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ANALYSIS OF ANCIENT CHINESE RECORDS OF OCCULTATIONS BETWEEN PLANETS AND STARS

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ABSTRACT

One hundred seventy-three historical Chinese records of occultations and appulses (conjunctions with small least separations) of planets with stars, other planets, and extended objects were examined. The observations were made by the Chinese imperial astronomers from 12 December 146 B.C. to 3 February 1761 A.D. and preserved in the Chinese dynastic histories. Sixty-six of the records were of occultations, 83 records were of appulses, and 24 records were questionable as to the objects involved. These observations were compared to both ephemerides derived from the Bretagnon (1982) planetary theory and the JPL planetary ephemeris DE102. Both of the ephemerides verified that all of the well-recorded events occurred, and usually on the recorded day. This constitutes the first comparison of planetary theories and integration with ancient Chinese observations giving a weak check of the theories over moderately long periods of time. The results of this check show no evidence within the accuracy of these observations, inferred to be about 300″, for secular discrepancies in the present theories on the timescale of two thousand years. When the deceleration of the Earth's rotation was taken into account, it was also found that the events usually took place at the time of night recorded by the Chinese observers, $\sim 1/10$ of the night. This constitutes a check on the ΔT determinations independent of solar eclipse observations. Therefore, these records reveal that to the accuracy of these observations there are no serious flaws in the presently accepted planetary theories or determinations of the rotational deceleration of the Earth (ΔT). Also, this study gives some insight into how the Chinese imperial astronomers charted the motions of the planets in the heavens.

I. INTRODUCTION

Most planetary ephemerides are based on observations made over the past two centuries, the time during which truly excellent records have been kept. However, there may be long-period perturbations in the planetary orbits which this relatively short period of observations may have failed to detect. In order to determine if these long-period perturbations exist it is necessary to turn to the older but less-exact records that exist. The time base over which the ephemerides are tested here increases by an order of magnitude, but is still only about 0.00005% the age of the solar system.

Another problem of interest is the slowing of the Earth's rotation rate due, primarily, to tidal drag. Current estimates of the rate of slowing, such as carried out by Stephenson and Morrison (1984), are based on records of total eclipses of the Sun and the difference between where the path of totality was observed and where it would have fallen if the Earth rotated uniformly on its axis. An independent check of this method can be carried out by comparing the recorded time of a celestial event such as planetary occultations and close approaches (appulses) with the time predicted by an ephemeris based on either the integration of planetary orbits or an analytic planetary theory. Obviously, this method of attack first requires that there are no long-term errors in the ephemerides. Therefore, it is necessary to address both the question of the accuracy of the planetary ephemerides and ΔT at the same time.

II. OBSERVATIONS

The Chinese have kept the most comprehensive record of celestial events of any culture on Earth. These records date back to the beginning of the former Han dynasty, 206 B.C. They are presented in the dynastic histories, a compilation of the political, administrative, and bureaucratic events of each of the Chinese dynasties. The astrological–political nature of celestial events required the observatory to be located on the palace grounds so as to have immediate access to the emperor and be under imperial control. Therefore, in addition to having a very complete record of observed celestial events, the place of observation is known with high accuracy (see Liu 1988).

The ancient Chinese histories contain several records of occultations of stars, planets, or extended objects by other planets. Liu (1988) extracted from the China Book-House (1975) edition of the 24 dynastic histories (this compilation of the Chinese dynastic histories is available in Chinese only) records of 173 occultations and appulses (very close approaches). These records were derived from observations made by the Chinese imperial astronomers at the various Chinese capitals over the period from 12 December 146 B.C. to 3 February 1761 A.D. The records are divided into three categories (see Tables I, II, and III): (1) A set of 66 occultations, from 12 February 73 A.D. to 3 February 1761, identifying the two objects involved, the recorded date of the occultation, the Chinese capital at which the observation was made, and, generally, the recorded time interval in which the occultation occurred; (2) a set of 24 questionable records (in this dataset, either the identification of the occulted object was in doubt, or the occulting planet has been misidentified. These records range in date from 17 July 403 A.D. to 16 August 1217); and (3) a dataset of 83 records of events where a planet was observed to have passed within approximately one degree of another object. (This set of records consists of observations made between 12 December 146 B.C. and 21 June 988 A.D.) The last dataset includes both the separation distance in tenths of a Chinese degree and the

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direction from the object to the planet at the time of observation for 48 of the 83 observations.

A Chinese degree is approximately 3550″. There are 365.25 "degrees" in a Chinese circle, i.e., one Chinese "degree" was the mean distance the Sun moved along the ecliptic in one solar day. However, the definition of a "degree" was not constant with time, and angular measure was not always differentiated from linear measure (see, for example, Needham 1959). Therefore, there is some trouble in translating the exact angular quantities involved.

