER[f]
Department of Astronomy, University of Florida, Gainesville, Florida 32611

WILLIAM J. SCHUSTER, M. A. MORENO, J. GUICHARD, AND G. R. SANCHEZ
Instituto de Astronomia, Universidad Nacional Autonoma de Mexico, Ensenada, Baja California, Mexico

GORDON E. TAYLOR[g]
Royal Greenwich Observatory, Herstmonceux Castle, Hailsham, East Sussex BN27 1RP, England

ARTHUR R. UPGREN
Van Vleck Observatory, Wesleyan University, Middletown, Connecticut 06457

THOMAS C. VAN FLANDERN[h]
U. S. Naval Observatory, Washington, DC 20390

Received 5 December 1989

ABSTRACT

This paper reports the analysis and results of what was, by a large margin, the best observed occultation of a star by an asteroid. The 29 May 1983 occultation of the spectroscopic binary star 1 Vulpeculae by the asteroid (2) Pallas was timed from 130 locations across the southern U.S. and northern Mexico. Bad weather prevented observation of the occultation by the southernmost part of Pallas, but over two-thirds of the circumference was outlined in detail, including some topographic features. The observations were well fit by an ellipse with major and minor axes of 529.6 ± 1.2 and 511.2 ± 1.2 km, respectively. When combined with previously observed occultations, Pallas was fit to a triaxial ellipsoid with axes of 574 ± 10 km, 526 ± 3 km, and 501 ± 2 km and has a mean diameter of 533 ± 6 km. Then its computed volume of $(7.91 \pm 0.15) \times 10^{22}$ cm^3, when combined with a mass of $(1.4 \pm 0.2) \times 10^{-10} \mathcal{M}_\odot$, yields a mean density of 3.5 ± 0.5 gm/cm^3. Most of the photoelectric, and some visual, stations were able to time events of the secondary of the binary pair, leading to a determination of an angular separation of $0\farcs0028 \pm 0\farcs0004$ and a position angle of 305° ± 10° for the companion. These indicate that the star's actual parallax is probably near $0\farcs008$, half of the published value. Comparison of neighboring visual and photoelectric/video timings permits a detailed study of visual reaction times, which seem to be longer for disappearances than for reappearances. When observations of the appulse from locations outside of the path are also considered, a large region of space near Pallas was sampled. The absence of any confirmed secondary extinctions shows that any satellites of Pallas must be rare, or small. The best photometric observations also seem to rule out a substantial cloud of dust surrounding Pallas postulated by Soviet astronomers from their recording of another occultation by the asteroid.

I. INTRODUCTION

On 29 May 1983, the spectroscopic binary star 1 Vulpeculae (SAO 87010, HR 7306, HD 180554, BD $+21° 3713$, V magnitude $= 4.77$, $B - V = -0.05$, spectral type B4 IV, spectroscopic binary period of revolution 249.4 days, $a \sin i$ of 28.72×10^6 km) was occulted by the asteroid Pallas. Occultations of stars by asteroids provide opportunities to directly measure the sizes and shapes of asteroids to very high accuracy; techniques, methods of analysis, and limitations have been described by Millis and Dunham (1989). The event was predicted to be visible along a path across the southern U.S. and northern Mexico, an area accessible to a large number of prospective observers. An occultation of a star as bright as 1 Vulpeculae is observable with equipment no more sophisticated than binoculars on a tripod. An attempt was made to obtain dense coverage of the occultation, with a goal of defining local features on the limb of Pallas, a survey of the sky plane about the asteroid at the time of the occultation, and a direct comparison of the errors in typical visual occultation timings of asteroid events as compared with the accuracies of photoelectric data.

Considerable effort was expended to plan for this event (see Dunham and Maley 1983b). The result was by far the largest set of data ever obtained during an occultation of a star by an asteroid, presented in this paper, with 131 stations reporting occultation timings and an additional 110 reporting in support of the skyplane survey. Poor weather along the southern portion of the path limited the data obtained to two-thirds of the asteroid's circumference. However, Pallas has the best-defined shape of all of the asteroids, where another well-observed occultation occurred five years earlier as reported by Wasserman *et al.* (1979). Four other occulta-

---

[a] Present address: Dept. of Earth, Atmospheric, and Planetary Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139.

[b] Present address: Center of Excellence in Information Systems Engineering and Management, Tennessee State University, Nashville, TN 37203-3401.

[c] Present address: U.S. Naval Observatory, Washington, DC 20390.

[d] Present address: 6500 Snapper Creek Rd., Miami, FL 33143.

[e] Present address: Cabrillo College, Aptos., CA 95003.

[f] Present address: Computer Sciences Corporation, Space Telescope Science Institute, Johns Hopkins University, Baltimore MD 21218.

[g] Present address: Five Firs, Cowbeech, Hailsham, East Sussex BN27 4HL, England.

[h] Present address: 6327 Western Avenue, NW, Washington, DC 20015.

tions by Pallas, none of them observed well enough to determine its outline, have been reported by Sinvhal *et al.* (1962), Clark and Milone (1973), Kapkov (1984), and Stamm (1985).

On the average, one occultation of an SAO star by a given asteroid can be seen from a narrow strip of the Earth's surface each year (O'Leary 1972). But occultations of a star as bright as 1 Vulpeculae are much rarer. Since there are only 1223 stars as bright or brighter than magnitude 4.77, these events occur only once every 212 yr for a given asteroid. There are four asteroids with diameters larger than 400 km, including Pallas. Consequently, an occultation of a star brighter than magnitude 4.78 by any one of them should occur about once every 53 yr. The U.S., where most occultation observers (especially those who are mobile) are located, has an area of 1.6% of the Earth's surface. An occultation as good as, or better than, the one on 29 May 1983 might occur in the U. S. only about once every 3000 yr.

II. ASTROMETRY

The prediction of this remarkable occultation was first published in a major journal by Taylor (1981), although it was known for some time before this, and, on notification from Wasserman (1979), preliminary predictions were published (Dunham 1979, 1981). A prediction was also published by Wasserman *et al.* (1981). The predictions published by Dunham were based on an ephemeris computed from orbital elements by Sitarski (1981), and on stellar positions from the SAO, Perth 70, N30, FK4S, and AGK3 catalogs. Although better orbital elements for Pallas are now available, such as those by Landgraf (1984), the ephemeris based on Sitarski's orbit has been retained for the analysis below. Sitarsky's orbit represented Pallas' motion very well in 1983, and use of it preserves the continuity with published predictions. The ephemeris of Pallas for the period near the occultation is given in Table I. The northernmost predicted occultation track was that near latitude 45° N, from the AGK3 stellar position; the southernmost predicted path, with maximum latitude near 27° N, used the SAO catalog, which in turn utilized data from the Albany General Catalog (GC).

The large scatter in the available star catalog positions was the major error source of the initial prediction. In 1982, Klemola obtained a plate of the 1 Vulpeculae star field to determine a better stellar position to remove this large uncertainty. Five exposures were also taken of Pallas that confirmed Sitarski's ephemeris. Klemola's updated star position and Sitarski's ephemeris were used to calculate a "nominal" prediction that formed the basis for coordinated planning and distribution of further astrometric updates. The Lick plates were reduced with AGK3R reference star data to define a system with much smaller local variations from the FK4 system than could be obtained from the other catalogs containing 1 Vulpeculae. A secondary network of faint star positions along the path of Pallas was measured by Klemola on his plate of 1 Vulpeculae for reduction of measurements of plates taken with other telescopes with smaller fields of view.

The corrections to right ascension and declination obtained from astrometric observations of the asteroid and the star were resolved into components parallel and perpendicular to the geocentric motion of Pallas to obtain the minimum geocentric separation and Universal Time of closest approach. The geocentric motion of Pallas was in the direction of position angle 315°.49, measured from the apparent North Celestial Pole, and was at a rate of 0″.3639/min. The nominal postion for 1 Vulpeculae, based on the 1982 Lick observations, was R.A. 19^h 14^m $03^s.978$, Dec. +21°18′ 02″.74 (B1950). This position for the star was used for all of the analyses discussed in the following sections.

As the two objects approached, the potential accuracy of the astrometry improved, but the time constraints became more critical. Plates of the star and asteroid were taken on 3 May and 18 May at Lick Observatory by Klemola, 25 May at Fan Mountain Observatory by McNamara and at Van Vleck Observatory by Upgren, and 27 May with the U.S. Naval Observatory (USNO) 155 cm astrometric telescope at Flagstaff by Conard C. Dahn. The predictions are summarized in Table II. A negative value for the minimum geocentric separation indicates that Pallas passed south of the star as seen from the Earth's center. The first line gives the nominal prediction based on Klemola's 1982 observation of the star and an ephemeris calculated with Sitarski's orbital elements for Pallas.

Pallas was not near 1 Vulpeculae in 1982; the "yes" in parentheses shows only that Sitarski's orbit was confirmed by the separate Lick plates of Pallas. The separate observations obtained at the University of Virginia's Fan Mountain 40 in. reflector and at Wesleyan University's Van Vleck Observatory on 25 May were both reduced with Klemola's secondary stars to obtain one prediction. The final entry in Table II is the actual path shift. This shows that the nominal prediction was actually the best, but its accuracy was unknown; it could have been off by 0″.2, 0.7 of the path width, a typical error in 1983 for an AGK3R star. All of the predicted occultation path center lines were within the actual path, and the actual center line was within the very small uncertainty of the last update obtained from the USNO plates exposed two nights before the occultation.

Table III contains photographic positions of 1 Vulpeculae

TABLE I. Astrometric (B1950.0) ephemeris of (2) Pallas.

Julian Ephemeris Date	RA	Dec	Δ(AU)
2445481.5	$19^h14^m58^s.830$	21°03′50″.39	2.70165
2445482.5	19 14 34.600	21 10 23.40	2.69477
2445483.5	19 14 09.206	21 16 45.86	2.68802
2445484.5	19 13 42.658	21 22 57.50	2.68141
2445485.5	19 13 14.971	21 28 57.99	2.67493
2445486.5	19 12 46.157	21 34 47.05	2.66859

TABLE II. Astrometry for the occultation of 1 Vulpeculae by Pallas.

Date	Observatory	No. of Expos.	Pallas	Star	Minimun Geocentric Separation		Universal Time	
1982	Lick	3	(Yes)	Yes	$-1\overset{''}{.}067$		$4^{h}\ 50^{m}\ 40^{s}$	
1983 May 3	Lick	3	Yes	Yes	-0.95	$\pm 0\overset{''}{.}12$	4 51	$\pm 0\overset{m}{.}2$
1983 May 18	Lick	6	Yes	Yes	-1.16	±0.11	5 50	$\pm 0\overset{m}{.}5$
1983 May 25	Fan Mountain	1	Yes	No	-1.02	±0.05		
1983 May 25	Van Vleck	3	No	Yes				
1983 May 27	USNO, Flagstaff		Yes	Yes	-1.06	±0.03	4 50 39	
1983 May 29	Occultation		Yes	Yes	-1.0745	±0.0003	4 50 34.1	$\pm\overset{s}{.}05$

and Pallas from Van Vleck Observatory, Lick Observatory, and Fan Mountain Observatory. The Lick photographic positions for Pallas for 1982 and 1983 are given in Klemola and Harlan (1982,1984).

III. OBSERVATIONS

Information on how to observe, and how and where to report the observations, was disseminated through the coordinators and organizations such as The Planetary Society (Chapman 1983), as well as via *Sky and Telescope* (Dunham and Maley 1983b) and publications of the International Occultation Timing Association (Dunham 1982). To provide sufficient monitoring of the sky plane for potential events, observers who could not travel to the predicted occultation path were encouraged to locate the star and observe it during the period when occultations or dimmings by secondary objects might occur. Efforts were made to inform observers that reports of no events seen were as important as reports of events. The many miss (no occultation) reports received were valuable for scanning the vicinity of Pallas, and showed that a few secondary extinctions were due to terrestrial causes (usually clouds) rather than objects near Pallas. More information on the preparation and data collection may be found in (Dunham and Maley 1983a, b).

All of the data are listed in Tables IV and V. Table IV contains the occultation timings, Table V the locations of those who monitored the star and reported no occultation. The 131 observing sites listed in Table IV reported a total of 306 observations, of which 266 were used in defining the asteroid location and shape. Observations made at five of the stations have been published previously, including stations 100 and 103 (Schuster *et al.* 1984), 110 (Douglass *et al.* 1983), 119 (Lee *et al.* 1987), and 128 (Hubbard and Reitsema 1983). Sites 1-131 were in the path of the occultation

TABLE III. Photographic positions of 1 Vulpeculae and Pallas.

A. 1 Vulpeculae

Location	Date (UTC)	RA (B1950.0)	Dec (B1950.0)
Van Vleck Obs	May 25 (2 exp.)	$19^{h}14^{m}03\overset{s}{.}968$	$21°18'02\overset{''}{.}80$
Lick Obs	May 3 $11^{h}25\overset{m}{.}19$	14 03.966	21 18 02.78
	29.0	03.970	02.83
	33.0	03.972	02.86
	May 18 8 38.0	03.964	02.72
	41.0	03.967	02.84
	44.0	03.970	02.85
	54.5	03.966	02.80
	56.5	03.972	02.79
	58.5	03.962	02.84

B. (2) Pallas

Location	Date (UTC)	RA (B1950.0)	Dec (B1950.0)
Fan Mtn Obs	May 25 $8^{h}\ 47^{m}$	19 15 35.844	20 52 45.70
	8 49	35.814	46.22

TABLE IV. Observations of the Pallas occultation of 29 May 1983.

