APPARENT CLOSE ENCOUNTERS OF MINOR PLANETS

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ABSTRACT

During the period 1985.0–2001.4, the 34 minor planets of the Texas Minor Planet Project experience 18 apparent close encounters, where two of the minor planets appear within one degree of each other. The dynamical importance of these close encounters is discussed. Observations are solicited, and the information needed for the observation of these rare events is illustrated and tabulated.

I. INTRODUCTION

Analysis of the orbits of the 34 minor planets (Table I) selected for the Texas Minor Planet Project (TMPP) has produced eighteen apparent close encounters during the period 1985.0 through 2001.4. An apparent close encounter (ACE) between two minor planets (MPs) is defined as occurring when the two MPs appear within 1° of each other in the sky.

Various aspects of the TMPP have been described by Hemenway (1980), Duncombe, Hemenway, and Whipple (1984), and Hemenway and Duncombe (1985). In these references and many others dating back to the fundamental papers of Numerov (1928), Denprovsky (1932), and Brouwer (1935), it has been shown that series of precise observations of selected minor planets can be utilized to improve the accuracy of the fundamental reference system. The astrometric observations of the minor planets enable the background-star positions to be tied to an accurately known dynamical system described by the minor planets, and such studies have, in fact, been carried out by several authors, including Naur (1957), Pierce (1971, 1978) and Orelskaya (1980).

The TMPP will utilize precise ground-based and *Space Telescope* observations of the 34 selected minor planets to make further improvements in the fundamental reference system.

One important phase of the TMPP is the identification of apparent crossing points: the *single point* on the celestial sphere where the two minor planets may be observed on different dates, usually widely spaced in time. Of the approximately 8000 crossing points found for the 34 minor planets, only on 18 occasions do two MPs move to within 1° of each other over the 16 yr span of the investigation. Any ACEs that occur within 55° of the Sun have been excluded, due to *Space Telescope* constraints.

II. IMPORTANCE OF ACEs

The observation of minor planets at crossing points in general and at the ACEs in particular are of special importance because they will yield more accurate relative positions (minor planet to minor planet) than traditional single absolute observations. When the two MPs pass through the same star field, either on the same date or on different dates, their relative position $(\alpha_2 - \alpha_1)$, $(\delta_2 - \delta_1)$ can be determined to a much higher degree of accuracy than the accuracy of a single observation (α_1, δ_1). The relative position is mostly independent of the absolute star positions, which are a major source of error in precise astrometry.

In principle, very accurate relative positions are possible when the two MPs can be observed simultaneously in the same field of view. Then the factors that vary over time, such as stellar proper motion, seeing, and zenith distance, do not contribute significant errors. Also, the simultaneous observation of the two MPs should reduce observation time and guarantee that if one MP is observed, then the other MP is also observed.

III. THE EARLIEST CLOSE ENCOUNTER

Minor planets (846) Ara and (965) Angelica have the earliest close encounter, in January 1986. Figure 1 shows the zero-hour (UT) positions of the two MPs at 2 day intervals surrounding the date of closest approach. Arrows indicate the directions of motion of the two MPs. Solid lines showing their separation are drawn between the positions of the two bodies on the first date and on the last date plotted. Note that the closest approach does *not* occur at the point where the apparent paths intersect, because the two MPs are not at that point simultaneously. In this case, MP 965 arrives at the apparent intersection nearly two days before MP 846.

Table II contains the ephemerides of the two minor planets in 2 day intervals. Also shown are the apparent magnitudes (MAG) and the separation (SEP, in arcminutes) of the two MPs. These two MPs will appear within 1° of each other for about 29 days, reaching a minimum separation of 47° on 19.0 January 1986.

TABLE I. Minor planets in the TMPP.

25 Phocaea	846 Lipperta
51 Nemausa	849 Ara
61 Danae	950 Ahrensa
148 Gallia	965 Angelica
218 Bianca	1108 Demeter
373 Melusina	1222 Tina
387 Aquitania	1252 Celestia
391 Ingeborg	1276 Ucclia
434 Hungaria	1310 Villigera
475 Ocllo	1320 Impala
502 Sigune	1340 Yvette
599 Luisa	1383 Limburgia
619 Triberga	1453 Fennia
637 Chrystothemis	1474 Beira
652 Jubilatrix	1584 Fuji
654 Zelinda	1626 Sadeya
692 Hippodamia	2000 Herschel

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TABLE II. Ephemerides for seven apparent close encounters: 1986–1990.