A few words need to be said about the dynastic histories, the source of the records used in this investigation.

First, the histories are not the original source of observations, but were generally compiled by imperially sanctioned Chinese historians during a subsequent dynasty. The historians worked with the imperial records left by the previous dynasty. For example, the history of the later Han dynasty (23–220 A.D.), the "Hou-han-shu" by Fan Yeh, was written during the San-kuo or Chin periods (220–420). This means that the records that have survived are only those that were available to the historians of a later dynasty. So, the astronomical records themselves are only summaries of the original observations, and a considerable amount of detail has been lost.

Second, Clark and Stephenson (1977) point out that the main function of the "Astronomical Bureau" was producing astrological prognostications, and its officials were held directly responsible for the completeness of observations as well as their predictions. Therefore, falsified records are a possibility. Eberhard (1957) argues that for a major political event that had not been astrologically prognosticated, an observation prophesying the event might be inserted into the History of the Han Dynasty after the fact. However, Bielenstein (1950, 1984) is of the opinion that rather than inserting false observations into the record, the imperial astrologers were more likely to ignore ominous portents in politically good times. For example, Bielenstein points out that with one exception the number of solar eclipses recorded during any Han emperor's reign was either less than or equal to the number of solar eclipses that should have been observed, and the proportion of eclipses recorded was inversely proportional to the emperor's perceived popularity in the dynastic histories. Sivin (1969) shows that spurious lunar eclipse records during this period may have been the result of inaccuracies in the algorithm used to predict lunar eclipses.

Third, there is the possibility of transcription errors in the records. For example, Ho Peng Yoke (1962) found the 1572 supernova described as a "hui-hsing" (broom star or comet) in the draft version of the "Ming-shih," the Ming dynasty history, but as a "k'o-hsing" (guest star) in the final edition.

Fourth, there are problems in interpreting the records. For example, the following is the translation by Stephenson and Clark (1978) of the 12 February 73 A.D. (JD 1747764) occultation of β Sco by Jupiter:

> "Sixteenth year (of the Yung-p'ing reign period), first month, (day) ting-ch'ou. Jupiter trespassed against Fang Yu-ts'an; the first star at the north was not visible. (On the day) hsin-szû it finally became visible."

The translation indicates the use of the Chinese character "fan" ("invade," "offend," or "trespass against"), which has been used to describe appulses as opposed to occultations in which one of the words "yen" (conceal), "shih" (eclipse), or "ju" (enter) was generally used. However, the record goes on to describe the star as being "not visible," which would suggest that the two bodies were close enough together to be inseparable by the naked eye. Another character used in the records is "shou," "guarding," which has been translated by Ho Peng Yoke (1966) as meaning "to attach and stay by the side of (a constellation or celestial body)," or "to stay (in a particular place) without leaving," describing a planet moving slowly across the sky. Clark and Stephenson (1977) add another possible translation of shou: "moving backwards and forwards without going away." This last translation could be used to describe not just the position of the planet with respect to a star or asterism, but retrograde motion of the planet as well.

Finally, there are two major sources of observational error that must be considered: the effects of weather on seeing and irradiation within the eye of the observer. Both of these effects make an observed object appear larger than it actually is. The turbulent air and thin clouds which cause poor seeing would not have been noticed in naked-eye observations. In addition, the effects of poor seeing when noted by the Chinese astronomers were not always separated out from the planetary observation, but were sometimes used as part of the prognostication process (Staal 1984). So it is not clear whether or not poor weather conditions were taken into account when occultation observations were made.

Irradiation is a physiological effect that is dependent on the observer. An example of this effect can be found in the Ho Peng Yoke (1966) translation of "Wu-pei-chi" (Treatise on Armament Technology), dated 1628, "When (a celestial body) comes within 7 ts'un of (another) such that their rays extend toward each other ..." One ts'un corresponds to about 6′. So 7 ts'un is about 42′, a very large separation. Therefore, it is possible that poor seeing and/or irradiation may have caused an observer to record an occultation when the objects were actually several minutes apart. The discussion of the results of the analysis of the records in Sec. IV indicates that the mean effect of these two sources of observational error is about 300″.

III. METHOD OF ANALYSIS

a) Well-Determined Occultations and Appulse Records

The first step in the analysis of these observations was to develop a program, on the U. S. Naval Observatory IBM 4341 computer, to generate an ephemeris of the relative apparent position of the occulting planet with respect to the occulted object. The position of the planet or planets involved in the occultation was determined by use of the VSOP82 planetary theory developed by Bretagnon (1982). If the occulted object was a star or extended object, the program computed the apparent place of the object on the date of the observation using the subroutine APSTAR (Kaplan 1984). The apparent position for the extended objects, M44 and the Pleiades, were taken as the apparent place of a member star near the center of the extended object. The variable parameters in the program were (1) the initial Julian date for which the ephemerides were generated, (2) the interval of the ephemerides, (3) the number of entries in the ephemerides, (4) the occulting planet, and (5) the object being occulted. No ΔT correction was applied to these ephemerides.