Station Name	Location					Observations					
Observers	C	Latitude	Longitude	Height	C	Time (UT) HHMMSS.SS	AB	React. (Sec)	W	Cor. Reac(s)	Accuracy (±s)
1 Junction, TX	0	304026.0	994638.0	1500.	F	45735.50	21		&		
Observers: E. Kolarich, Bartz, Hoke						45813.00	22		1	0.9	0.4
2 Menard, TX	0	304700.0	994555.0	1500.	F	45732.00	21		1	1.1	0.4
Observers: B. Snow, D. Hensch						45812.00	22		1	0.9	0.4
3 Menard, TX	0	305230.0	994542.0	1500.	F	45735.20	21		&		
Observers: A. New, Garcia						45814.20	22		&		
4 Menard, TX	0	305647.0	994647.0	1500.	F	45731.00	21	0.500		1.1	0.4
Observers: A. Reeves, Tafliger						45809.40	22	0.700	&		
5 Big Bend National Park, TX	0	291044.5	1025713.5	1845.		45739.50	21	0.500		1.1	0.4
Observers: T. Freeman, V. Brady						45821.00	22	0.300		0.9	0.4
6 Titusville, FL	0	283351.0	805024.3	6.		45558.00	21	0.500		1.1	0.4
Observer: W. Hoffler						45633.80	22	0.500		0.9	0.4
7 Odessa, TX	0	313738.0	1020725.0	2880.	F	45747.70	21	0.300		1.1	0.4
Observers: J. Stafford, J. Camp						45818.80	22	0.300		0.9	0.4
8 Van Cleave, MS	0	303353.0	883746.0	80.	F	45647.00	21	0.50		1.1	0.4
Observers: J. Treadway, R. Cates, P. Lenart						45717.10	22	1.00		0.9	0.4
9 Austin, TX	0	302242.0	974512.0	880.	F	45722.12	21	0.300		1.1	0.4
Observer: J. Young						45804.41	22	0.300		0.9	0.4
10 Midland, TX	0	315208.3	1021042.8	2800.	F	45751.00	1		1	1.1	0.4
Observer: J. Rose						45816.80	2		1	0.9	0.4
11 Waco, TX	0	313043.0	970524.0	400.	F	45727.60	21		1	1.1	0.4
Observer: J. Barton						45758.10	22		1	0.9	0.4
12 Brownwood, TX	0	314126.0	985737.0	1200.	F	45737.30	21	0.600		1.1	0.4
Observers: B. Blagg, J. Abdias, P. Romig						45806.00	22	0.600		0.9	0.4
13 Leakey, TX	0	295101.2	994518.9	2000.	F	45747.00	21	1.000	&		
Observer: R. Phillips						45823.20	22	0.300	&		
14 Corsicana, TX	0	320225.2	961847.0	360.	F	45732.90	21	0.400		1.1	0.4
Observer: T. Williams						45747.80	22	0.400		0.9	0.4
15 Athens, TX	0	320952.7	954500.8	530.	F	45734.90	21	0.800	3	-1.1	0.8
Observer: W. Darnell						45735.90	27	0.800	3	-1.1	0.8
						45737.90	22	0.400	3	-1.3	0.8
16 Conroe, TX	0	302033.7	952744.0	230.	F	45713.00	21		1	1.1	0.4
Observer: D. Baker						45804.00	22		&		
17 San Angelo, TX	0	312605.0	1002324.0	1800.	F	45743.00	21		&		
Observer: K. Mace						45816.30	22		&		
18 Mexia, TX	0	313939.0	962058.0	500.	F	45726.30	21	0.300		1.1	0.4
Observer: C. Sexton						45753.00	22	0.300		0.9	0.4
19 Centerville, TX	0	312041.0	955947.0	450.	F	45754.10	22	1.000		0.9	0.4
Observer: A. Jones											
20 Jonesboro, TX	0	313817.0	975132.0	1000.	F	45732.50	21	0.700		1.1	0.4
Observer: J. Culberson						45802.40	22	0.700		0.9	0.4
21 Nacogdoches, TX	0	314247.8	944944.7	250.	F	45722.00	21		1	1.1	0.4
Observer: R. Teed						45744.90	22		1	0.9	0.4

TABLE IV. (continued)

Station Name Observers	Location C	 Latitude	 Longitude	 Height	 C	 Time (UT) HHMMSS.SS	 AB	Observations React. (Sec)	 W	 Cor. Reac(s)	 Accuracy (±s)
22 Robbins, TX	O	311654.0	960818.9	500.	F	45721.75	21	1.000		1.1	0.4
Observer: B. Birdsong						45721.75	27	0.250		1.1	0.4
						45754.25	22	0.500		0.9	0.4
23 Centerville, TX	O	311153.0	960135.0	300.	F	45720.40	21	0.500		1.1	0.4
Observers: K. Jurgens, D. Brunette						45753.90	22	0.500		0.9	0.4
24 Nacogdoches, TX	O	314442.8	944717.6	250.	F	45722.70	21		1	1.1	0.4
Observers: T. Fox, B. Prislovsky						45745.00	22		1	0.9	0.4
25 Rye, TX	O	302447.2	944609.3	50.	F	45709.30	21		1	1.1	0.4
Observer: J. Petersen						45750.60	22		1	0.9	0.4
26 Nacogdoches, TX	O	312950.6	943608.3	400.	F	45719.70	21		1	1.1	0.4
Observers: J. Mote, P. Powell						45745.60	22		1	0.9	0.4
27 Lufkin, TX	O	312652.0	944742.0	400.	F	45725.00	21	2.000	&		
Observer: J. Breazeale						45747.60	22	0.400		0.9	0.4
28 Meridian, TX	O	315545.1	974146.9	900.	F	45737.00	21	0.500		1.1	0.4
Observers: C. Herold, T. Schultz, D. Schultz						45755.00	22	0.300		0.9	0.4
29 Corsicana, TX	O	320132.7	962339.3	435.	F	45732.90	21		1	1.1	0.4
Observer: F. Harvey						45748.30	22		1	0.9	0.4
30 Corsicana, TX	O	320856.6	963547.0	460.	F	45736.50	21		1	1.1	0.4
Observer: R. Harper						45745.50	22		1	0.9	0.4
31 Hempstead, TX	O	300326.5	960034.6	45.	F	45713.00	21	0.500		1.1	0.4
Observers: M. Lawson, D. Siner						45755.30	22	0.300		0.9	0.4
32 Odessa, TX	O	320241.0	1024530.0	3265.	F	45753.00	31		&		
Observer: A. Moore						45808.30	32		&		
33 Hubbard, TX	O	315220.0	964441.0	530.	F	45820.00	31		&		
Observer: M. Jones						45828.00	32		&		
34 Woodlands, TX	O	301000.0	953019.0	100.	F	45711.60	26	2.000	&		
Observer: J. Bragg						45711.60	26	1.500	&		
						45711.60	21	1.000		1.1	0.4
						45754.20	22	0.500		0.9	0.4
35 Barksdale, TX	O	294419.0	1000325.0	1000.	F	45730.00	21		&		
Observers: S. Elsner, B. Jansen						45814.00	22		1	0.9	0.4
36 Navasota, TX	O	302056.0	961047.0	150.	F	45715.00	21	0.500		1.1	0.4
Observer: J. Erickson						45757.70	22	0.500		0.9	0.4
37 Centerville, TX	O	311410.5	955939.0	300.	F	45720.80	21		1	1.1	0.4
Observer: C. Davis						45754.30	22		1	0.9	0.4
38 Santa Elena Canyon, TX	O	291310.0	1034500.0	2500.	F	45743.50	21		1	1.1	0.4
Observers: D. Green, V. Sims, R. Monk, C. Rodriguez, V. Buih, N. Taylor						45825.00	22		1	0.9	0.4
39 San Augustine,TX	O	313400.8	940836.9	400.	F	45717.40	21		1	1.1	0.4
Observer: P. Sventek						45742.00	22		1	0.9	0.4
40 San Augustine,TX	O	313158.4	941013.8	400.	F	45717.20	21		1	1.1	0.4
Observers: D. Le Blanc, D. Sventek						45743.00	22		1	0.9	0.4
41 Brookland, TX	O	310728.0	940512.0	170.	F	45712.20	21	0.300		1.1	0.4
Observer: J. Chauvin						45745.00	22	0.500		0.9	0.4
42 Seabrook, TX	O	293432.0	950307.0	0.		45711.00	21		&		
Observer: G. Kiser						45751.00	22		1	1.1	0.4

TABLE IV. (continued)

Station Name	Location				Observations						
Observers	C	Latitude	Longitude	Height	C	Time (UT) HHMMSS.SS	AB	React. (Sec)	W	Cor. Reac(s)	Accuracy (±s)
43 Iraan, TX	O	305403.7	1014924.3	2570.	F	45741.00	21	0.500		1.1	0.4
Observers: L. Delaney, E. Manual						45820.40	22	0.500		0.9	0.4
44 Salt Flat, TX	O	314448.9	1051202.1	4000.	F	45800.50	21	1.000		1.1	0.4
Observer: R. Weber						45829.00	22	0.400		0.9	0.4
45 Splendora, TX	O	301353.5	951000.0	100.	F	45709.60	21	0.500	2	0.5	0.2
Observer: P. Maley						45753.30	22	0.400	2	0.4	0.2
46 Italy, TX	O	321037.5	965428.9	608.	F	45739.20	21		1	1.1	0.4
Observer: D. Clark						45746.80	22		1	0.9	0.4
47 Cleburne, TX	O	321357.4	971745.0	840.	F	45742.25	21	0.300	4	1.1	0.4
Observer: J. Craft						45743.00	27	0.300	5	1.1	0.4
						45748.30	22	0.400	4	0.9	0.4
48 Walburg, TX	M	3041.8500	9736.8000	750.	F	45722.50	21	0.300		1.1	0.4
Observers: J. Graves, J. Graves						45803.40	22	0.300		0.9	0.4
49 Walburg, TX	M	3043.6200	9735.5800	800.	F	45722.80	21	0.200		1.1	0.4
Observers: J. Dellinger, L. Dedear						45803.30	22	0.200		0.9	0.4
50 Theon, TX	M	3046.3800	9737.1200	800.	F	45723.30	21	0.400		1.1	0.4
Observers: J. Lucke, G. Keith						45803.40	22	0.300		0.9	0.4
51 Jarrell, TX	M	3048.7100	9738.1900	850.	F	45724.00	21	0.500		1.1	0.4
Observers: M. Brewster, A. Jones						45803.30	22	0.300		0.9	0.4
52 Prairie Dell, TX	M	3049.8300	9733.6400	800.	F	45723.00	21	0.500		1.1	0.4
Observers: R. Rouw, B. Wren, M. Crawford						45802.70	22	0.500		0.9	0.4
53 Salado, TX	M	3054.1700	9731.1000	700.	F	45726.80	21	1.500	&		
Observer: R. Foster						45803.60	22	1.500		0.9	0.4
54 Salado, TX	M	3056.1600	9730.0800	700.	F	45724.00	21	0.500		1.1	0.4
Observer: P. Roy						45802.00	22	0.500		0.9	0.4
55 Belton, TX	M	3100.0900	9729.1900	550.	F	45724.80	21	0.500		1.1	0.4
Observer: A. Whipple						45802.40	22	0.500		0.9	0.4
56 Belton, TX	M	3102.0400	9729.4000	670.	F	45725.70	21	0.500		1.1	0.4
Observers: S. Sawyer, D. Garnett, J. Gyorgyey						45802.50	22	0.400		0.9	0.4
57 Belton, TX	M	3105.5700	9725.5200	600.	F	45725.00	21	0.300		1.1	0.4
Observer: M. McCants						45801.10	22	0.300		0.9	0.4
58 Belton, TX	M	3109.7100	9724.2800	700.	F	45725.10	21	0.500		1.1	0.4
Observers: S. Roby, J. Cannizzo						45800.70	22	0.500		0.9	0.4
59 Moffat, TX	M	3112.2100	9726.1500	700.	F	45725.00	21	1.000		1.1	0.4
Observers: B. Cuthbertson, K. Scholtz						45759.20	22	0.500		0.9	0.4
60 Stampede, TX	M	3113.8400	9726.5300	700.	F	45726.50	21	0.500		1.1	0.4
Observer: G. Roark						45800.50	22	0.500		0.9	0.4
61 Stampede, TX	M	3115.5900	9724.7100	700.	F	45726.00	21	0.400		1.1	0.4
Observers: L. Forrest, G. Metcalf						45726.70	27	0.400		1.1	0.4
						45800.00	22	0.200		0.9	0.4
62 Austin, TX	O	301720.0	974410.0	700.	F	45720.00	41				0.100
Observer: R. Binzel						45802.60	42				0.100
63 McDonald Obs, TX		30.672620	104.022910	2050.		45746.68	41				0.001
Observers: M. Frueh, D. Evans						45747.07	47				0.001
						45828.64	42				0.001
						45829.29	48				0.001

TABLE IV. (continued)

Station Name	Location							Observations			
Observers	C	Latitude	Longitude	Height	C	Time (UT) HHMMSS.SS	AB	React. (Sec)	W	Cor. Reac(s)	Accuracy (±s)
64 Nacogdoches, TX	O	314535.0	943942.0	461.	F	45721.09	41				0.05
Observer: N. Markworth						45742.25	42				0.05
65 Blum, TX	O	321045.3	972345.0	650.	F	45739.10	21		1	1.1	0.4
Observer: G. Ellis						45749.20	22		1	0.9	0.4
66 Nacogdoches, TX	O	312738.2	943455.7	400.	F	45717.50	21	1.000		1.1	0.4
Observer: W. Settle						45746.10	22	0.300		0.9	0.4
67 Milburn, TX.	O	312230.0	990139.0	1450.	F	45733.30	21	0.300		1.1	0.4
Observers: D. Garland, J. Andrews, J. Williams						45806.80	22	0.300		0.9	0.4
68 Milburn, TX	O	311911.0	990254.0	1525.	F	45733.30	21	0.600		1.1	0.4
Observer: R. Di Iulio						45807.00	22	0.600		0.9	0.4
69 Dania, FL.	O	260332.0	800643.0	1.		45543.20	21	0.400		1.1	0.4
Observer: W. Nissen						45622.90	22	0.700		0.9	0.4
70 Dania, FL	O	260259.8	800644.6	1.		45544.00	21	0.700		1.1	0.4
Observer: J. Zitwer						45544.50	27	0.700		1.1	0.4
						45623.00	22	0.700		0.9	0.4
71 Andytown, FL	O	260752.5	802618.6	3.		45544.90	21	0.700	2	1.1	0.3
Observer: D. Dunham						45545.50	27	0.700	2	1.1	0.3
						45624.60	22	0.500	2	0.5	0.2
72 Andytown, FL	O	260751.4	802618.5	3.		45544.02	41				0.1
Observer: J. Dunham						45544.59	47				0.1
						45624.03	42				0.1
						45624.40	48				0.1
73 Andytown, FL.	O	260332.7	802552.2	3.		45545.00	21	0.700		1.1	0.4
Observer: L. Woods						45624.00	22	0.300		0.9	0.4
74 Andytown, FL	O	260025.9	802558.4	4.		45545.00	21	0.500		1.1	0.4
Observer: R. Taibi						45545.50	27	0.500		1.1	0.4
						45625.00	22	0.400	&		
75 Green Valley, AZ	O	315119.0	1110015.0	905.		45828.10	21	0.300		1.1	0.4
Observers: G. Ratley, L. Paller						45838.00	28	0.300		0.9	0.4
						45839.30	22	0.500		0.9	0.4
76 Davidson Ranch, AZ	O	315116.0	1104137.7	1366.	F	45826.95	21	0.300	4	1.1	0.4
Observer: J. McGaha						45827.25	27	0.300	5	1.1	0.4
						45838.80	22	0.300	4	0.9	0.4
						45839.25	21	0.300	4	1.1	0.4
						45840.25	22	0.300	4	0.9	0.4
77 Gainsville, FL	O	293834.8	822056.3	100.	F	45615.22	21	0.220		1.1	0.4
Observer: R. Mitchell						45640.42	22	0.220		0.9	0.4
78 Rockledge, FL	O	281611.3	804128.1	15.	F	45554.00	1		1	1.1	0.4
Observer: M. Seslar						45632.00	2		&		
79 Satellite Bch,FL	O	281105.8	803554.1	25.	F	45553.30	21	0.200	2	0.6	0.3
Observers: H. Povenmire, K. Izor, K. Thomas						45553.50	27	0.200	2	0.6	0.3
						45637.00	22	1.000	&		