		MP 846				MP 965				
DATE	ET	R.A. (1950)	DEC.	MAG.	R.A. (1950)	DEC.	MAG.	SEP.
1986	1 2	15 13.88	-18 8.7	17.4	15 17.82	-17 46.8	17.2	63.0
1986	1 4	15 15.97	-18 16.8	17.4	15 19.80	-17 59.4	17.2	60.1
1986	1 6	15 18.03	-18 24.8	17.4	15 21.76	-18 11.9	17.2	57.4
1986	1 8	15 20.07	-18 32.5	17.3	15 23.69	-18 24.2	17.2	54.9
1986	1 10	15 22.08	-18 40.0	17.3	15 25.59	-18 36.4	17.2	52.7
1986	1 12	15 24.06	-18 47.3	17.3	15 27.45	-18 48.4	17.2	50.8
1986	1 14	15 26.02	-18 54.5	17.3	15 29.28	-19 .2	17.2	49.2
1986	1 16	15 27.94	-19 1.4	17.3	15 31.07	-19 11.9	17.2	48.1
1986	1 18	15 29.83	-19 8.2	17.3	15 32.82	-19 23.5	17.2	47.5
1986	1 20	15 31.68	-19 14.7	17.3	15 34.54	-19 34.9	17.1	47.3
1986	1 22	15 33.50	-19 21.1	17.2	15 36.21	-19 46.2	17.1	47.8
1986	1 24	15 35.28	-19 27.2	17.2	15 37.84	-19 57.3	17.1	48.8
1986	1 26	15 37.03	-19 33.2	17.2	15 39.43	-20 8.3	17.1	50.3
1986	1 28	15 38.74	-19 38.9	17.2	15 40.98	-20 19.1	17.1	52.4
1986	1 30	15 40.40	-19 44.5	17.2	15 42.48	-20 29.8	17.1	55.0
1986	1 32	15 42.03	-19 49.8	17.2	15 43.93	-20 40.4	17.1	58.1
1986	1 34	15 43.60	-19 55.0	17.1	15 45.33	-20 50.9	17.1	61.6

		MP 1474				MP 61				
DATE	ET	R.A. (1950)	DEC.	MAG.	R.A. (1950)	DEC.	MAG.	SEP.
1986	2 15	7 13.80	39 .1	15.2	7 14.58	37 14.9	13.4	105.9
1986	2 16	7 13.57	38 32.7	15.2	7 13.99	37 9.2	13.4	83.8
1986	2 17	7 13.39	38 5.7	15.3	7 13.44	37 3.3	13.4	62.4
1986	2 18	7 13.26	37 39.0	15.3	7 12.91	36 57.4	13.4	42.0
1986	2 19	7 13.18	37 12.7	15.3	7 12.41	36 51.4	13.4	24.2
1986	2 20	7 13.15	36 46.8	15.4	7 11.93	36 45.4	13.5	18.3
1986	2 21	7 13.17	36 21.2	15.4	7 11.49	36 39.3	13.5	31.1
1986	2 22	7 13.24	35 55.9	15.4	7 11.08	36 33.2	13.5	49.4
1986	2 23	7 13.35	35 31.1	15.5	7 10.69	36 27.0	13.5	68.7

		MP 619				MP 1453				
DATE	ET	R.A. (1950)	DEC.	MAG.	R.A. (1950)	DEC.	MAG.	SEP.
1986	7 4	2 2.77	12 2.9	15.1	2 4.23	11 2.2	17.0	64.5
1986	7 5	2 4.31	12 6.9	15.1	2 5.76	11 18.9	17.0	52.7
1986	7 6	2 5.85	12 10.8	15.1	2 7.28	11 35.6	17.0	41.2
1986	7 7	2 7.38	12 14.7	15.1	2 8.80	11 52.3	17.0	30.8
1986	7 8	2 8.91	12 18.4	15.1	2 10.30	12 9.0	17.0	22.9
1986	7 9	2 10.42	12 21.9	15.1	2 11.80	12 25.6	17.0	21.0
1986	7 10	2 11.93	12 25.4	15.1	2 13.29	12 42.3	17.0	26.5
1986	7 11	2 13.43	12 28.7	15.1	2 14.78	12 59.0	17.0	36.4
1986	7 12	2 14.92	12 32.0	15.0	2 16.25	13 15.7	17.0	48.1
1986	7 13	2 16.41	12 35.1	15.0	2 17.72	13 32.4	16.9	60.6