The source of the J2000.0 positions, parallaxes, and radial velocities of the stars used by APSTAR was Hoffleit and Jaschek (1982). The proper motions of the stars were taken from Rhoades (1976).

The time of least separation was calculated by manually searching through the ephemeris until the least separation was found on the timescale of 0.01 day for occulted planets or stars and 0.1 day for extended objects. The ephemerides for least separation and time of least separation from the Bretagnon (1982) theory was then checked by using positions obtained from the DE102 ephemeris developed by Newhall, Standish, and Williams (1983). Since DE102 has a coordinate system closely aligned with that of 1950.0, the 1950.0 coordinates for the occulted stars were obtained from Rhoades (1976). The mean discrepancy between the DE102 relative positions and the Bretagnon (1982) relative positions of the occulting planet and the occulted object was about 2″ in separation and less than 0.01 day in time.

The next step was to try to match the calculated times of least separation with the recorded times of observation. Checks were made to determine whether it was daytime or nighttime at the place of observation and whether the recorded objects were above the horizon both at the time of least separation and the time recorded for the event. To do this, it was necessary to correct the ephemeris-derived times to UT. The ΔT correction for slowing of the Earth's rotation was calculated from the algorithm given by Stephenson and Morrison (1984). Although his method of deriving the algorithm for ΔT is different, the values determined by Newton (1984) are indistinguishable at the 0.01 day level of accuracy over the period covered by the records. A standard rise/set program was then used to test whether the Sun or occulting planet was above the horizon at the time of least separation. If the Sun was above the horizon and time of sunrise/sunset, the separation at that time was computed and compared with the recorded data. Similarly, if the objects involved in the occultation or appulse were below the horizon at the time of least separation, then the rise time and separation at the rise time were computed and compared with the recorded data.

b) Poorly Determined Records

In order to determine whether the planet reported in an occultation was in the right part of the sky for a given observation, a short program was developed to give the positions of all the planets visible with the naked eye on a given Julian date. If the reported planet was not in the proper area, it was then determined if there were any other candidates among the other visible planets.

Having then determined if there was a planet in the right part of the sky, the first program described was used to determine (1) the date of the occultation, if it was uncertain, and/or (2) the objects reported occulting each other from the possible planetary candidates and a short list of possible occulted objects determined from the records.

IV. RESULTS

a) Well-Observed Occultations

Of the original 66 records of well-determined occultations shown in Table I, only seven actual occultations occurred. All of these occurred when a planet passed in front of either M44 or the Pleiades, both of which are extended objects. Of the remaining 59 observations, 11 events occurred in which the two objects passed so close to one another that they would definitely have been inseparable by the unaided eye.

According to Needham, the smallest Chinese angular unit of measurement actually used corresponds to about 4′. However, the historical Chinese units of measure are not precise and may have changed significantly over the period of observations. It is possible that the translation of the "occultation" observations actually meant that the separation between the planet and the second object was less than this smallest angular distance. If so, an additional 19 events meet this criterion. This leaves only 30 "occultations" to be explained. Of these remaining "occultations," the range of separation at closest approach is about 5′ to 71′. The mean least separation for a close approach was 9.′4.

Of the 66 observations, 34 had their closest approach according to the ephemerides during the *daytime*. These daytime close approaches included 13 of the 21 approaches with greater than 15′ least separation. The daytime close approaches also included six of the seven actual occultations with extended objects, but these objects have large enough angular sizes so that they were still occulted during the nighttime hours. Of the nine approaches too close to separate by eye, five occurred during the daytime. Of these, five "occultations" still had a separation of less than 1′ after nightfall and three others had a separation of 4′ or less after sunset. Of the 19 small least-separation "occultations," nine occurred during the daytime and three of them still had less than 4′ separations during the night. Looking at the nighttime close approaches, it was found that only eight of the 32 observations had separations of greater than 15′, but six of these large-separation "occultations" had their closest approach occur while the planet and the "occulted" object were below the horizon. In summary, of the 66 observations, seven would have been seen as actual occultations, five would have been seen too close together to separate by eye, 14 had visual approaches of $<4'$, ten seen as approaches between 10′ and 15′, two seen as approaches $>15'$, and 28 would have been seen as "occultations" that had occurred during the daytime. Finally, it was determined that all of the times of observation for events that happened during the daytime or while the "occulting" planet was below the horizon were recorded at the time closest to the event after the sun set or the occulting planet rose above the horizon.