TABLE IV. (continued)

Station Name	Location				Observations						
Observers	C	Latitude	Longitude	Height	C	Time (UT) HHMMSS.SS	AB	React. (Sec)	W	Cor. Reac(s)	Accuracy (±s)
80 Bronson, FL	O	292359.4	823511.0	44.		45611.60	41				0.04
Observers: G. Schneider, M. Reeves, G. Fitzgibbons						45611.84	47				0.04
						45642.86	42				0.04
						45643.36	48				0.04
81 Cocoa, FL	O	282304.5	804544.9	60.	F	45607.80	1		&		
Observer: R. Wood						45633.90	2		1	0.9	0.4
82 W. Melbourne, FL	O	280516.8	803901.2	25.	F	45554.40	21	0.700	&		
Observer: D. Schinkevich											
83 S. Melbourne, FL	O	280250.3	803658.3	25.	F	45552.90	21	0.700		1.1	0.4
Observers: N. Henderson, D. Salzburg						45633.60	22	0.600		0.9	0.4
84 Valkaria AFB, FL	O	275724.9	803331.4	30.	F	45552.50	21	0.700		1.1	0.4
Observers: J. Doryk, S. Panossian						45633.60	22	0.600		0.9	0.4
85 Valkaria AFB, FL	O	275735.9	803352.1	30.	F	45552.40	21	0.700		1.1	0.4
Observers: R. McCormick, L. Moore						45633.00	22	0.600		0.9	0.4
86 Wabasso, FL	O	274452.2	802612.6	15.	F	45550.10	21	0.520		1.1	0.4
Observers: L. Reed, S. Haigh						45634.40	22	0.420	&		
87 Melbourne, FL	O	280330.7	803810.6	40.	F	45551.76	41		5		0.3
Observers: J. Smith, E. Strother						45552.31	47		5		0.3
						45633.25	42		5		0.3
						45633.79	48		5		0.3
88 Cape Kennedy, FL	O	280128.6	-2791851.8	-4.		45552.00	41				0.03
Observers: R. Betts, H. Haynes, R. Orcutt						45633.40	42				0.03
89 N. Naples, FL	O	261538.0	814807.5	14.	F	45553.70	21	0.600	2	1.0	0.3
Observer: T. Campbell						45554.10	27	0.500	2	0.9	0.3
						45631.40	22	0.400	2	0.4	0.2
90 Myakka S.P., FL	O	271401.2	821839.6	20.	F	45556.40	21	0.500		1.1	0.4
Observer: T. Kenyon						45557.10	27	0.400		1.1	0.4
						45641.40	22	0.400		0.9	0.4
91 St.Petersburg,FL	O	274838.3	823602.1	5.	F	45600.70	21	0.500		1.1	0.4
Observer: C. Gramm						45645.50	22	0.500		0.9	0.4
92 Hickory Hill Obs., FL	O	282843.0	821748.9	255.	F	45600.00	21	0.600	&		
Observer: G. Marcy						45640.70	22	0.500	&		
93 Clermont, FL	O	283306.1	814225.5	265.	F	45601.20	21	1.200		1.1	0.4
Observers: A. Hradesky, T. Izor						45640.20	22	0.400		0.9	0.4
						45640.40	21	0.400	&		
						45640.50	22	0.400	&		
94 Tampa, FL	O	280102.0	822637.4	26.	F	45601.45	21	0.250		1.1	0.4
Observer: C. McDougal						45643.85	22	0.250		0.9	0.4
95 Melbourne, Fl	O	280331.4	803812.3	55.	F	45553.00	21	0.330		1.1	0.4
Observers: T. Oswalt, P. Hutchinson						45634.00	22	0.500		0.9	0.4
96 Coronado Peak, AZ	O	312040.6	1101455.7	5100.	F	45817.34	21	0.340		1.1	0.4
Observers: R. Peters, W. Wright, F. Chapman						45846.14	22	0.340		0.9	0.4
97 Biloxi, MS	O	302340.4	885355.0	20.	F	45647.00	21	2.000		1.1	0.4
Observer: J. Meadows						45719.70	22	0.500		0.9	0.4
98 Hialeah, FL	O	254657.6	802855.8	5.	F	45544.90	1		1	1.1	0.4
Observer: G. Gonzales						45621.30	2		1	0.9	0.4
						45744.00	6		&		

1990AJ.....99.1636D

TABLE IV. (continued)

Station Name	Location				Observations						
Observers	C	Latitude	Longitude	Height	C	Time (UT) HHMMSS.SS	AB	React. (Sec)	W	Cor. Reac(s)	Accuracy (±s)
99 Venice, FL	O	270624.0	822534.0	0.		45558.00	21	1.000		1.1	0.4
Observer: D. Strum						45641.00	22	0.500		0.9	0.4
100 San Pedro Martir, Baja Cal.	O	310240.8	1152800.3	2790.		45833.83	41				0.22
Observers: W. Schuster, M. Moreno, J. Guichard, G. Sanchez						45855.17	42				0.22
						45856.24	48				0.22
101 Presidio, TX	M	2952.5300	10415.5700	4390.	F	45744.60	41				0.1
Observers: R. Dietz, C. Moncivais, K. Moody, M. Verchota						45829.30	42				0.1
102 Ft. Pierce, FL	O	272830.0	801736.0	12.	F	45546.69	41				0.001
Observers: M. A'Hearn, R. Schnurr						45547.09	47				0.001
						45629.91	42				0.001
						45630.48	48				0.001
103 San Pedro Martir, Baja Cal.	O	310240.9	1152756.8	2790.		45834.72	41		&		
Observers: W. Schuster, M. Morenao, J. Guichard, G. Sanchez						45856.11	42		&		
						45857.25	48		&		
104 W. Palm Beach, FL	O	263940.5	801437.1	20.	F	45543.70	1		1	1.1	0.4
Observer: G. Zentz						45544.20	7		1	1.1	0.4
						45627.20	2		1	0.5	0.4
105 Brescia, FL	O	280039.8	803958.3	30.	F	45633.60	2		1	0.9	0.4
Observers: M. Adams, S. Morgan											
106 Tampa, FL	O	280651.0	822946.0	55.	F	45601.97	21		1	1.1	0.4
Observer: J. Robicheaux						45642.82	22		1	0.9	0.4
107 Burns Lake, FL	O	255339.0	811348.0	10.	F	45550.30	21	0.400		1.1	0.4
Observer: R. Riefer						45551.00	27	0.400		1.1	0.4
						45624.70	22	0.400		0.9	0.4
108 Miami, FL	O	254451.0	801245.0	30.	F	45543.67	1		1	1.1	0.4
Observers: M. Mooney, S. Ireland						45620.17	2		1	0.9	0.4
109 Palm Bay, FL	O	280115.0	803452.0	25.	F	45553.00	1		&		
Observer: J. Hagan						45633.00	2		1	0.9	0.4
110 S. Miami, FL	O	254237.0	801802.0	3.		45543.18	41				0.05
Observers: W. Douglass, D. Parker, J. Beish,						45543.69	47				0.05
J. Martin, D. Monger						45619.65	42				0.05
						45620.13	48				0.05
111 Sierra Vista, AZ	O	312953.8	1101448.0	4500.	F	45818.40	21		1	1.1	0.4
Observers: H. Stanley, L. Stanley						45845.00	22		1	0.9	0.4
113 Houston, TX	O	294222.0	953648.0	80.	F	45710.60	21	0.300		1.1	0.4
Observer: D. Oliver						45754.90	22	0.500		0.9	0.4
114 Wausau, FL	O	303713.1	853433.0	240.	F	45637.70	21		1	1.1	0.4
Observers: J. Mix, M. Greer						45654.80	22		1	0.9	0.4
115 Coleman, TX	O	315728.0	993238.0	1500.	F	45742.00	21		1	1.1	0.4
Observer: T. Malone						45804.50	22		1	0.9	0.4
116 Melbourne, FL	O	280950.9	803526.3	10.	F	45553.00	21		1	1.1	0.4
Observer: J. Schroeder						45633.00	22		1	0.9	0.4
117 Carmen, AZ	O	313337.4	1110324.5	1082.		45822.80	21	0.300	4	1.1	0.4
Observer: R. Kennedy						45845.20	22	0.300	4	0.9	0.4
118 Springfield, LA	O	302628.6	903801.9	6.		45653.20	21	0.300	2	0.7	0.3
Observer: B. Hudgens						45729.70	22	0.300	2	0.3	0.2

1990AJ.....99.1636D

TABLE IV. (continued)

Station Name	Location							Observations			
Observers	C	Latitude	Longitude	Height	C	Time (UT) HHMMSS.SS	AB	React. (Sec)	W	Cor. Reac(s)	Accuracy (±s)
119 Baton Rouge, LA	H	302444.1	60443.0	31.		45653.75	41				0.05
Observers: R. James, P. Lee, C. Watson, H. Williams, S. Mims						45654.25	47				0.05
						45732.35	42				0.05
						45732.95	48				0.05
120 B. de Los Angeles, Baja Ca.	O	285720.0	1133318.0	1.	F	45812.78	21	0.420	2	0.42	0.2
Observer: R. Nolthenius						45812.78	27	0.000	2	0.0	0.2
						45857.60	22	0.500	2	0.5	0.2
121 Campo Juarez, Baja Cal.	O	290158.0	1133320.0	27.	F	45813.82	21	0.500		1.1	0.4
Observer: S. Dale						45857.66	22	0.700		0.9	0.4
122 New Orleans, LA	O	295622.0	900710.0	10.	F	45646.80	41		5		0.3
Observers: R. Purrington, C. Trenary						45727.60	42		5		0.3
123 Eastpoint, FL	O	294415.0	845315.0	20.	F	45631.50	31		&		
Observer: R. Oldham						45704.50	32		&		
124 Imuris, Sonora	H	304442.1	72300.4	1480.		45811.99	41				
Observers: L. Wasserman, R. Nye						45812.13	47				
						45849.54	42				
						45849.63	48				
125 Palm Harbor, FL	O	280405.1	824603.6	15.	F	45603.70	21	0.500	&		
Observer: G. Felos						45647.00	22	0.700		0.9	0.4
126 St.Petersburg, FL	O	274856.6	824542.2	30.	F	45602.40	21	0.400		1.1	0.4
Observer: G. Page						45645.90	22	0.400		0.9	0.4
127 St.Petersburg, FL	O	274333.2	823811.5	5.	F	45600.30	21	0.400		1.1	0.4
Observer: J. Shinner						45600.50	27	0.400		1.1	0.4
						45645.00	22	0.400		0.9	0.4
128 Bennett Ranch, TX	O	293743.8	1035146.2	1255.		45741.76	41				0.03
Observers: W. Hubbard, H. Reitsema						45742.28	47				0.03
						45826.37	42				0.03
						45826.80	48				0.03
129 Springfield, LA	O	302611.9	903224.8	5.		45655.00	1		&		
Observer: B. Roberts						45731.00	2		&		
130 McDonald OBS, TX		30.673270	104.022150	2050.		45746.70	41				0.001
Observer: G. Henry						45747.08	47				0.001
						45828.64	42				0.001
						45829.23	48				0.001
131 Casselberry, FL	O	283918.0	811911.0	72.	F	45600.00	21	0.530		1.1	0.4
Observer: D. Kornbluh						45637.58	22	0.510		0.9	0.4
201 Tempe, AZ	O	332523.0	1115749.0	335.		50713.50	21	0.500	&		
Observer: K. Terry						50716.50	22	0.500	&		

Notes to TABLE IV

3 Saw secondary event at D, not timed.

5 Reported secondary event at D, not timed.

13 Event duration disagrees with nearby stations.

14 Slow fades 0.3 to 0.4 sec. reported for both events.

15 Time adjusted to fit so that the center of the cord is in agreement with neighboring stations.

19 Missed disappearance.

32 Event times from duration timing; 15.3 ± 0.3 sec.

33 Tape recording ended at 4:52 when tape ran out.

1990AJ.....99.1636D

Notes to TABLE IV. (continued)

44 Times are corrected for apparent 1 min transcription error.

62 Photoelectric, 0.01 sec resolution, 41cm aperture, seeing poor.

63 Photoelectric, 30-inch telescope.

64 Photoelectric, Stephen F. Austin State University Observatory, 46cm aperture.

69 Duration of disappearance 0.2 seconds.

72 Video timings, 20cm telescope.

76 Saw 2 dimmings 7 min. after occultation, probably caused by aiplane contrail

77 Ft. Cohen Observatory.

78 Events described as "slow fade".

79 Satellite Beach Observatory 16-inch.

80 Photoelectric, Rosemary Hill Observatory, 76cm aperture.

81 Astronaut Hall 24-inch cassegrain.

82 R unobserved due to clouds.

87 Photoelectric., time base manually keyed from WWV, Florida Ins. Tech. Obs 41cm aperture.

88 Video timings with Air Forece telescope, 48-inch aperture.

90 Myakka River State Park

93 Slow reappearance.

100 Photoelectric, chart recorder, Mexican National Observatory 150cm telescope.

101 Video timings, 20cm aperture.

102 Photoelectric, 36cm aperture.

103 Photoelectric, Mexican National Obs. 84cm telescope, times set manually.

105 D unobserved due to clouds.

106 Reported poor seeing.

108 Southern Cross Observatory.

110 Photoelectric, W. T. Douglass Observatory 35.6cm telescope.

119 Photoelectric, Louisiana State Univ. Observatory 11.5cm refractor.

122 Video timings, Cunningham Obs., Tulane University, 36cm aperture.

124 Photoelectric, 36cm aperture.

125 Reported clouds and haze.

127 Pallas seen as "slightly reddish-orange faint object".

128 Photoelectric, 36cm aperture.

130 Photoelectric, McDonald Observatory 36-inch telescope.

201 Observations discordant with other stations.

TABLE V. Observing sites outside the path of the Pallas occultation of 29 May 1983.