		MP 846				MP 1252				
DATE	ET	R.A. (1950)	DEC.	MAG.	R.A. (1950)	DEC.	MAG.	SEP.
1987	10 15	20 .53	-20 18.5	15.7	20 .94	-19 14.9	16.6	63.9
1987	10 16	20 1.20	-20 16.6	15.8	20 1.66	-19 20.8	16.6	56.2
1987	10 17	20 1.90	-20 14.6	15.8	20 2.39	-19 26.6	16.6	48.6
1987	10 18	20 2.62	-20 12.6	15.8	20 3.14	-19 32.2	16.6	41.1
1987	10 19	20 3.35	-20 10.5	15.8	20 3.91	-19 37.7	16.6	33.9
1987	10 20	20 4.11	-20 8.3	15.8	20 4.70	-19 43.0	16.6	26.8
1987	10 21	20 4.88	-20 6.0	15.8	20 5.50	-19 48.1	16.6	20.2
1987	10 22	20 5.67	-20 3.7	15.8	20 6.33	-19 53.1	16.7	14.4
1987	10 23	20 6.48	-20 1.3	15.8	20 7.16	-19 57.9	16.7	10.8
1987	10 24	20 7.31	-19 58.9	15.8	20 8.02	-20 2.6	16.7	11.2
1987	10 25	20 8.16	-19 56.3	15.8	20 8.89	-20 7.1	16.7	15.4
1987	10 26	20 9.02	-19 53.8	15.8	20 9.77	-20 11.5	16.7	21.0
1987	10 27	20 9.90	-19 51.1	15.8	20 10.68	-20 15.7	16.7	27.2
1987	10 28	20 10.80	-19 48.3	15.9	20 11.59	-20 19.8	16.7	33.6
1987	10 29	20 11.71	-19 45.5	15.9	20 12.53	-20 23.7	16.8	40.1
1987	10 30	20 12.64	-19 42.7	15.9	20 13.47	-20 27.5	16.8	46.6

TABLE II. (continued)

		MP 652				MP 1340				
DATE	ET	R.A. (1950)	DEC.	MAG.	R.A. (1950)	DEC.	MAG.	SEP.		
1988	2 13	18 38.77	-22 36.4	17.2	18 41.62	-23 26.4	17.7	65.7		
1988	2 15	18 42.35	-22 39.1	17.1	18 44.84	-23 23.1	17.7	57.8		
1988	2 17	18 45.92	-22 41.5	17.1	18 48.04	-23 19.7	17.7	49.7		
1988	2 19	18 49.48	-22 43.7	17.1	18 51.21	-23 16.0	17.7	41.5		
1988	2 21	18 53.02	-22 45.8	17.1	18 54.35	-23 12.2	17.7	33.1		
1988	2 23	18 56.54	-22 47.6	17.1	18 57.45	-23 8.1	17.7	24.6		
1988	2 25	19 .05	-22 49.4	17.1	19 .52	-23 3.9	17.7	16.2		
1988	2 27	19 3.54	-22 50.9	17.0	19 3.55	-22 59.5	17.6	8.6		
1988	2 29	19 7.01	-22 52.3	17.0	19 6.55	-22 55.0	17.6	7.5		
1988	3 2	19 10.47	-22 53.6	17.0	19 9.50	-22 50.3	17.6	14.8		
1988	3 4	19 13.90	-22 54.7	17.0	19 12.43	-22 45.5	17.6	23.9		
1988	3 6	19 17.31	-22 55.7	17.0	19 15.31	-22 40.5	17.6	33.7		
1988	3 8	19 20.70	-22 56.7	16.9	19 18.15	-22 35.5	17.6	43.8		
1988	3 10	19 24.07	-22 57.5	16.9	19 20.95	-22 30.3	17.6	54.1		
1988	3 12	19 27.41	-22 58.3	16.9	19 23.71	-22 25.0	17.6	64.8		