The 32 "occultations" that definitely took place during the nighttime were selected to test the change in the slowing of the Earth's rotation rate determined by Stephenson and Morrison (1984). The ΔT for each record is given in Table I. This was done by comparing the time of night for which the close approaches were recorded in the Chinese records with the time determined by the planetary theory. The planetary theory values were then corrected for slowing of the Earth's rotation with time using the method developed by Stephenson and Morrison (1984). Of the 32 observations, 26 of the recorded observations agreed with the calculations as to the time of night that the event occurred, and five observations in which the time of closest approach occurred while the planet and the "occulted" object were below the horizon. The final observation has a discrepancy in the observed minus calculated time of greater than 8 hr, so it cannot be adequately accounted for except by an observer error or an error in the transcription or interpretation of the record. Therefore, except for the one questionable record, the time of the observations agrees with the time of the calculated closest approach when the change in time as determined by Stephenson and Morrison (1984) is included. As noted before, at the 0.01 day level of accuracy it was not possible to differentiate between the algorithms of Stephenson and Morrison (1984) and Newton (1984). Since the time of the night of

TABLE I. Analyses of records from the Chinese dynastic histories in which the recorded events were characterized as occultations.

No.	Recorded Julian Date	Obj. Involved. Planet	Object	Rec. time (JD + T) Begin	End	Observed Closest Dist.	R.A.	Dec.	Calculated Julian Date	Closest Approach Dist.	R.A.	Dec.	Delta T days	d/n	y/n	Comments
						″	s	″		″	s	″				
1	1747764	Jupiter	β Sco	0.16	0.48	110	−7.5	−9	1747765.44	26	0.1	26	0.15	d		f.
2	1850421	Saturn	η Gem	−0.08	0.19	513	−6.4	505	1850422.64	513	−7.5	501	0.11	d		c.
3	1855681	Venus	Mars	−0.05	0.04	693	−46.2	−64	1855681.28	266	−7.9	−238	0.10	d		f.
4	1858040	Venus	Mars	−0.10	0.03	69	−2.4	59	1858039.86	69	−2.4	59	0.10	n	y	
5	1858315	Mars	η Vir	0.29	0.43	974	−65.0	137	1858315.76	244	−3.1	−243	0.10	d		a(1), f.
6	1858543	Mars	φ Sgr	−0.02	0.38	224	8.3	195	1858543.40	176	−2.3	174	0.10	d		f.
7	1868173	Venus	β Vir	0.28	0.42	541	20.0	454	1868172.15	524	11.9	494	0.10	n	n	g.
8	1869986	Venus	Mars	0.31	0.42	410	26.8	−112	1869986.02	20	0.5	18	0.10	d		c.
9	1872914	Venus	η Vir	0.32	0.42	794	−42.4	482	1872914.50	216	6.7	192	0.10	d		f.
10	1907312	Jupiter	η Vir	0.16	0.48	320	−6.5	303	1907309.24	320	−6.5	303	0.08	n	y	b(3), j.
11	1908173	Jupiter	β Sco	0.00	0.41	63	1.1	61	1908173.20	63	1.1	61	0.08	n	y	l.
12	¯1909073	Venus	β Vir	0.31	0.44	2964	−117.2	2407	1909075.92	1689	37.1	1598	0.08	d		f, k.
13	1911903	Jupiter	η Vir	−0.02	0.12	439	−5.4	431	1911902.72	427	−11.2	−392	0.08	d		c.
14	1916266	Mars	τ Sgr	−0.02	0.39	258	−4.5	252	1916266.30	258	−4.5	252	0.08	n	y	e.
15	1926265	Mars	σ Leo	0.23	0.46	393	−13.7	338	1926265.54	253	6.1	237	0.08	d		a(1), c.
16	1928955	Jupiter	σ Leo	−0.06	0.41	535	−13.3	−499	1928956.82	535	−12.7	−502	0.08	d		c.