Station		Location					Observers
No.	Name	C	Latitude	Longitude	Height	C	
201	Tempe, AZ	O	332523.0	1115749.0	335.		K. Terry, J. Manly
202	Madison, FL	O	302617.0	831752.0	75.	F	D. Bacon, W. Cooke, 6 others
203	Westmorland, CA	O	330430.0	1153103.0	-175.	F	C. Bynum, T. Lucier
204	Kane Sprint, CA	O	330733.0	1155327.0	-120.	F	D. Werner, J. Holbrook
205	Hillside, AZ	O	342545.0	1125742.8	4960.	F	G. De Lange, J. Stevens
206	Kitt Peak Obs,AZ		31.958000	111.595000	2064.		Kitt Peak National Observatory
209	Abilene, TX	O	322617.7	994550.8	1732.	F	B. Kish
210	Waxahache, TX	M	3225.1000	9650.4700	625.	F	J. Cotton
211	Abilene, TX	O	323845.0	992730.0	1500.	F	J. Holcumb
212	Glastonbury, CT	D	41.726400	72.579900	43.		P. Dombrowski
213	Hampton, VA	O	370021.7	762226.6	30.	F	C. Evans
214	Ithaca, NY	O	422729.3	762304.5	0.		S. Ostro, M. Skrutskie, J. Gradie, P. Nicholson
215	Valdosta, GA	O	305600.0	831445.0	250.	F	P. Bigelow
216	Valdosta, GA	O	305051.6	831740.0	230.	F	Marks, Meddox, Van Peenen
217	Valdosta, GA	O	304537.0	831556.0	200.	F	K. Bedsole, T. Hiott
218	Lake Park, GA	O	304056.0	831005.0	50.	F	W. Peck
219	Pinetta, FL	O	303605.0	831604.0	150.	F	M. Leake, T. Strickland
220	Deas Strip, FL	O	303218.0	831740.0	100.	F	W. Cook
221	Salt Lake City, UT	O	404020.0	1115924.0	4430.	F	S. Wasserbaech
222	Edenvale, R.S.A.	O	-260915.1	-280820.1	1602.		D. Overbeek
223	Foster, RI	O	414432.0	714654.0	540.	F	D. Pray
224	Naples, ME	O	435741.0	703902.0	645.	F	P. Burnham
225	Belmont, MA	O	422249.0	711116.0	100.	F	R. Sinnott
226	Seattle, WA	M	4739.9000	12218.4000	200.	F	B. Van Deventer
227	Laramie, WY	O	411848.7	1053500.3	2208.		Y. Sheffer
228	Spokane, WA	M	4742.0000	11724.0000	0.		J. Ulowetz
229	New Britain, CT	O	423406.0	724612.2	0.		D. Menke, J. Carter, M. Tinnirello
230	Carolina Trace, NC	M	3525.0000	7906.0000	0.		B. McGowan
231	Wilson, NC	O	354240.0	775535.0	0.		W. Gladson
232	Cary, NC	O	354925.8	784317.8	0.		M. Lang, J. Watson
233	Central, NC	O	344638.4	825155.9	0.		D. Lomax
233	Central, NC	O	344638.4	825155.9	0.		D. Lomax
234	Wolfville, NS	D	45.107500	64.232500	0.		R. Bishop
235	Hingham, MA	M	4215.0000	7053.0000	0.		T. Norton
236	Big Bear, CA	M	3415.0000	11648.0000	6000.	F	S. Edberg
238	Stoney Ridge, CA	O	341655.0	1175850.0	7000.	F	G. Hoover, P. Weissman, R. Carlson, A. Harris
239	Mexico City, DF	O	192352.5	990827.0	7000.	F	H. Cabrera
240	S. Mexico City, DF	O	191842.0	991254.0	7000.	F	R. Robles Gil
241	Cuernavaca, Mex.	M	1855.0000	9915.0000	4000.	F	J. de la Herran
242	Lovington, NM	O	330237.0	1034902.0	4300.	F	A. Gorski
243	Kelso Dunes, CA	O	345321.0	1154226.0	2570.	F	G. Lyzenga
244	Bristol Lake, CA	O	341536.0	1154239.0	1920.	F	R. Clark
245	Bristol Lake, CA	O	342630.0	1153852.0	638.	F	J. Cromer
246	Moonridge, CA	O	341348.0	1164518.0	7250.	F	A. Meckler, 30 or more additional observers
247	Waterman Mt, CA	O	341628.0	1175915.0	5111.	F	J. Codona, D. Sensiper
248	Warm Spring Mt, CA	O	343102.0	1183530.0	1995.	F	J. Hemans
249	Cayon De Muerto, AZ	O	360814.0	1092932.0	1870.		J. Greenfield, S. Greenfield
250	Atolia, CA	O	351627.2	1173645.8	945.		P. Manly, S. Stiers

TABLE V. (continued)

Station		Location					Observers
No.	Name	C	Latitude	Longitude	Height	C	
251	Shadow, CA	O	344307.4	1172133.3	869.		D. Churchill, P. Maloney
252	Phelan, CA	O	342536.6	1172358.3	1086.		T. McGrath, J. McGrath
253	San Bernadino, C	O	342730.5	1165654.6	875.		R. Hill, D. Hill
254	Casa Grande, AZ	O	323601.3	1111941.1	1082.		D. Kennedy, F. Roth
255	Casa Grande, AZ	O	324428.5	1113155.5	479.		K. McCaslin
256	Coolidge, AZ	O	325927.0	1113655.0	413.		G. Fillingham, D. Blanchard, P. Kurcera
257	Chapa de Mota, Mex.	O	194724.0	993123.4	3070.		G. Mallen
258	Denton, TX	M	3323.0000	9710.0000	0.		R. Fleming
259	Denton, TX	M	3316.0000	9709.0000	0.		J. Love, J. Gilkison
260	Denton, TX	M	3312.0000	9709.0000	0.		J. Lively
261	Duncanville, TX	M	3238.0000	9653.0000	0.		B. Williams
262	Burleson, TX	M	3233.0000	9718.0000	0.		C. Rogers
263	Midlothian, TX	M	3230.0000	9701.0000	0.		C. Schweers
264	Paris, TX	O	333950.0	952748.0	600.	F	C. Goodwin
265	Plano, TX	M	3302.0000	9643.0000	0.		C. Whitaker, W. Whitaker
266	Carrollton, TX	O	330037.0	965326.0	600.	F	J. Prall
267	Mesquite, TX	M	3248.0000	9636.0000	600.	F	W. Sheffield
268	Greenville, TX	O	330732.0	960639.0	600.	F	T. Hooten
269	Southlake, TX	M	3257.0000	9709.0000	600.	F	C. Ryals
271	Liberal, KS	M	3703.0000	10055.0000	0.		C. Brownlee
272	Ducanville, TX	M	3238.0000	9656.0000	600.	F	J. Carpenter
273	Garland, TX	M	3259.0000	9638.0000	600.	F	W. Burton, W. Hullett, P. Luna
274	Terrell, TX	O	324029.0	962013.0	600.	F	T. Baker
275	Green Forest,AR	O	361942.5	932313.5	378.		P. McBride
276	Frisco, TX	M	3309.0000	9648.0000	0.		G. Deen, B. Deen
277	Marietta, OK	M	3351.1400	9708.1100	0.		B. Bigbee
278	Dickson, OK	M	3407.6800	9659.8600	0.		J. Winchester
279	Ardmore, OK	M	3413.9300	9707.8400	0.		K. Odell
280	Springer, OK	M	3418.9200	9706.8100	0.		S. Girard
281	Lake Murray SP, OK	M	3403.2900	9705.3100	0.		M. Teders
282	Cresson, TX	M	3233.0000	9737.0000	0.		M. Ward
283	Grays Prairie, TX	M	3227.0000	9621.0000	0.		J. Nelson
285	Arlington, TX	M	3240.0000	9707.0000	0.		J. Hutchins
286	Farmers Branch, TX	M	3251.0000	9653.0000	0.		R. Aulbaugh
287	Garland, TX	M	3251.0000	9642.0000	0.		R. Price
289	Springtown, TX	M	3301.0000	9741.0000	0.		T. Duff
291	Lucas, TX	M	3305.0000	9635.0000	600.	F	D. Worrall & family
292	McKinney, TX	M	3313.0000	9637.0000	590.	F	K. Shank
293	Krum, TX	M	3316.0000	9714.0000	780.	F	T. Wrzesinski
294	Garland, TX	M	3254.0000	9638.0000	0.		M. Ohl, J. Wilson
295	Howe, TX	O	333034.0	963606.0	600.	F	J. Welsh
296	Sandusky, TX	M	3343.0000	9653.0000	750.	F	J. Green, J. Wagoner
297	Lancaster, TX	M	3236.0000	9645.0000	0.		D. Wadsworth
298	Arlington, TX	O	324518.0	970853.0	570.	F	F. Kahr
299	Burns, TN	O	360238.2	871434.8	730.	F	M. Crist
300	Auburn, AL	O	322640.0	852922.0	440.	F	J. Chesnutt, K. Hudson, R. Jenkins, R. Whigham
301	Searcy, AK	O	351445.0	914348.0	0.	F	A. Bailey
302	Paragould, AK	D	36.030000	90.290000	0.	F	K. Rhea
303	Kaufman, TX	M	3236.5000	9616.0000	450.	F	B. Pate
304	Lubbock, TX	M	3335.0000	10155.0000	4000.	F	F. Redburn, P. Bell

TABLE V. (continued)

Station No.	Name	Location C	Latitude	Longitude	Height	C	Observers
305	Slaton, TX	O	334144.0	1013924.0	4000.	F	R. Gott, L. Keith, J. Stevens
306	Lubbock, TX	O	333818.0	1015226.0	4000.	F	R. Orr, R. Pritle
307	Hale Center, TX	O	340710.0	1014328.0	4000.	F	W. Julian, W. Long, K. Olsen
308	Tulia, TX	O	342817.0	1014511.0	4000.	F	G. Leiker, S. McMullen
309	Lubbock, TX	O	333453.0	1015528.0	4000.	F	D. Loftins
310	Wellman, TX	O	330238.0	1022531.0	4000.	F	R. Knox
311	Lubbock, TX	O	332835.0	1015422.0	4000.	F	W. Lewis
312	Whitewright, TX	O	333348.0	962515.0	600.	F	B. Bailey
313	Arbuckle Mtn, OK	O	342549.0	970840.0	600.	F	W. Wyrick
314	Americus, GA	O	320319.0	841258.0	435.	F	P. Manker
315	N. of Tucson, AZ	M	3151.0000	11620.0000	0.	F	Burke
316	Tonanzintla Obs.,Mx	H	100157.9	63315.3	2150.		J. Barral, R. Costero
317	Grandview, TX	O	321546.25	971336.95	744.	F	D. Stotz

Notes to TABLE V

Station	Note
201	K. Terry's observations given with the observation table
206	Steward 90 inch
214	Hartung-Boothroyd Observatory, Cornell University
216	Valdosta State College Observatory
229	Copernican Observatory
238	Stoney Ridge Observatory
246	At Riverside Telescope Makers Conference, large number of observers
254	Blinks at 44918.0, 45406.0, "uncertain"
317	Miss station closest to the northern limb

Table key for TABLES IV and V

Station and Observer Names

The observers' names are given as reported. The names for the locations were as reported or, in the absence of a usable name, determined from survey maps.

Location

The latitude is positive North, longitude positive West.

The coordinates are, as nearly as is possible, presented as reported by the observers. In some cases, the coordinates were determined by the authors upon request by observers, or when analysis found the reported location to be in error.

Table key for TABLES IV and V (continued)

Coordinates Code

C	Explanation
O	Latitude and longitude in XX° XX' XX".X
M	Latitude and longitude in XX° XX'.XXXX
D or blank	Latitude and longitude in XX°.XXXXXX
H	Latitude as in code O, longitude in $XX^{h}\ XX^{m}\ XX^{s}.XX$
F	Altitude in feet above mean sea level
M or blank	Altitude in meters

Observations

The uncorrected visual observations are presented with the reported reaction times and the corrected reaction time, as determined from the reaction time analysis (see text). The accuracy of visual observation is the value determined from the reaction time study. The accuracy given for photoelectric and video observations is the reported or determined value of the observing equipment.

Observation Codes

A	Explanation
blank	Visual observation with stopwatch or tape recorder reported as corrected for reaction time, correction applied not reported
2	Raw visual observation with stopwatch or tape recorder, uncorrected for reaction time
3	Visual observation performed with the eye-and-ear technique (see text)
4	Photoelectric or video equipment used to record occultation

B	Explanation
1	Disappearance of primary star
2	Reappearance of primary star
6	Flash or blink
7	Disappearance of secondary star
8	Reappearance of secondary star

Observation Weighting Code

W	Weight in Solution
blank	0.1 for visual observations 1.0 for photoelectric observations
&	0.0 (Observation discordant, deleted from reduction data set.)
1	0.07
2	0.25
3	0.5
4	1.0
5	0.1

events; sites numbered 201 and above were outside the path. Station numbers were assigned in approximate order of receipt. Missing numbers in the sequence indicate stations deleted for duplicate reports or, in a few cases, observations of no events when it was clear the observer was within the occultation path. These data are available from the first authors in an MS DOS machine-readable format as printed or in a database. The locations of sites in North America are shown by dots in Fig. 1, along with the occultation path. No stations were on any of the islands shown on the map.

Three additional lists, mainly to help observers identify their station and locate their observed points on the plots, are available from the first authors in either hard or soft form. The first list gives the station data (city, state, longitude, latitude, observer(s), and height above sea level) in longitude order from east to west. The second gives the sky-plane coordinates for all of the observations in station-number order. The third gives station name and number, observation time, position angle in the sky plane, observation type, weight, and residual in position-angle order, to locate information about adjacent stations.

Data-reduction procedures included the following: The raw, uncorrected observations of the occultation were plotted, as shown in Fig. 2. Explanations were sought for obvious discrepancies. In some cases, reexamination of reports and observation records, as well as questioning of observers, led to corrections which resolved discrepancies. The remaining discordant observations were not included in reduction datasets. Discordant observations were determined by inspection of residual lists ordered by impact parameter and of plots of the observations on the mean limb. Observations were judged to be discordant when their radial residuals differed by more than 20 km from those of neighboring stations. Visual observations within 2° of position angle of photoelectric observations were discarded if they disagreed by more than 15 km. Near the northern limit, less discordancy was tolerated. This allowed preservation of data recording actual variations in the profile of Pallas, and was only possible due to the large volume of data. As much as could be done, the neighboring datasets used in local comparisons included photoelectric or video timings, or at least timings from experienced visual observers.