		MP 1383				MP 637				
DATE	ET	R.A. (1950)	DEC.	MAG.	R.A. (1950)	DEC.	MAG.	SEP.		
1988	12 18	22 51.54	-7 15.8	17.0	22 55.29	-6 52.5	17.6	60.9		
1988	12 19	22 52.82	-7 8.0	17.0	22 56.00	-6 48.1	17.6	51.7		
1988	12 20	22 54.10	-7 .1	17.0	22 56.71	-6 43.6	17.6	42.5		
1988	12 21	22 55.40	-6 52.2	17.0	22 57.44	-6 39.1	17.6	33.3		
1988	12 22	22 56.70	-6 44.2	17.0	22 58.18	-6 34.5	17.6	24.1		
1988	12 23	22 58.02	-6 36.1	17.0	22 58.93	-6 29.8	17.7	15.0		
1988	12 24	22 59.34	-6 27.9	17.0	22 59.68	-6 25.1	17.7	5.9		
1988	12 25	23 .67	-6 19.6	17.0	23 .45	-6 20.3	17.7	3.4		
1988	12 26	23 2.01	-6 11.3	17.0	23 1.23	-6 15.4	17.7	12.4		
1988	12 27	23 3.36	-6 2.9	17.1	23 2.02	-6 10.5	17.7	21.5		
1988	12 28	23 4.72	-5 54.5	17.1	23 2.82	-6 5.5	17.7	30.6		
1988	12 29	23 6.08	-5 46.0	17.1	23 3.62	-6 .4	17.7	39.6		
1988	12 30	23 7.46	-5 37.4	17.1	23 4.44	-5 55.3	17.7	48.7		
1988	12 31	23 8.84	-5 28.7	17.1	23 5.27	-5 50.1	17.7	57.7		
1989	1 1	23 10.23	-5 20.0	17.1	23 6.10	-5 44.8	17.7	66.7		

		MP 434				MP 51				
DATE	ET	R.A. (1950)	DEC.	MAG.	R.A. (1950)	DEC.	MAG.	SEP.		
1990	11 1	21 5.92	-12 34.7	14.5	21 8.86	-12 54.8	12.4	48.3		
1990	11 2	21 7.56	-12 41.6	14.5	21 9.72	-12 55.0	12.4	35.1		
1990	11 3	21 9.22	-12 48.1	14.5	21 10.61	-12 55.1	12.4	22.0		
1990	11 4	21 10.88	-12 54.3	14.6	21 11.51	-12 55.1	12.4	9.4		
1990	11 5	21 12.56	-13 .2	14.6	21 12.43	-12 54.9	12.4	5.7		
1990	11 6	21 14.26	-13 5.8	14.6	21 13.36	-12 54.6	12.5	17.5		
1990	11 7	21 15.97	-13 11.2	14.6	21 14.31	-12 54.2	12.5	30.0		
1990	11 8	21 17.69	-13 16.2	14.6	21 15.28	-12 53.6	12.5	42.6		
1990	11 9	21 19.42	-13 20.9	14.6	21 16.27	-12 52.9	12.5	55.0		

IV. THE SET OF CLOSE ENCOUNTERS

We have illustrated (Figs. 1–7) the seven apparent close encounters that occur during the remainder of this decade. Most are similar to the ACE described above: the two minor planets are in direct motion, on intersecting apparent paths, with one slowly overtaking and passing the other, with minimum separations as small as 3′.

The ACE between MP 1474 and MP 61 (Fig. 2) is of interest because the MPs are in retrograde motion and their paths are steeply inclined to each other. Their rapid relative motion brings them within 1° of each other for less than 6 days.

The ACE illustrated in Fig. 6 is interesting because both minor planets 637 ($i = 0.°29$) and 1383 ($i = 0.°05$) are in very low-inclination orbits. After mid-December 1988 the fast moving MP 1383 ($\approx$54 arcsec/hr) will appear to pursue MP 637 ($\approx$31 arcsec/hr) along the same path. On the evening of 24 December 1988 UT they will reach their closest apparent separation of less than 3′, and then MP 1383 will move steadily ahead.