17	1930450	Mars	η Cnc	−0.03	0.22	1912	20.0	1893	1930450.14	1912	20.0	1893	0.08	n	y	
18	1930486	Venus	η Cnc	−0.02	0.12	4126	115.7	3182	1930485.62	4016	46.2	3966	0.08	d		c.
19	1930489	Venus	ι Cnc	−0.02	0.12	2188	14.8	−2259	1930487.86	2183	−29.1	−2143	0.08	d		b(1), c.
20	1932759	Mars	δ Sco	−0.02	0.14	37	−1.0	−34	1932758.94	37	−1.0	−34	0.08	n	y	
21	1933292	Mars	β Sco	0.24	0.49	143	−7.2	96	1933292.48	66	1.4	62	0.08	d		f.
22	1959274	Jupiter	σ Leo	−0.05	0.41	553	−13.0	−519	1959265.74	553	−13.0	−519	0.07	n	y	b(8), d, j.
23	1959395	Mars	β Vir	−0.01	0.09	582	37.3	183	1959394.73	386	10.3	355	0.07	d		c.
24	1978768	Mars	ι Lib	−0.02	0.15	729	42.0	397	1978766.72	592	15.3	549	0.06	d		b(1), c.
25	¯1997787	Venus	Jupiter	0.29	0.44	4281	−54.4	−4210	1997805.33	4281	−54.4	−4210	0.06	n	y	g, k.
26	1999050	Jupiter	β Sco	0.21	0.48	162	−6.5	−132	1999048.66	145	−2.5	−140	0.05	d		b(1), e, l.
27	2003520	Jupiter	β Sco	−0.03	0.41	136	−2.4	−131	2003520.16	136	−2.4	−131	0.05	n	y	l.
28	2003730	Venus	β Sco	0.39	0.48	936	18.4	898	2003730.34	936	18.4	898	0.05	n	y	g.
29	¯2006288	Jupiter	M44	−0.04	0.49	3167	−44.8	−3106	2006309.7	3166	−38.1	−3122	0.05	d		c, h, k.
30	2022506	Mars	M44	−0.03	0.19	1274	−28.3	1214	2022506.4	1128	20.8	1091	0.05	n	y	h.
31	2023731	Mars	M44	0.25	0.43	2171	−112.3	−1512	2023732.0	1712	−16.0	−1697	0.05	d		b(1), f, h.
32	2023999	Mars	β Vir	−0.02	0.22	463	13.7	415	2023999.02	463	13.7	415	0.05	n	y	j.
33	2026431	Venus	ξ Sgr	0.37	0.49	1703	−8.0	−1699	2026431.39	1703	−8.0	−1699	0.05	n	y	g.
34	¯2029381	Jupiter	β Sco	0.16	0.47	850	−54.4	330	2029385.92	850	−54.2	332	0.05	d		f, l, k.
35	2029769	Venus	19 Tau	−0.05	0.10	1498	93.1	−724	2029767.64	1187	34.3	−1083	0.05	d		b(1), c, h.
36	2069067	Venus	η Vir	0.31	0.44	1480	95.8	−374	2069066.94	179	6.9	147	0.04	n	n	g.
37	2075245	Mars	M44	0.20	0.43	1676	−59.3	−1461	2075245.7	1561	−14.6	−1548	0.03	d		f, h.
38	2080729	Venus	ρ Leo	0.29	0.43	322	4.6	315	2080729.27	322	4.6	315	0.03	n	y	
39	2091141	Mars	ε Gem	−0.06	0.19	296	−0.3	−296	2091142.06	296	−0.3	−296	0.03	n	y	a(1).
40	2093953	Mars	θ Vir	0.22	0.47	932	−52.9	488	2093952.92	143	3.4	133	0.03	d		f, j.
41	2096379	Mars	Saturn	0.13	0.40	215	−5.5	199	2096379.26	215	−5.5	199	0.03	n	y	a(2), c.
42	2098048	Jupiter	η Vir	−0.03	0.46	835	21.9	769	2098050.90	835	23.0	761	0.03	d		f.
43	2098071	Mars	γ Cnc	−0.06	0.30	460	−18.7	−382	2090870.42	445	−11.1	−419	0.03	d		e.
44	2098259	Venus	ρ Leo	0.29	0.43	1089	22.7	1037	2098259.40	1089	22.7	1037	0.03	n	y	g.
45	2098861	Jupiter	β Sco	−0.04	0.37	291	−4.8	283	2098862.14	291	−4.8	283	0.03	n	y	a(1), l.
46	2111068	Venus	β Vir	0.29	0.44	177	2.4	174	2111069.32	177	2.4	174	0.03	n	y	a(1).
47	2113224	Venus	ι Lib	−0.07	0.01	1085	2.3	−1085	2113233.80	967	−24.4	−928	0.03	d		c.
48	2121964	Mars	μ Cnc	0.27	0.41	1503	−13.0	−1492	2121965.26	1504	−13.0	−1492	0.03	n	y	a(1).
49	2122104	Mars	γ Vir	0.12	0.48	231	5.0	218	2122104.46	231	5.0	218	0.02	n	y	e.
50	2145315	Venus	β Vir	−0.05	0.04	457	−22.6	308	2145315.14	133	2.6	127	0.02	n	n	g.
51	2148655	Mars	Jupiter	0.08	0.42	7	0.4	−3	2148655.36	7	0.4	−3	0.02	n	y	
52	2149436	Mars	η Cnc	0.07	0.45	1303	−18.5	1278	2149435.74	1277	0.8	1277	0.02	d		f.