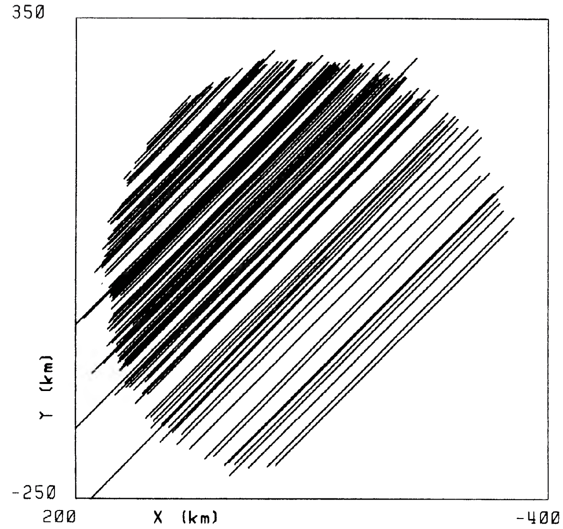

FIG. 2. Raw occultation observations. The valley that caused the second short disappearance at station 76 is evident as a break in its chord in the upper left part of the figure.

One discrepancy noted was the time difference between the nearby photoelectric stations 100 and 103, equivalent to about 10 km, while the stations were within 10 m of each other in the direction perpendicular to the path. Since they are so close, the limb effects postulated by Schuster *et al.*

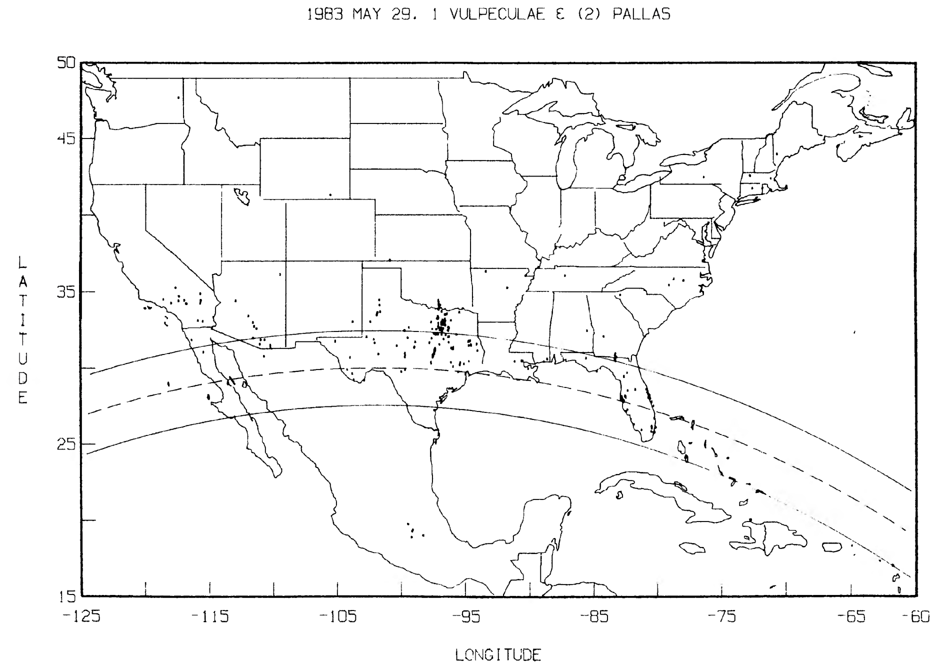

FIG. 1. Path of the occultation. Observation sites are shown with dots. All reported observations from the western hemisphere were from the continental U.S. and Mexico.

(1984) are very unlikely. The distant photoelectric station 64 was within 100 m of 100 and 103 in perpendicular distance, and agreed well with station 100's chord. The timings from station 103 were considered discordant, and were not used in the analysis. A possible explanation of the discrepancy is that an error was made in the manual calibration of those timings.

Solutions were performed with the edited data, and with subsets of the data that consisted of photoelectric and video stations, experienced visual observers, and a few visual stations near the northernmost limb of Pallas. The results from these solutions were used to analyze the visual observation data for accuracy and reaction time, as described in Sec. V. A final reduction dataset, consisting of the edited, corrected, visual data and the photoelectric and video data, was created for use in analysis of the occultation.

IV. (2) PALLAS TOPOGRAPHY AND NEIGHBORHOOD

Figures 3–13 show the resulting profile of Pallas. Figure 3 is a plot of the error bars for the observations from the reduction dataset with the solution ellipse included. Figures 4–12 trace the profile as defined by the data in detail. On these skyplane plots, small circles mark photoelectric and video contact timings, while visual observations are depicted with error bars. Corrections have been applied to the visual timings, as described in the next section. The derivation of the length of the error bars, corresponding to 0.8 s (error ± 0.4 s) for most visual observations, is also given in the next section. Numbers of chords correspond to the station numbers of Table IV. The secondary data are also included on these figures, with the shift of center of figure, as discussed later. The Pallas shape is shown to be nearly circular, with clearly defined local features of the order of a few percent of the asteroid's radius discussed in the figure captions. Figure 13 shows the resolution of the observational data around the

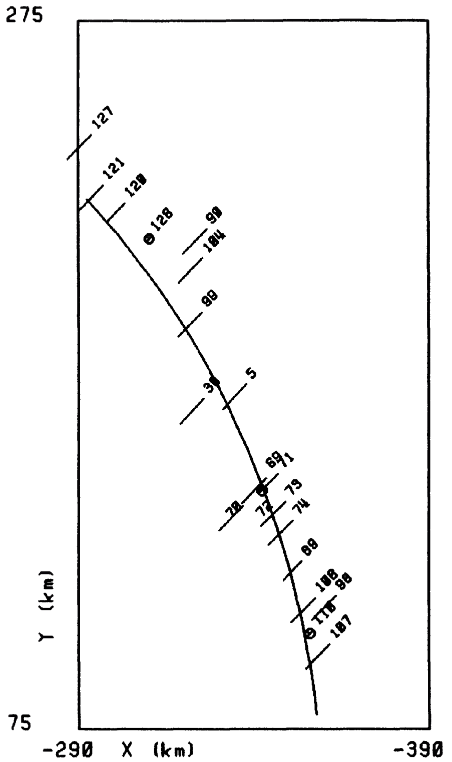

FIG. 4. Pallas profile (1 of 9). Photoelectric and video observers are indicated with a circle; visual timing error bars are shown by short lines (see Sec. V). The station numbers are given for each.

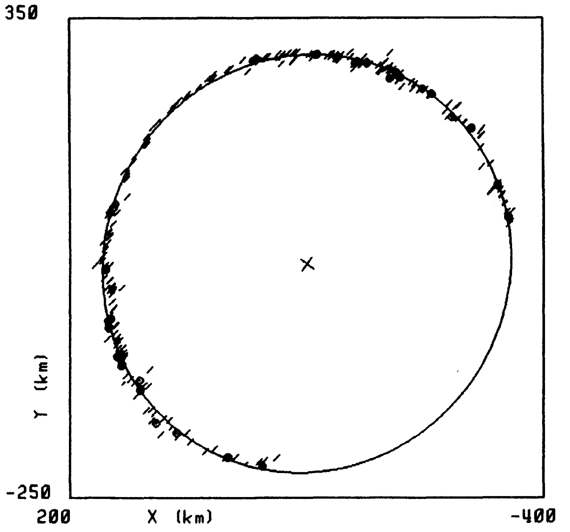

FIG. 3. Pallas solution ellipse and observation error bars photoelectric and video observations are indicated with a circle; visual timing error bars are shown by short lines. Systematic corrections and errors that have been used with the visual timings are discussed in Sec. V.

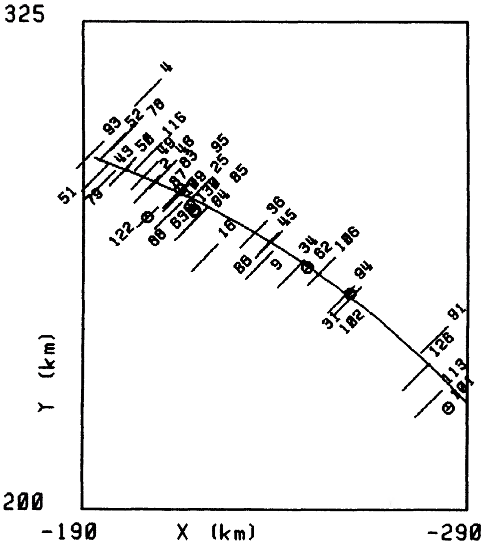

FIG. 5. Pallas profile (2 of 9).

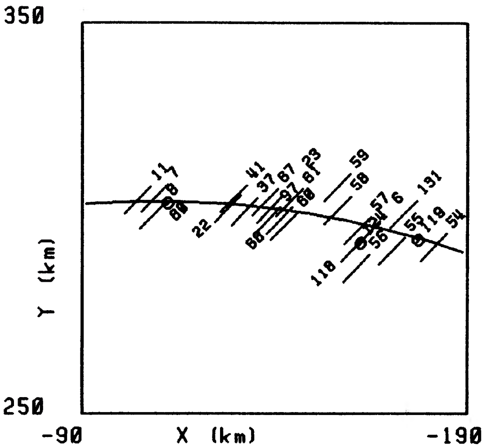

FIG. 6. Pallas profile (3 of 9).

northern cap of Pallas. Station 15 was the most northernly to observe an occultation, station 317 the closest station to observe a miss.

A second discrepancy among the reported observations was found between station 15 and a station at Corsicana, TX (latitude 32°16′04″.6N, longitude 97°28′18″.4W, height above mean sea level 200 ft) reporting a miss. The second station location produced a chord 0.40–0.45 km deeper than the chord from station 15. Both station locations were well defined and reevaluation of the positions did not resolve the discrepancy. A changing limb profile, as Pallas rotated during the 7ˢ.5 between the times of closest approach at the two stations, would not have been sufficient to cause an observer at station 15 to see an event while an observer at the Corsicana station would not. A 20 km limb feature, larger than any observed, would make a difference in the perpendicular distance of less than 0.1 km between the two locations. The second station was removed from Table V, and was not included in the solutions.

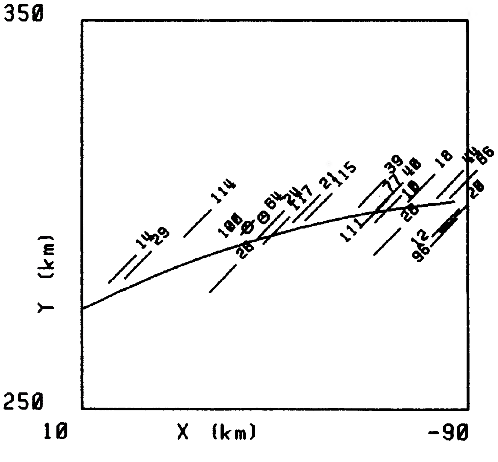

FIG. 7. Pallas profile (4 of 9).

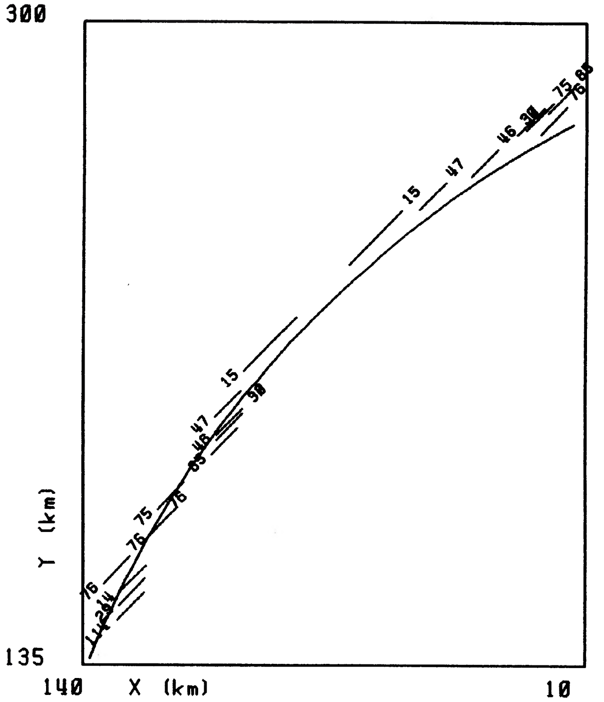

FIG. 8. Pallas profile (5 of 9). A steep slope is defined on the reappearance (left) side by stations 47 to 65. The valley that produced the short reappearance for station 76 is in the lower left part of the figure. A 50 km crater might explain this topography. A seond slope is traced by the final reappearance at stations 76 and 114. The topography is clearest in this area near the northern limit, where the effects of visual timing errors are minimal. See also Fig. 13.

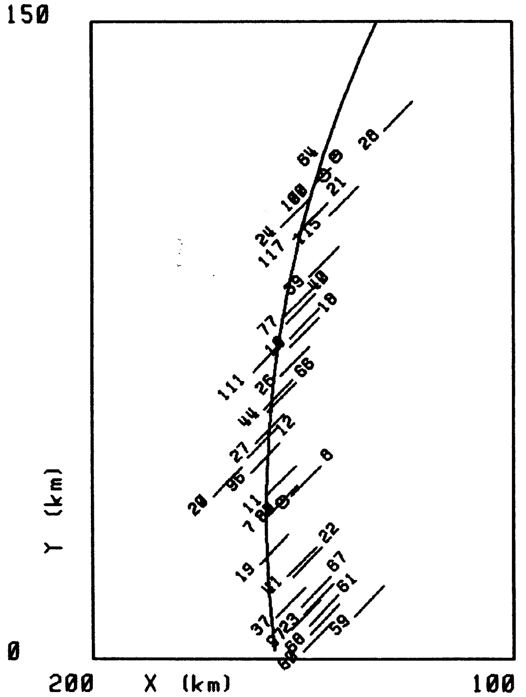

FIG. 9. Pallas profile (6 of 9). Stations 39 to 96 ($Y = +95$ to $+45$) seem to show a slight increase of elevation towards the south. From station 96 to the bottom, the elevation decreases significantly.

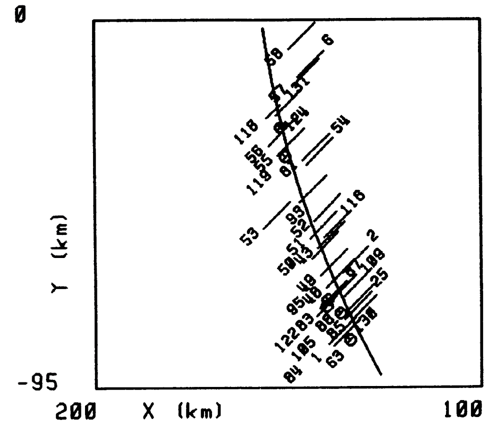

FIG. 10. Pallas profile (7 of 9). The low area at the bottom of Fig. 9 recovers near station 118 ($Y = -15$). The depression from station 96 to 118 could be a 60 km crater.