For observers, the ephemerides for all seven illustrated events (1986–1990) are tabulated in Table II.

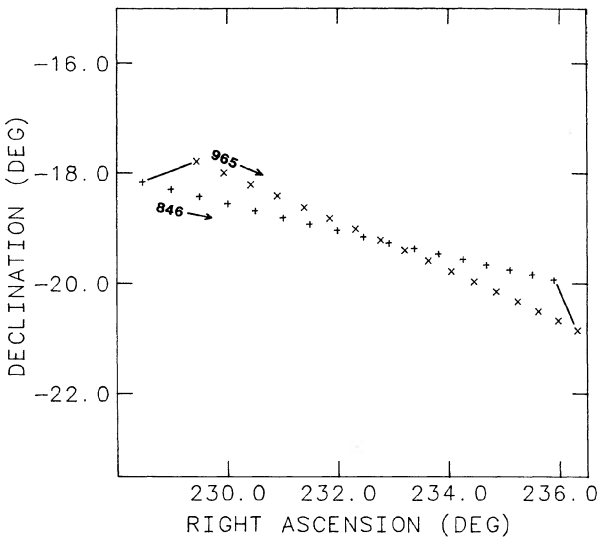

FIG. 1. Positions of MPs 846 and 965 during the ACE of January 1986; 2 day steps.

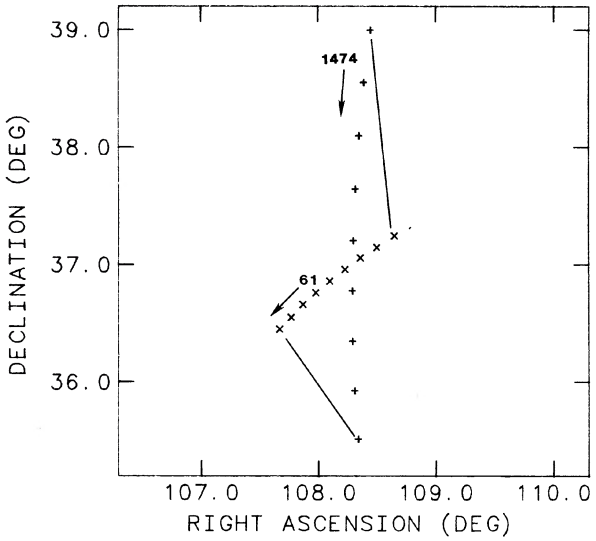

FIG. 2. Positions of MPs 1474 and 61 during the ACE of February 1986; 1 day steps.

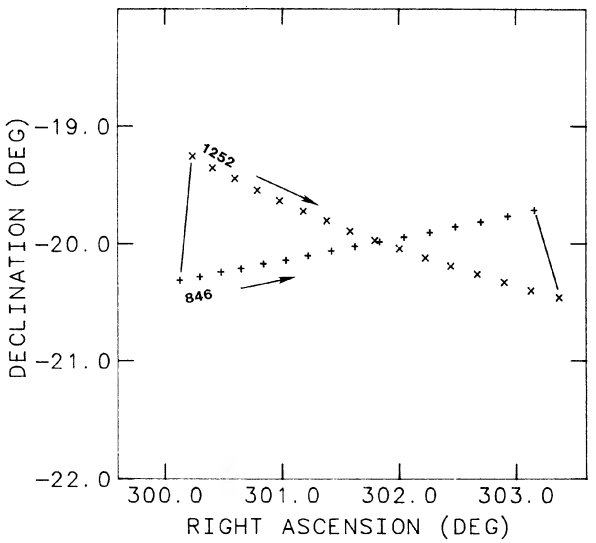

FIG. 4. Positions of MPs 846 and 1252 during the ACE of October 1987; 1 day steps.

The data for the 11 ACEs that occur during the last decade of the century are summarized in Table III. Ephemerides are available from the second author. The date is that of apparent closest approach. The positions (α, δ), the rates of change of the positions $(\dot{\alpha}, \dot{\delta})$, the apparent magnitudes (m) and the separation (SEP) are given for the same date. The number of days during which the two MPs are within 1° is given by INT.