TABLE I. (continued)

No.	Recorded Julian Date	Obj. Involved. Planet	Obj. Involved. Object	Rec. time (JD + T) Begin	Rec. time (JD + T) End	Observed Closest Dist.	Observed Closest R.A.	Observed Closest Dec.	Calculated Closest Approach Julian Date	Calculated Closest Approach Dist.	Calculated Closest Approach R.A.	Calculated Closest Approach Dec.	Delta T days	d/n	y/n	Comments
						″	s	″		″	s	″				
53	2151701	Saturn	μ Gem	−0.11	0.37	60	0.4	60	2151702.36	60	−0.1	60	0.02	d		a(1), f, j.
54	2151598	Mars	λ Sgr	−0.09	0.07	144	−10.3	37	2151958.11	43	−0.9	−41	0.02	d		f.
55	2152038	Mars	Jupiter	−0.12	0.05	141	−5.8	114	2152038.05	136	−3.2	128	0.02	n	n	g.
56	2152579	Mars	τ Sgr	−0.01	0.38	1599	−22.6	1571	2152579.46	1595	−31.4	1541	0.02	d		f.
57	2156586	Mars	β Vir	−0.03	0.20	244	15.8	67	2156585.84	164	5.0	146	0.02	d		f.
58	2168002	Mars	M44	0.26	0.42	1743	−39.6	−1654	2168002.5	1725	−24.3	−1691	0.02	d		f, h.
59	2187488	Mars	ω Sco	0.29	0.48	1123	20.4	1086	2187487.42	1123	20.4	1085	0.01	n	y	g, j.
60	2189780	Jupiter	β Sco	0.02	0.40	112	1.9	109	2189779.14	112	1.9	109	0.01	n	y	b(1), i.
61	2197870	Jupiter	η Vir	−0.02	0.18	105	−3.3	−93	2197870.04	105	−3.3	−93	0.01	n	y	
62	2199205	Venus	ν Sgr	0.35	0.47	4324	−21.4	−4313	2199205.22	4324	−19.6	−4315	0.01	n	n	g.
63	2220017	Jupiter	β Sco	0.23	0.47	318	−18.6	−176	2220018.06	228	−3.5	−223	0.01	d		a(1), f, i.
64	2307987	Mars	Jupiter	−0.12	0.09	51	1.1	−49	2307986.93	51	1.1	−49	0.00	n	y	
65	2335696	Jupiter	Saturn	0.19	0.44	928	−14.7	−903	2335694.85	925	−19.8	−880	0.00	d		a(1), c, j.
66	2364286	Mars	Jupiter	−0.10	−0.04	1346	85.8	93	2364285.22	50	0.8	−48	0.00	n	n	

Explanation of the Columns in Table I

Column 1: The number of the observation in chronological order.
Column 2: The recorded date converted to a Julian Day Number. The symbol ˜ denotes an approximate date.
Column 3: The planet involved in the occultation.
Column 4: The second object involved in the occultation.
Column 5: The beginning of the recorded window of time for the observation converted to the fraction of a Julian Day.
Column 6: The end of the recorded window of time for the observation converted to the fraction of a Julian Day.
Column 7: The calculated least separation between the two objects during the time window.
Column 8: The calculated separation in Right Ascension for the separation given in Column 7.
Column 9: The calculated separation in declination for the separation given in Column 7.
Column 10: The calculated time of least separation.
Column 11: The separation at the calculated time of least separation.
Column 12: The separation in Right Ascension at the time of least separation.
Column 13: The separation in declination at the time of least separation.
Column 14: The calculated value of Delta T in Julian Days.
Column 15: Closest approach occurred during (d) the daytime or (n) the nighttime.
Column 16: If closest approach occurred during the nighttime, (y) it occurred in the recorded time period, or (n) it did not occur during the recorded time period.
Column 17: Comments, see the Footnotes

Footnotes:

a(n): Recorded date was n days early.
b(n): Recorded date was n days late.
c: Closest approach occurred before sunset.
d: Closest approach occurred during evening twilight.
e: Closest approach occurred during morning twilight.
f: Closest approach occurred after sunrise.
g: Closest approach occurred while objects were below the horizon.
h: Extended object.
i: Member of Jupiter-β Sco group of 'occultations.'
j: Planet is moving very slowly across sky (<2′ /day).
k: Date recorded is only approximate.

the ephemerides corrected for ΔT agrees with the recorded observations for the nighttime "occultations," this also provides a positive check on whether the closest approach occurred during the daytime or nighttime.

Many of the recorded "occultations" had their closest approaches during the daytime, when they could not have been seen. Some of the events, such as record number 1, would have appeared as if they were occultations because of the small least-visible separation during the night, the effects of irradiation, and the changing background brightness of the morning or evening twilight sky. Other observations may be the result of a transcriber recording an appulse as an occultation.