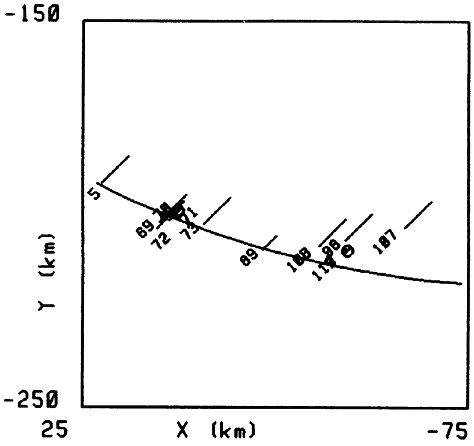

FIG. 12. Pallas profile (9 of 9).

The sky plane data of Table V, along with the observation data of Table IV, are combined in Fig. 14, to show the areas around Pallas monitored for secondary events. The reported starts and ends of the observing periods were used in preparing Fig. 14. When these times were not reported, the beginnings and ends of the observing periods were taken to be 5 min before and after the time of closest approach. No unambiguous event or dimming of the star was recorded in these regions. Kapkov (1984) had interpreted dimmings in a photoelectric trace of an earlier occultation by Pallas as observations of a dust cloud around the asteroid. The lack of such data in the dataset of the 29 May 1983 event indicates that either the dust cloud had dissipated or that the dimmings in the data reported by Kapkov were due to instrumental or atmospheric causes. Although conditions were poor at most photoelectric and video sites, relatively good conditions did prevail for several minutes before and after the occultation at stations 72, 80, 100, 103, 119, and 122, spanning a perpendicular distance of over half the diameter of Pallas. No strong evidence for significant dimming was reported from any of these stations. Lee *et al.* (1987) reported no decrease in brightness within an uncertainty in magnitude of 3%. Additional investigations on the other records are in progress and will be reported separately. This illustrates the critical importance of confirming observations of events of this nature. There were a few observations within the dataset for the 29 May 1983 event which, by themselves, would have indicated secondary objects about Pallas, but which were not confirmed by neighboring stations.

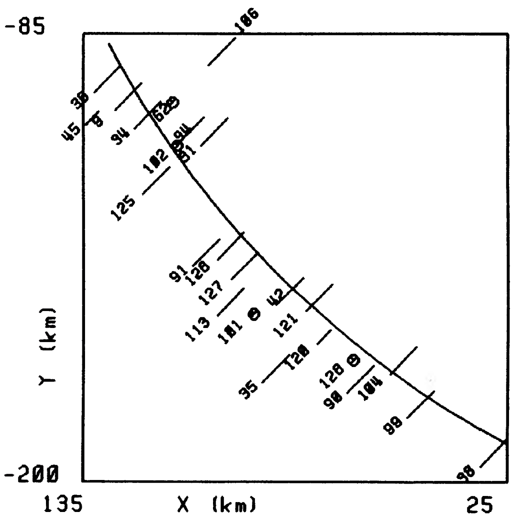

FIG. 11. Pallas profile (8 of 9). A large slope is indicated by the photoelectric timings at stations 62 and 102 in the upper left corner. A continued increase in height to station 101's reappearance seems to be confirmed by visual timings at stations 91, 126, 127, and 113.

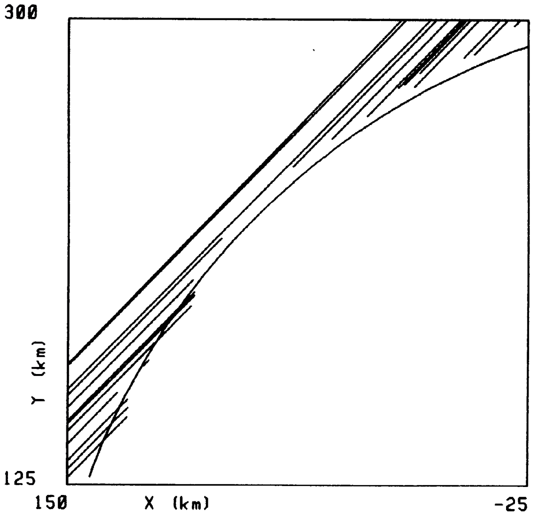

FIG. 13. Northern cap observations. The lines indicate when the star was seen, interruptions when it was occulted. The three miss stations plotted are 317 (closest to the asteroid), 206, and 209.

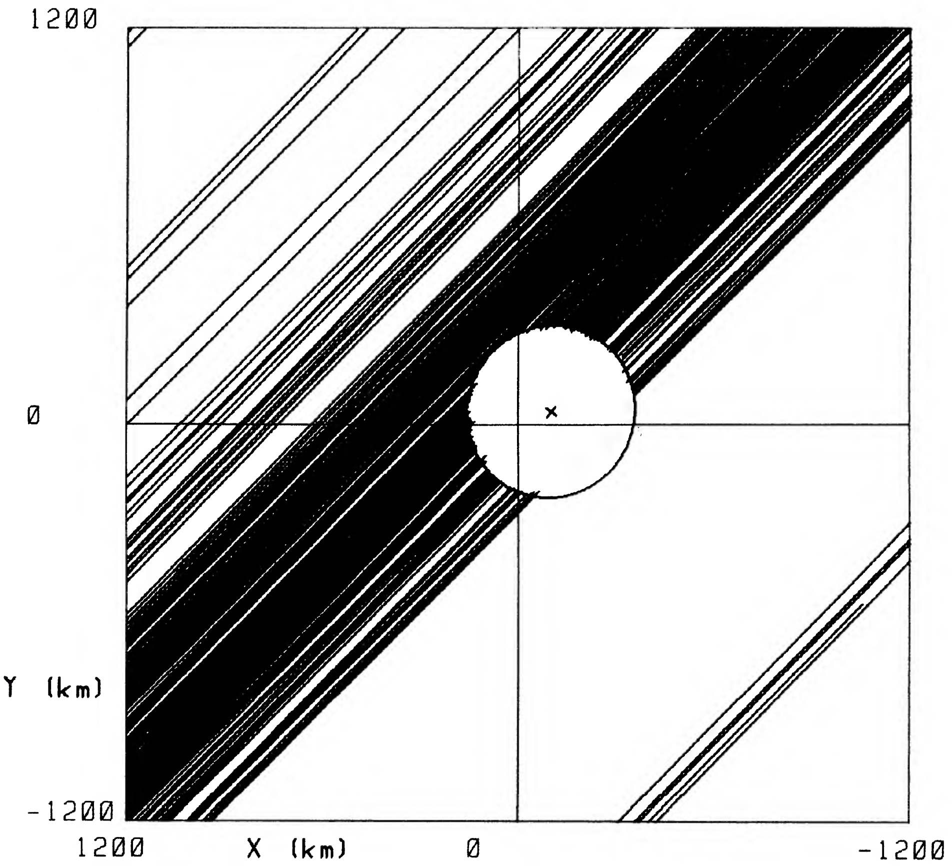

FIG. 14. Sky plane observed around Pallas.

V. COMPARISON OF OBSERVATION TECHNIQUES

A rich variety of techniques and instrumentation was used to record these events, providing a unique opportunity for comparison of their effectiveness. It is of particular interest to compare the visual observation data with that collected with photoelectric or video equipment. These comparisons provide a means of calibrating the expected accuracy for visual asteroid occultation timings for use in the more usual case in which fewer observations are obtained, and direct comparisons are not possible. For many previous occultations, it was clear that visual observers usually underestimate their reaction times, and their timings had to be adjusted, or "slid," to agree with photoelectric data. This was also the case for this occultation, as shown by the disappearances plotted in Fig. 15. In this figure, stations 72 and 110 were video and photoelectric, respectively. Asterisks mark visual timings before reaction times were applied, and + 's show timings after the observer's estimate of reaction time was applied. Circles mark photoelectric and video observations. As expected, the *'s are well below the mean limb of Pallas, but even the + 's are systematically below a line passing through 72's and 110's disappearance points, which is a better representation of the asteroid's limb in this area. In order to avoid systematic biases in the solutions, it is necessary to quantify these differences.

To perform the comparisons, the visual data were divided into three classes by experience. Only data that had been

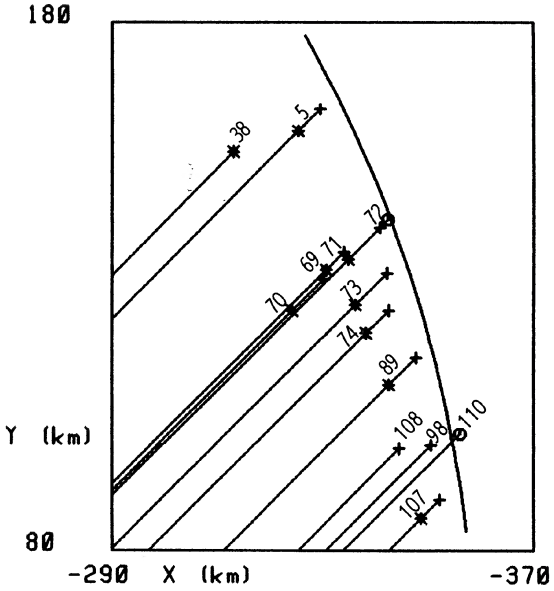

FIG. 15. Enlarged region of observations. The visual observations are plotted as uncorrected (*) and corrected with the reported reaction time (+). Photoelectric and video observations are plotted as circles.

accepted for use in the reduction dataset were included in the comparison study. The dataset was searched to find suitable candidates for comparison, ones in which visual and nonvisual data were closely enough aligned in impact parameter (perpendicular distance) so that they probably observed the same local features of Pallas. A total of 44 disappearance and 30 reappearance timing comparisons was made. The actual reaction time of the observation was computed as follows: The distance of the visual timing on the sky plane above or below the limb of (2) Pallas, as defined by nearby photoelectric or video points, was computed. This was converted to time by dividing the distance by the topocentric velocity of Pallas. Fewer comparisons were made with reappearance timings as some of the photoelectrically timed reappearances showed evidence of large irregularities in the observed Pallas limb.

The data are plotted in Figs. 16 and 17. Examination of these data show that the true reaction time of visual observations of the disappearance is larger than that of the reappearance. This we attribute to a "startle delay," caused by the reaction of the observer on seeing a relatively bright star disappear from the star field. Observing experience diminished this effect only slightly. Lunar occultation observers often see the advancing lunar limb as a reference to alert them to expect a disappearance, while for this event the asteroid was not visible in the glare of the star. For the reappearance, observers knew where to look for the reappearing star and knew that the event was imminent. This also differs from the usual case for visual observations of reappearances from behind the lunar limb.

After allowing for the effects discussed above, the visual timing errors for the event averaged ± 0.4 s for all of the observers. This agrees well with studies of visual observer reaction times during lunar occultations (Sinzi and Suzuki 1967; Morrison *et al.* 1971). Very experienced occultation observers achieved a timing accuracy of about ± 0.2 s. Consequently, the visual timings were given much lower weight (usually $\frac{1}{10}$th) than those from photoelectric and video timings. The exceptions were the visual observations made very close to the northern limit of the occultation, where the motion was nearly parallel to the asteroid's surface so that the timing error would produce only a small error in the radial direction. These data were given increased weight in the analysis.

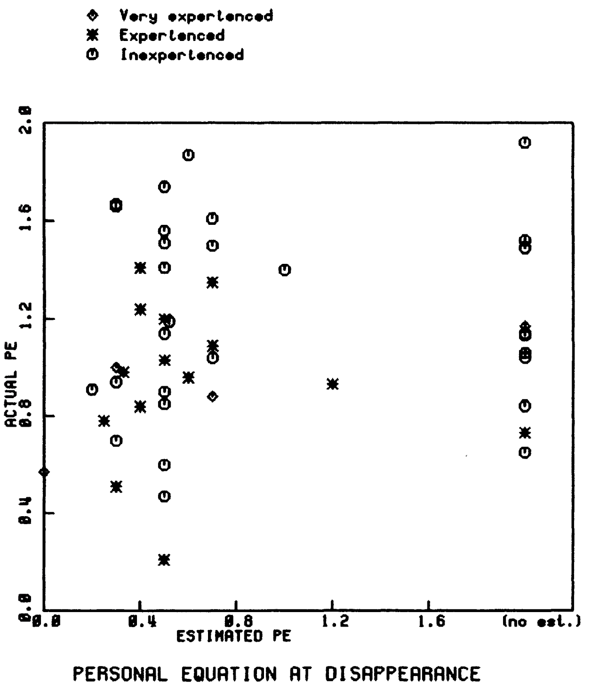

FIG. 16. Personal equation at disappearance.

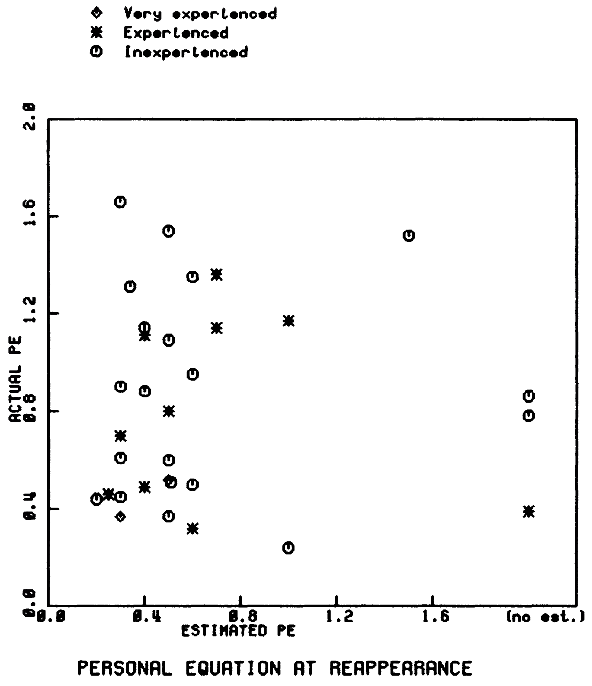

FIG. 17. Personal equation at reappearance.

As expected, the actual reaction times compared to the estimated reaction times show that observers virtually always underestimate their reactions. The reporting or not of an estimated reaction time was taken as one indication of the level of sophistication and experience of the observer. The actual versus the estimated reaction times are plotted in Figs. 16 and 17, with the disappearance and the reappearance data plotted separately. The mean true reaction times of those who estimated their reaction times were less than those who did not. However, this figure shows virtually no correlation of the estimated and actual reaction times except for the very experienced observers. One conclusion is that reports of estimated reaction times cannot be used to compute the appropriate reaction time correction for most visual observations.

The results of the study are summarized in Table VI. The reaction times used for correcting the data are listed by experience class in Table VI, and are listed with the observations in the second-to-last column of Table IV. The experience classes were defined as follows:

Very experienced. Observers who had made large numbers of occultation timings, including grazing occultations from different locations. Most judged very experienced had timed previous asteroidal occultations.

TABLE VI. Summary of true reaction time statistics.