V. CALL FOR OBSERVATIONS

We urge observers to take advantage of the opportunities to observe and record these rare and important events. Observations of the ACEs should be sent to the second author, and to the Minor Planet Center at the Harvard-Smithsonian Observatory.

VI. A VERY CLOSE ENCOUNTER

The importance of predicting apparent close encounters before they occur was demonstrated to Richard Binzel, who inadvertantly missed the opportunity to witness an appulse between two minor planets. In his thesis he writes (Binzel 1985):

"While locating 1178 Irmela on the night of May 1, 1984 UT, the author independently 'discovered' asteroid 485 Genua which happened to be 2.5 arcminutes south of 1178.

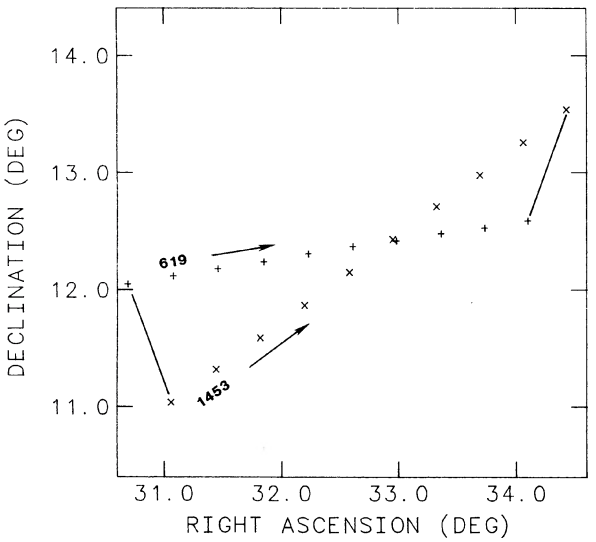

FIG. 3. Positions of MPs 619 and 1453 during the ACE of July 1986; 1 day steps.

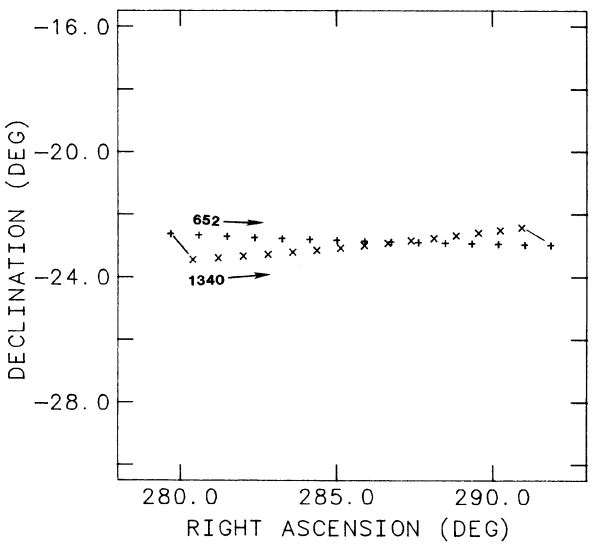

FIG. 5. Positions of MPs 652 and 1340 during the ACE of February 1988; 2 day steps.

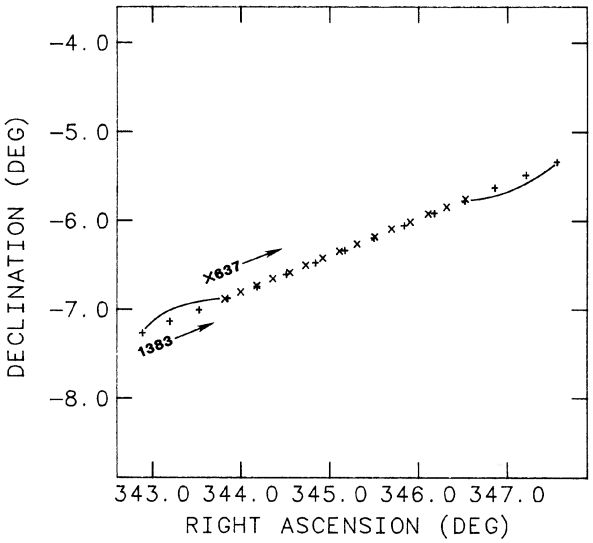

FIG. 6. Positions of MPs 637 and 1383 during the ACE of December 1988; 1 day steps.