A third possible explanation can be inferred from Needham (1959). Needham documents a case in which an imperial astronomer discovered that his staff had been submitting ephemerides rather than actual observations of events. Table III shows that records were kept of both the distance and direction of the planet from the background object. It is therefore possible that the records of daytime "occultations" are based on the apparent motion of the planet from one observation to the next describing a path that would appear to cause an occultation of the background object by the planet. This may explain the occurrence of many of the "occultations," such as record number 5 in Table I, where the least separation visible is about 15′ but the motion of the planet takes it from the northwest to the southeast with respect to the background object during the daytime. This scenario can also be used to explain the six nighttime observations in which the planet and background object would have been below the horizon at the time of least separation.

It is expected that the indirect observations would have greater mean least separations. The increase in mean least separation is a result of the difficulties in making measurements of naked-eye observations. For the nighttime "occultations" where the objects were above the horizon, the mean least separation is 310″. This least separation is best explained to be a result of the combined effects of atmospheric seeing and irradiation from the bright planetary objects. For the daytime "occultations," the mean least separation is 742″. For eight of the daytime least separations, the least visible separation, that is, the least separation after sunset, would have been 318″ or less, so these records should be taken as observed occultations. If these are removed from the daytime least separations, the mean least separation for daytime approaches becomes 970″, and for the nighttime "occultations" where the object was below the horizon, the mean least separation was 1479″. Therefore, it is likely that some Chinese astronomers would record inferred events as having occurred.

All of the records considered in this section agree with ephemerides that a close approach occurred between the two objects in a given observation. The nighttime "occultations" have a mean separationof 300″ when the objects were above the horizon. This error is most easily explained by the effects of weather and irradiation. So, there is no evidence of any systematic problems with current planetary theories such as DE102 and Bretagnon (1982). However, the rather large observational error of 300″ is inferred from the mean least separation. This means that the records only weakly constrain the planetary ephemerides. The weakness of the constraint is easily seen by considering that a 300″ observational error over 2000 yr is the equivalent of a secular error of 3″ in the planetary positions over 20 yr. This error is orders of magnitude larger than current observations of the planets would suggest possible.

Two other patterns appeared in the analysis of this group of well-determined "occultations." First, there were eight observations of approaches between Jupiter and the star β Scorpii. In each instance, the observation was made at a time when Jupiter was in retrograde motion in the region of β Scorpii, resulting in a "triple" conjunction. This event occurs at about 96 yr intervals. The recorded observation also corresponds to the closest, within the observational error, of the three conjunctions between Jupiter and the star. This suggests that the observers were using the occulted objects as markers for the motion of the planets in the sky.

Second, the large majority of the records not involving two planets were clustered near the northern and the southern limits of the ecliptic. This suggests that the observations were used, at least in part, to map the northern and southern limits of the positions of the planets in the sky. However, the distribution of observations may be the result of selection effects in the records because the northern and southern extremes of the ecliptic are also where it cuts across the disk of the galaxy.

b) Poorly Determined Records

From the ambiguous records shown in Table II, four useful observations were discovered.

First, on 16 August 435, JD 1880170.4, Mars passed through M44 and then 70 days later passed within 32″ of the star σ Leo. This was recorded as a single, undifferentiated event mentioning both of the occulted objects. This interpretation would tend to support the idea proposed above that the stars and extended objects were being used as points to trace the paths of the planets in the sky.

The second useful event to be found in the poor observations is a close pass of 5′.5 between Mars and the star ρ Capricorni on JD 1890945.5 (6 February 465). This event confirms another planet–star close approach that was both recorded and predicted from a planetary ephemeris.

Third, in an event similar to the Jupiter–β Scorpii observations described above, in 537 Jupiter moved in retrograde motion in the vicinity of π Sagittarii. The planet had two close approaches of 82′.23 and 87′.84 from the star, about 70 days apart. These two events appear to have been recorded as a single event at a date midway in between the two close approaches.

Fourth, there is a record of a very close pass between Venus and Saturn in the year 573. According to the ephemerides, this event occurred on JD 1930709.44 (29 December 573). The least separation between the planets was about 67″.

Like the observations in the well-determined occultation dataset, the observations tend to show evidence that the stars were being used as "signposts" in determining the planets' motions across the sky. Also, the observations tend to cluster around those stars at the northern and southern limits of the ecliptic, possibly testing the northern and southern limits of the positions of the planets in the sky.

c) Close Approaches

The 83 observations of the close approaches are shown in Table III. The recorded separations vary between 200″ and 3200″ and have a recorded accuracy, inferred from the records, of about 180″, or 0.05 Chinese degrees. Like the ob-

TABLE II. Analysis of records from the Chinese dynastic histories in which the recorded events were characterized as occultations, but the objects involved in the events are uncertain.