	Disappearances			Reappearances		
Class	No	Avg	St. Dev.	No	Avg	St. Dev.
all	53	$1^{s}09$	$\pm 0^{s}40$	35	$0^{s}78$	$\pm 0^{s}44$
V	4	0.91		2	0.45	
E	14	0.95		10	0.80	
B	30	1.22		20	0.89	
E + B	44	1.13	±0.39	30	0.86	±0.41

B - Beginner
E - Experienced
V - Very experienced

Experienced. Observers who had reported lunar occultation timings more than once.

Inexperienced. Observers who were unfamiliar with occultation reaction times, and with little, if any, previous experience in timing occultations.

The figures and final data reductions utilized event times incorporating these corrections. Thus, the utilized time is the (uncorrected) time listed in Table IV minus the corrected reaction time given in the second-to-last column of that table. The length of the error bars shown in the figures is twice the timing accuracy (± 0.4 s for most visual observers) given in the last column of Table IV, converted to kilometers on the sky plane by the transverse velocity of Pallas, about 12 km/s.

A few observers, most of them inexperienced, used the visual technique known as eye-and-ear, in which the observer tries to determine the time of the event by listening to time signals while observing. Their results were less successful than the more standard technique of recording a mark for the event simultaneously with the time signals. All timings made of this event with the eye-and-ear were discordant, and were not used in the solution. This may indicate that using such a technique might be asking too much of observer capabilities, and observers should be requested to use other methods in the future.

Comparisons of video timings against nearby photoelectric timings usually did not show significant differences.

VI. TWO-DIMENSIONAL ANALYSIS

The final results for the projected ellipse of Pallas at the time of the occultation is shown in Table VII. This was generated from a reduction dataset which had been edited and corrected as discussed above. Two solutions are shown in this table, the first incorporating only the photoelectric, video, and northern limit visual observations, and the second with all of the data. The chords and fitted ellipse for the first solution are shown in Fig. 18. The second solution was the source of the ellipsoid plotted in the previous figures. Observations of flashes and blinks were not included in the reduction dataset, although those not edited for other purposes are included in the reduction data plots. The two disappearances observed at station 76 were included, since, as can be seen in Fig. 13, they were in agreement with timings at adjacent stations. Data from the 1978 previously reduced observation are shown for comparison in Table VII.

There were sufficient observations of events of the secondary (25 disappearance and 12 reappearance timings) to solve for the stellar component separation and position angle of 1 Vulpeculae. This solution is also included in Table VII. Secondary star data plotted in Figs. 3–12 were corrected for the shift of center of figure presented in Table VII. These data will be used in a more detailed analysis of 1 Vulpeculae in Sec. VIII.

The total rotation of Pallas from the first timing to the last was no more than $2^{\circ}5$, based on the several determinations of the sidereal periods of $0^{d}325440$ to $0^{d}325995$ reported by Lagerkvist *et al.* (1989). This would cause only minor changes in the apparent limb profile, but can explain some of the small discrepancies seen in the photoelectric and video data. If a 10 km mountain were just rotating into view over an otherwise smooth limb, it could cause an "irregularity" of 2.9 km to grow during the 3.2 min separating the first and last timings.

The geometric visual albedo p_V for (2) Pallas is determined from the equation (Wasserman *et al.* 1979)

$$\log p_V = 0.4[V_\odot - V(1,0)] - \log(a'b'), \tag{1}$$

TABLE VII. Solutions derived from observations of the occultation of 1 Vulpeculae by Pallas.

Sol. No.	No. Obs.	Center Corrections X (km)	Center Corrections Y (km)	Mean Radius (km)	Flattening	Min.Axis P.A.	Secondary Star Separation	Secondary Star P. A.
1	64	-99.4 ±0.6	43.2 ±0.6	260.3 ±0.4	4.5 ±0.5	$50^{\circ}9 \pm 2^{\circ}3$	$0''0027 \pm 0''0004$	313° ± 8°
2	264	-100.2 ±0.7	42.9 ±0.7	260.2 ±0.6	4.6 ±0.6	53.0 ±2.9	0.0028 ±0.0004	305 ±10
1978 May 29th Occultation of SAO 85009 (Wasserman <u>et al</u>, 1979)								
	14	-1281 ±3	1011 ±3	271.0 ±3	8.4 ±4	58 ±15		

Sol. No.	Ephemeris Corrections △ RA	△ Dec
1	$-0^{s}00340 \pm 0^{s}00002$	$+0''0222 \pm 0''0003$
2	-0.00343 ±0.00002	+0.0220 ±0.0004

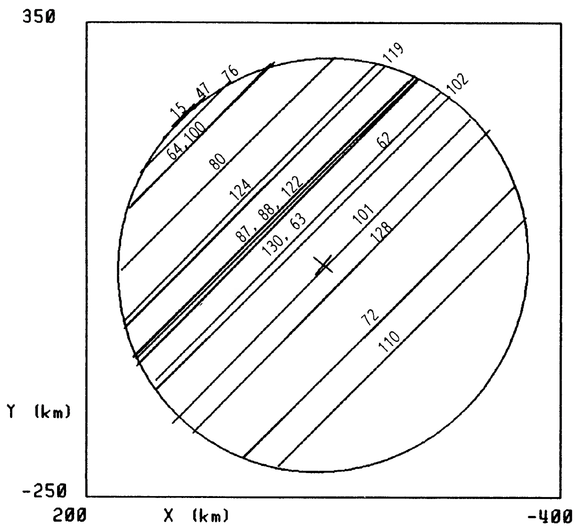

FIG. 18. Solution using photoelectric and video timings.

where $V_{\odot}$ is the absolute visual magnitude of the Sun, $V(1,0)$ the absolute visual magnitude for Pallas measured at the time of the occultation, and $a'b'$ the squared mean apparent radius. The albedoes in U and B, p_U and p_B, are computed in the same way. Results of the computations for the albedos are presented in Table VIII.

VII. THREE-DIMENSIONAL ANALYSIS

Pallas is assumed to be a triaxial ellipsoid with orthogonal axes $2a > 2b > 2c$. For dynamical reasons, Pallas can also be assumed to rotate about its shortest axis, the c axis. The apparent ellipse at the time of an occultation is the asteroid's ellipsoid projected onto the sky plane, with equatorial axis $2a'$ and orthogonal axis in the direction of the projected pole $2b'$, which is usually the shortest axis. The projected axes are functions of a, b, c, B, and ϕ, where B is the latitude of the Earth above the equatorial plane of Pallas, the plane that contains the a and b axes. The angle ϕ is the rotational phase angle, defined to be 0 when the projected area of Pallas has a minimum value. Another angle, P, is needed to describe the orientation of the projected ellipse; it is the position angle of the rotation pole, usually coincident with the b' axis.

TABLE VIII. Pallas photometric data and albedo.

V(1,0) (Binzel, 1984)		4.51 ± 0.02
Color indices	U-B	0.29 ± 0.02
(Tedesco, 1989)	B-V	0.66 ± 0.02
Mean apparent radius $(a'b')^{\frac{1}{2}}$		260.2 ± 0.8km
Geometric albedoes:		
Visual	p_V	0.101 ± 0.002
Blue	p_B	0.051 ± 0.003
Ultraviolet	p_U	0.082 ± 0.003

When the projected area is a minimum, $\phi = 0°$ or 180° and $a' = b$. When the projected area is maximum, $\phi = 90°$ or 270° and $a' = a$. In general,

$$a' = (a^2 \sin^2 \phi + b^2 \cos^2 \phi)^{1/2}. \tag{2}$$

For calculating b', it is convenient to define an auxiliary quantity, q, which is the projected length of the asteroid's equator in the direction of P, perpendicular to a':

$$q = (a^2 \cos^2 \phi + b^2 \sin^2 \phi)^{1/2}. \tag{3}$$

Then,

$$b' = (q^2 \sin^2 B + c^2 \cos^2 B)^{1/2}. \tag{4}$$

The albedo of Pallas is assumed to be uniform over its surface, which implies that its brightness is proportional to its projected area. If the period of rotation is known, ϕ can be determined from observations of the asteroid's light curve near the time of the occultation. The latitude B can be determined if the location of the rotation pole is known from a comprehensive study of many observed light curves measured at different aspects. Good observations of the Pallas light curve were obtained in May 1983 by Binzel (1984). Adopting Binzel's value for B at the time of the occultation, 22°, Binzel's Fig. 3 can be measured to obtain $\phi = 16°$. In his paper, Binzel notes that, at the time of the occultation, "Pallas was about 0.5 hr past minimum light," which gives $\phi = 24°$, the value used by Drummond and Cocke (1989). However, the minimum closest to the occultation phase is not symmetric, probably due to a large irregularity or an albedo feature, and is defined by only one point. A better method, used here, is to compute ϕ from all nine observed points of the much more symmetric deeper minimum at 8.5 hr. The angle ϕ is then computed to be $16° \pm 3°$. The semiaxes of the projected outline are found by adding and subtracting the value for the flattening to and from the mean radius of solution 2 given in Table VII to obtain a' (264.8 ± 0.8 km) and b' (255.6 ± 0.8 km). More information is needed since there are only two equations, (2) and (4), and three unknowns, a, b, and c.

The additional information can be obtained from the change in brightness from the minimum to the maximum of the light curve. Assuming a uniform albedo is equivalent to assuming that the brightness is proportional to the projected area, $A = \pi a'b'$. Evaluating Eqs. (2) and (4) for $\phi = 90°$ and 0° gives the ratio

$$\frac{A_{\max}}{A_{\min}} = \frac{[\sin^2 B + (c/b)^2 \cos^2 B\,]^{1/2}}{[\sin^2 B + (c/a)^2 \cos^2 B\,]^{1/2}}. \tag{5}$$

This is like Eq. (1) in Dunham *et al.* (1984), which contained an error, corrected here. However, Eq. (3) of that paper, derived from Eq. (1), is consistent with Eq. (5) of this paper. The light-curve magnitude range, $V_{\min} - V_{\max}$, in May 1983 was 0.08 ± 0.01, according to Binzel (1984). Then, $A_{\max}/A_{\min} = 1.076$.

It is very difficult to solve Eqs. (2), (4), and (5) for the unknowns a, b, and c. The problem can be simplified by assuming a value for B and using an iterative process to find an exact solution. Since B has a small value, it can be approximated with 0° in Eq. (5), which reduces to

$$A_{\max}/A_{\min} = a/b. \tag{6}$$

Combining Eq. (6) with Eq. (2) gives

$$a = a'/[\sin^2\phi + (b/a)^2\cos^2\phi]^{1/2}, \tag{7}$$

or $a = 283.2$ km. From the known value of $A_{\max}/A_{\min}$ and Eq. (6), $b = 263.2$ km. Then, q can be calculated from Eq. (3) and Eq. (4) inverted to give

$$c = (b'^2 - q^2\sin^2 B)^{1/2}/\cos B, \tag{8}$$

or $c = 251.1$ km.

As a check, Eq. (5) can be evaluated to obtain $A_{\max}/A_{\min} = 1.0633$, which is not the observed value of 1.076. By using the steps following Eq. (6) above with a secant method with different assumed values of a/b, different values of a, b, c, and $A_{\max}/A_{\min}$ are calculated until $A_{\max}/A_{\min}$ equals the observed value. This is obtained with $a/b = 1.092$, which gives $a = 287.0$ km, $b = 262.9$ km, and $c = 250.4$ km. The projected ellipse for the 1978 occultation can be computed using these values, and compared with the observed parameters (Wasserman *et al.* 1979). For that event, Binzel's pole gives $B = 45\overset{\circ}{.}7$. Using this with a, b, and c above give $A_{\max}/A_{\min} = 1.039$, or a magnitude range of 0.041. Unfortunately, the complete light curve was not observed that year, but the observations that were made (Wasserman *et al.* 1979) indicated a variation "less than 0.03 magnitude," in rough agreement with the above value. In any case, ϕ is not known for the 1978 occultation, since useable light variations were not detected that year, and the period of rotation is not known well enough to extrapolate the phase from other years. However, a' and b' can be calculated for different values of ϕ to try to find a value that matches the observed values reported by Wasserman *et al.* If $\phi = 55\overset{\circ}{.}5$, $a' = 279.5$ km, the value reported by Wasserman *et al.*, and b' is then 261.1 km, only 1.6 km less than their value and well within their error of ± 4.5 km. The error in ϕ is $\pm 10°$ to correspond to the ± 2.9 km error in a' reported by Wasserman *et al.*

Finally, P, the position angle of the pole of Pallas (also assumed to be the minor axis of the apparent ellipse), can be calculated using Binzel's pole. The results for P are 81° and 62° for the 1983 and 1978 occultations, respectively. The result for 1983 is 28° greater than the position angle of the (occultation) minimum axis, or ten times the formal observed error. But the flattening then was small, less than 5 km, smaller than many of the departures of the observed profile from the fitted ellipse, which were of the order of 10 km. For the 1978 occultation, where the flattening of the apparent ellipse was much larger, the calculated value of P differs from the observed value by only 4°, compared with the observed error of $\pm 15°$. Overall, the triaxial ellipsoid model, derived from the 1983 observations, as well as from Binzel's pole and light-curve data, agrees very well with results of the 1978 occultation. The largest disagreement is with the position angle of the pole for the 1983 event, but that is understandable considering the small flattening of the apparent ellipse in 1983, and departures from our model that would be expected from the observed variations from a perfect sinusoid in the light curve for Pallas (Binzel 1984), and the limb irregularities revealed by the 1983 occultation data.

Errors in values of a, b, and c defining the triaxial ellipsoid from the occultation data and from the light-curve parameters are listed in Table IX. Since both B and ϕ were small for the 1983 occultation, the occultation errors for b and c are close to those for a' and b' for that event. The occultation error for a is calculated from the errors for the 1979 occultation at our derived phase angle for that event. The $2\overset{\circ}{.}5$ rotation of Pallas during the 3.3 min that timings were made of the 1983 occultation can contribute an error of 0.40 km in a' and 0.13 km in b', so this error source is relatively unimportant.

TABLE IX. Triaxial solution.

Error Source	Error in a	Error in b	Error in c
Occultation	3.5	0.6	0.6
Rotation	0.4	0.4	0.4
$A_{\max}/A_{\min}$	3.0	1.0	1.0
Phase angle, ϕ	1.1	0.9	0.2
Total	4.8	1.5	1.2
Final values	2a = 574 ±10 km		
	2b = 526 ± 3		
	2c = 501 ± 2		
Mean diameter $2(abc)^{1/3}$ = 533 ± 6 km			

The full axes, $2a$, $2b$, and $2c$ are 574 ± 10, 526 ± 3, and 501 ± 2 km, respectively. However, the uncertainties need to be increased, since errors of the location of the asteroid's pole have not been considered. The pole used (Binzel 1984) is about 30° from that determined by Drummond and Cocke (1989). The values of a and b determined by Drummond and Cocke (1989) are well within the errors of the values presented here, but their value of c was lower, especially for their occultation-only solution. Their lower value for c is probably caused by use of 24° for ϕ and the derived position angle of the apparent minor axis for the 1983 occultation. The position angle of the apparent minor axis can be in error by more than the computed formal error due to the small flattening of the apparent ellipse and departures from a triaxial shape, as noted above.