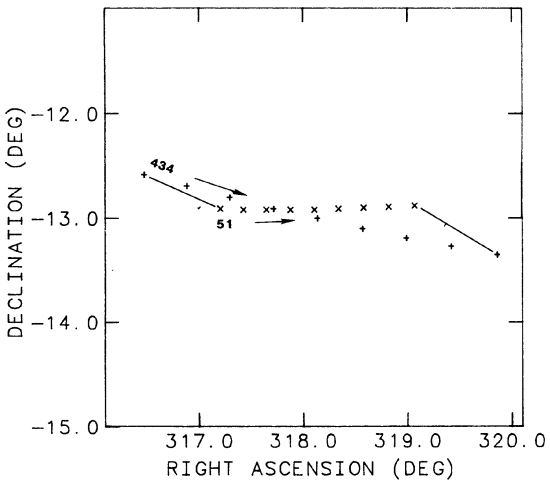

FIG. 7. Positions of MPs 434 and 51 during the ACE of November 1990; 1 day steps.

Genua was about two magnitudes brighter than Irmela. On the following night, May 2, at 4:20 UT, the author was able to locate 485 Genua but not 1178 Irmela. Clouds interrupted observations from 4:50–7:50 UT. When observations resumed, 1178 Irmela was easily found and 485 Genua was located less than 1 arc-minute north of 1178. It is estimated that an appulse between 485 Genua and 1178 Irmela occurred near 4:30 UT, and that their minimum apparent separation was less than 2 arcseconds (the size of the seeing disk). Their spatial separation was greater than 0.5 AU."

TABLE III. Data for 11 apparent close encounters: 1991–2001.

Closest approach	MP No.	α(1950.0) (deg)	$\dot{\alpha}$ ("/min)	δ(1950.0) (deg)	$\dot{\delta}$ ("/min)	m	Sep.(') INT(days)
2.0 May 1992	2000	238.25	−0.72	−47.34	0.06	16.9	41
	1310	239.23	−0.79	−47.51	−0.14	17.0	19
21.1 Feb. 1993	148	188.78	−0.26	15.16	0.50	12.7	12
	599	188.58	−0.35	15.22	0.21	14.4	16
4.5 Aug. 1993	654	320.67	−0.65	4.55	0.03	13.1	17
	2000	320.41	−0.78	4.42	0.31	15.1	15
17.4 Jun. 1994	1474	0.53	0.95	3.61	1.00	16.3	10
	51	0.35	0.64	3.67	0.21	12.6	6
29.2 May 1995	25	358.96	1.27	17.34	0.52	12.2	1
	1584	358.97	0.67	17.35	0.62	16.9	8
23.0 Aug. 1995	599	70.50	0.81	22.84	0.33	13.1	36
	637	70.59	0.60	22.49	0.08	17.2	12
20.4 Jun. 1996	51	151.26	1.07	11.34	−0.26	12.4	23
	218	151.46	0.92	11.67	−0.18	14.2	26
29.0 Aug. 1996	434	73.32	0.99	4.47	−0.40	15.2	9
	387	73.39	0.49	4.60	−0.11	13.2	8
8.0 Sep. 1996	148	113.47	1.00	4.94	−0.15	12.7	12
	25	113.59	0.75	4.78	−0.32	14.3	16
14.8 Nov. 1996	349	325.06	0.55	−21.07	0.33	11.4	29
	1453	325.53	0.77	−21.27	0.83	16.6	8
13.8 Jun. 1997	2000	0.86	0.95	18.85	0.87	15.9	36
	654	1.33	0.60	18.43	0.52	13.9	8
7.7 Oct. 1999	1383	354.94	−0.38	−2.17	−0.16	15.8	12
	950	355.14	−0.44	−2.19	−0.52	15.9	13

VII. CONCLUSIONS

There are eighteen opportunities over the next 16 yr to observe two minor planets in the TMPP when they are within 1° of each other. Observations of these events will aid greatly in the improvement of the orbits of these objects and in the fundamental reference system studies of the TMPP.

The 18 ACEs described are too faint to be observed visually or with small telescopes. However, a similar study of bright minor planets, none of which are included in the TMPP set, is under way to discover apparent close encounters that can be more easily observed.

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