The mass of Pallas was determined to be $1.08 \pm 0.22 \times 10^{-10}$ times that of the Sun by Schubart and Matson (1979). Using the mean diameter of 533 ± 6 km, the asteroid's volume is then $7.91 \pm 0.15 \times 10^{22}$ cm^3 and the mean density is 2.7 ± 0.6 gm/cm^3. Standish and Hellings (1989), using Viking lander ranging data, have determined a mass for Pallas of $1.4 \pm 0.2 \times 10^{-10}\,\mathscr{M}_\odot$. Their formal error for the mass is only $\pm 0.07 \times 10^{-10}\,\mathscr{M}_\odot$, so we prefer it. Standish and Hellings' mass gives a mean density of 3.5 ± 0.5 gm/cm^3. Both values are considerably higher than the mean densities of either C or S class asteroids given by Standish and Hellings.

VIII. PARAMETERS OF THE 1 VULPECULAE SYSTEM

The separation and position angle derived for the secondary can be used to define parameters of the 1 Vulpeculae stellar system. The system also includes two more distant, fainter, companions, as given in the Aitken (1932) catalog (ADS 12243). They are of visual magnitudes 11.8 and 13.0 and are at separations of 39″ and 44″, respectively. These can be safely ignored as too distant and too faint.

The magnitude differences reported at immersion and emersion are given in Table X. The absolute magnitudes produced from the observed magnitude changes are also given in Table X. The absolute magnitudes are calculated using the quoted parallax of 0″.017 (Hoffleit and Jaschek 1982).

TABLE X. Magnitude parameters for the 1 Vulpeculae system.

A. Observed Magnitude Changes

Station	$\triangle m$	Wavelength
63	0.88	Stromgren y (5470 Å)
130	0.78	Unfiltered tube with maximum response near 4000 Å
128	0.9	470nm
128	0.6	800nm

B. Computed UBV Magnitudes

	V	B-V	B	U-B	M_V	M_B	S_p
Pair	4.77	-0.05	4.72	-0.54	0.92	0.87	B4IV
Primary	5.17	-0.02	5.15		1.32	1.30	
Secondary	6.05	-0.12	5.93		2.20	2.08	

1 Vulpeculae is stated (Abt and Levy 1978) to be a spectroscopic binary with $P = 249^{\mathrm{d}}4$ and $a \sin i = 28.72$ million kilometers. This corresponds to a total mass of $5\,\mathscr{M}_{\odot}$, and a value of roughly 200 million kilometers for a, or an almost face-on orbit. With the adopted value of the parallax, the deduced separation from the occultation, is 24 ± 4 million kilometers. This suggests that either the parallax is too large or the orbit very eccentric.

Considering the absolute magnitude expected for a subgiant with a color near zero and a probable main-sequence companion about three quarters of a magnitude fainter and possibly somewhat bluer, an absolute magnitude near zero for the primary would be more likely, which would make the parallax approximately $0\farcs008$. With this parallax, the occultation separation becomes 51 million kilometers, indicating that 1 Vulpeculae was near periastron with an eccentricity of about 0.75, within the spectroscopic value of 0.64 ± 0.16.

The occultation occurred 14.35 ± 0.21 revolutions after the spectroscopic periastron reported by Abt and Levy, so it is reasonable to suggest that it was near periastron. If so, the separation near apastron might be $0\farcs02$, perhaps resolvable with speckle interferometry on a large telescope. Since the spectroscopic elements are only marginal, the discussion above could contain errors. More good spectroscopic observations would improve the orbit and better establish the orbital phase at the time of occultation, with a potential for detecting lines of the secondary, considering its brightness as determined from the occultation data.

An attempt was made to fit theoretical diffraction light curves to the high-speed digital photoelectric data obtained at station 102 (White 1988). This trace had the highest, or equal to the highest, signal-to-noise ratio of any of the photoelectric records. Even so, it was not possible to determine the primary star's angular diameter from these data. The observer noted that conditions "were not photometric." Unfortunately, either clouds, large-amplitude scintillation, or low time resolution, or a combination of these factors, affected each of the photoelectric recordings, apparently precluding determination of the diameters of the stellar components. The record of angular diameters determined from lunar occultations shows that it should be possible to derive the diameter of a star like 1 Vulpeculae from a high-speed recording of an asteroidal occultation obtained in good atmospheric conditions.

IX. CONCLUSIONS

The results of this occultation show the roughness of the Pallas topography, resolving features of approximately 10–20 km, or about 2%–4% of the asteroid's diameter. Combination of solutions from this and previous occultations shows the triaxial shape of Pallas to be elongated, but not severely so, with the ratio of the largest to the smallest axes less than 1.15. Also, the data from this event provide a separation and a position angle of the secondary component of 1 Vulpeculae. The analysis of the observations gives a calibration of the accuracy and the reaction time corrections for visual observations of asteroidal occultations. Finally, through lack of any unambiguous anomaly observed in the sky plane near the asteroid, these data provide no evidence of a companion to the asteroid, nor of a surrounding cloud of particles.

We thank all obervers who provided us with their timings. We thank Roger Beehler and John Milton at the National Bureau of Standards, Ft. Collins, CO, for making arrangements to broadcast prediction updates on WWV at no cost to us. We also thank Carolyn Schoemaker at the U.S. Geological Survey in Flagstaff for measuring the critical 27 May USNO plates while the machine at Lowell Observatory was inoperable. Hubbard and Reitsema acknowledge support from NSF Grant No. AST-8205728 and NASA Grant No. NSG-7045. Klemola acknowledges support from NSF Grant No. AST 81-12347. We acknowledge the provision of data about 1 Vulpeculae by Wayne Warren at the Astronomical Data Center at Goddard Space Flight Center. We thank Don Stotz (station 317) for his special efforts to refine the coordinates of some of the stations near the northern limit. We would like to acknowledge especially the contributions from the following persons, who made attempts to observe but were unable to monitor 1 Vulpeculae; the success of the overall effort was due to the coordinated wide dispersal of hundreds of observers, and inevitably, many were clouded out: J. Aczel, B. Adams, Jr., L. Adams, J. Africano, J. Arnold, D. Ashcraft, W. Aulenbacher, M. Avery, W. Bagget, G. Balazs, B. Barber, B. Baskett, B. Bearden, G. Bell, L. Biser, W. and M. Blackmon, J. Blair, M. Blanchette, T. Blocker, L. Borden, B. Bourgeois, D. Boyd, J. Boyd, P. Bradley, D. Bricker, B. Broussard, D. Brown, S. Brown, R. Bryant, J. Buciaga, D. Burkes, J. Busch, J. Busch, R. Busdosh, C. Byars, L. Cain, F. Cerkan, J. and P. Chambliss, A. Ciampi, D. Clark, M. Clark, J. Clement, H. Cohen, A. Coleman, D. Coleman, J. Colgrove, Collier, K. Collins, N. Combs, T. and C. Contant, A. Contreras, E. and J. Cooper, F. Cooper, Corpus Christi Astronomical Society members, O. Courtney, D. Dailey, O. Dane, M. Delavoryas, S. Demaree, B. Dillon, L. Duemer, B. Dunbar, T. and M. Dyson, S. and B. Etheridge, C. Faircourt, R. Fairman, R. and P. Ferdie, R. Fischer, C. Fore, B. and L. Frenzel, W. Frerk, L. Friesen, L. Frost, F. Garcia, S. Goldberg, P. Goodman, C. Gould, M. Greffin, D. Griesel, L. Hadwig, D. Halter, D. Heath, L. Hellman, T. Henderson, S. Hendrix, C. Herseim, J. Hilton, J. Holberg, B. and A. Hollingsworth, R. Hovie, J. Hubisz, M. Hurta, J. Hyatt, D. Irvin, I. Izaguirre, T. Izor, N. James, M. Jenness, D. Johnson, J. Johnson, W. Johnson, G. Jones, K. Kaufman, A. Kelly, R. Kenefick, B. Killingsworth, S. Lacy, K. Ladwig, W. LaFleur, B. LaFrance, M. Lardas, B. Larue, M. Lawrence, R. Lynch, E. and E. Malewitz, A. Maller, D. Mandelstein, T. Markin, M. Martin, P. and D. Mason, F. Mawhinney, D. McDavid, J. McEven, T. McFaul, C. McKay, D. McKenna, G. McLerran, J. McMahon, M. McNeil, C. Meister, S. Merin, D. G. Miller, R. Millis, D. Mink, W. Moore, D. Morrell, K. Morris, M. Morris, P. Muhm, S. Nanning, G. Nealis, G. Nelson, P. Newman, G. Nickas, S. Nixon, P. and T. Nolan, R. O'Dell, R. Oliver, W. Osborn, Palomar Amateur Astronomers, A. Parker, J. Penn, R. Petersen, D. Peterson, F. Pilcher, R. Plooard, S. Preston, R. Prince, J. Prukop, D. Rachal, P. Radoff, D. Rask, M. Raymond, B. Reed, P. Reiff, K. and J. Richardson, R. Ricklefs, L. Rimes, M. Rios, P. and P. Robertson, R. Robertson, D. Robinson, R. Robinson, B. and M. Rogge, J. Roland, L. Roth, R. Rouse, M. Rowe, K. Ruzyla, E. Sarratt, I. Saulietis, R. Schaeffer, B. Schmidt, R. Schmude, S. Schwartz, E. Sczepanski, A. Seacord, A. Sifford, C. Smreker, G. Sotek, J. Stamm, T. Stoa, D. Stockbauer, D. Stone, R. Stone, C. Sumners, J. Sunkel, R. Sutton, T. Taylor, S. Teplitz, K. Thomson, R. Trank, M. Trinaystich, E. Untermeyer, D. Walker, R. Weil, S. Welch, J. West, J. West, R. White, R. and C. Wilcox, J. Wilkerson, R. Williamon, P. Williams, T. Williams, K. Windhorst, G. Witkowski, R. Wooley, D. Wylie, Wyrick Teams 1 to 8 (Oklahoma), B. Yeats, G. Young, T. Younts, L. Zepeda, and D. Zwicky.

REFERENCES

Abt, H. A., and Levy, S. G. (1978). Astrophys. J. Suppl. Ser. **36**, 241.

Aitken, R. G. (1932). *New General Catalog of Double Stars* (Carnegie Institution of Washington, Washington, DC).

Binzel, R. P. (1984). Icarus **59**, 456.

Chapman, C. (1983). Planetary Report **3**, 20.

Clark, T. A., and Milone, E. F. (1973). J. R. Astron. Soc. Can. **67**, 198.

Douglass, W. T., Parker, D. C., Beish, J. D., Martin, J. O, and Monger, D. R. (1983). IAPPP Communications No. 14, 71.

Drummond, J. D., and Cocke, W. J. (1989). Icarus **78**, 323.

Dunham, D. W. (1979). Occultation Newsl. **2**, 62.

Dunham, D. W. (1981). Occultation Newsl. **2**, 146.

Dunham, D. W. (1982). Occultation Newsl. **3**, 2 and 9.

Dunham, D. W., and Maley, P. (1983a). Occultation Newsl. **3**, 46 and 67.

Dunham, D. W., and Maley P. (1983b). Sky and Telescope **65**, 440.

Dunham, E. W., Baron, R. L., Conner, S., Dunham, D. W., Dunham, J. B., Schneider, G., Cohen, H. L., Helms III, V. T., Croom, M., and Safko, J. (1984). Astron. J. **89**, 1755.

Hoffleit, D., and Jaschek, C. (1982). *Yale Bright Star Catalog*, Fourth Revised Edition (Yale University Observatory, New Haven, CT).

Hubbard, W., and Reitsema, H. J. (1983). IAUC No. 3825.

Kapkov, V. B. (1984). Sov. Astron. Lett. **10**, 26.

Klemola, A. R., and Harlan, E. A. (1982). Astron. J. **87**, 1242.

Klemola, A. R., and Harlan, E. A. (1984). Astron. J. **89**, 879.

Lagerkvist, C.-I., Harris, A., and Zappala, V. (1989). In *Asteroids II*, edited by R.P. Binzel and T. Gehrels (University of Arizona, Tucson), p. 1162.

Landgraf, W. (1984). MPC 8665, April 15.

Lee, P., Watson, C., Williams, H., Miller, R., James, R., and Coskrey, W. (1987). IAPPP Communications No. 30, 5.

Millis, R. L., and Dunham, D. W. (1989). In *Asteroids II*, edited by R.P. Binzel and T. Gehrels (University of Arizona, Tucson), p. 148.

Morrison, L. V. and Appleby, G. G., (1971). Mon. Not. R. Astron. Soc. **196**, 1005.

O'Leary, B. (1972). Science **174**, 1108.

Schubart, J., and Matson, D. L. (1979). In *Asteroids*, edited by T. Gehrels (University of Arizona, Tucson), p. 84.

Schuster, W. J., Moreno, M. A., Guichard, J., and Sanchez, G. R. (1984). Rev. Mexicana Astron. Astrof. **9**, 21. (Research Note: The occultation of 1 Vulpeculae by Pallas.)

Sinvhal, S. D., Sanwal, N. B., and Pande, M. C. (1962). The Observatory **82**, 16.

Sinzi, A. M., and Suzuki, H. (1967). Report of Hydrographic Researches, No. 2, Maritime Safety Agency, Tokyo, 154.

Sitarski, G. (1981). MPC 6464, November 11.

Stamm, J. (1985). Occultation Newsl. **3**, 296.

Standish, E. M., Jr., and Hellings, R. W. (1989). Icarus **80** 326.

Sullivan, W. (1983). New York Times, July 19, Cl.

Taylor, G. (1981). Astron. J. **86**, 6.

Tedesco, E. F. (1989). In *Asteroids II*, edited by R. P. Binzel and T. Gehreb (University of Arizona, Tucson), p. 1093.

Wasserman, L. H. (1979). Private communication.

Wasserman, L. H., Bowell, E., Millis, R. L. (1981). Astron. J. **86**, 2.

Wasserman, L. H., Millis, R. L., Franz, O. G., Bowell, E., White, N. M., Giclas, H. L., Martin, L. J., Elliot, J. L., Dunham, E., Mink, D., Baron, R., Honeycutt, R. K., Henden, A. A., Kephart, J. E., A'Hearn, M. F., Reitsema, H. J., Radick, R., and Taylor, G. E. (1979). Astron. J. **84**, 259.

White, N. M. (1988). Private communication.