No.	Date	Planet	Object	Notes
1	1868451 7/17/403	Jupiter	ϕ Sgr	Moon, Jupiter was > 6 hr away.
2	1869333 12/15/405	Venus	ω Sco	"Fan"?, Venus 154′ to the north at conjunction.
3	1880169 8/16/435	Mars	M44 or σ Leo	On JD 1880170.2 Mars was in M44, 28′.01 from the center, on JD 1880240.04 Mars was 31″.5 from σ Leo.
4	1890944 2/14/465	Mars	o Cap, ρ Cap, π Cap	On JD 1890945.50 Venus was 5′.50 from o Cap.
5	1917312 4/25/537	Jupiter	π Sgr	"Fan"? Jupiter moved in retrograde motion in this area of the sky and there were two close approaches between Jupiter and this star. On JD 1917269.0 the separation was 82′.23 and on JD 1917338.7 the separation was 87′.84. The given date is approximately halfway between the two close approaches.
6	~1930527 573	Venus	Saturn	Between μ Sco and τ Sgr on JD 1930709.44, Venus was 67″ from Saturn.
7	1933281 1/13/581	Venus	Mercury	Conjunction with > 4° separation on JD 1933281.
8	~2018367 ~12/27/813	Mars	ϵ Vir	On JD 2018353.0 separation between Mars and ϵ Vir was 68′.65.
9	2074809	Mars	α Sco	Moon, Mars > 6 hr away.
10	2085467	Mars	λ Sgr	Moon, Mars > 10 hr away.
11	2086450 5/22/1000	Venus	Mercury	On JD 2086447.28 the separation between Venus and Mercury was 23′.80.
12	2087117	Venus	?	
13	2087119	Venus	β Tau	Venus > 9 hr away.
14	2088306	Venus	σ Sco	
15	2091323	Venus	α Tau	Moon
16	2091900 4/24/1015	Mars	ϵ Gem	Mars was 52′.7 N of star on JD 2091655.6 or 8/23/1014.
17	2092676 6/8/1017	Mars	γ Vir or σ Leo	On JD 2092674.52 Mars was 45′.27 from σ Leo.
18	2093824	Venus	π Sco	Moon
19	2093867	Venus	β Tau	Moon
20	2094237	Mars	τ Sgr	Moon
21	2108370 5/27/1060	Mars	M44	On JD 2108361.6 Mars was in M44 110″ from the center.

TABLE II. (continued)

No.	Date	Planet	Object	Notes
22	2147106 6/16/1166	Saturn	ω Sgr	The planets Mars, Jupiter, and Saturn and the Moon were all within 5° of ω Sgr at this time. The Moon should have occulted the star at about JD 2147106.0 and Mars at about JD 2147107.5 but missed Jupiter and Saturn by about 2° to 3°.
23	2149378 9/4/1172	Mars	36 Gem	Mars passed 88'.68 north of 36 Gem on JD 214.9379.1.
24	2149378 8/16/1217	Mars	Jupiter	Mars passed 32'.46 south of Jupiter on JD 2165796.00.

servations recorded as occultations, many of the times of least separation occurred either during the daytime or while the objects were below the horizon. The separation recorded at the time when the planet was visible agrees, generally, with the separation that is calculated for that time. The mean absolute difference between the predicted least visible separation and the recorded separation at the recorded time is 473". While this separation is a factor of 1.5 greater than the spread for the occultation observations, this may be the result of the additional difficulty in translating the Chinese angular measurements rather than a decrease in the accuracy of the observations over the occultation observations.

The first close-approach record is different from the other observations. Rather than being the record of a single close approach, it is a record of a double conjunction between Mercury and Venus. The recorded date is approximately midway between the two approaches. Both of the conjunctions have been recorded as numbers 1 and 1a in Table III.

For four of the observations, the date of least separation is later than the date recorded, but the separation on the recorded date agrees with the calculated separation for that date. This indicates that it was likely that there was bad weather on the date of least separation and the observer then recorded what he saw on a previous night.

For the 48 observations with directions given, 38 agree with the direction computed. Of the ten observations that disagree with the calculated direction, five are off by approximately 180° and probably represent a mistake in head and tail ends of the direction vector. The head–tail ambiguity is definitely the case for observation number 2, where both the objects involved are planets.

Although the observations of the close approaches were recorded between 146 B.C. and 988 A.D., observations 4–42 come from the 7 yr span 487–494 (JD 1899195–1901686) and hence probably represent the work of a particular imperial astronomer. Similarly, observations 63–70 cover 767–771 and observations 72–81 cover the 10 yr period 821–830. Therefore, it is possible that many of the records of close approaches were recorded by observers who were more careful than the observers who reported the daytime "occultations." An alternate explanation, suggested by Bielenstein (1950, 1984), is that the clustering of the appulses may be the result of the political conditions in the Chinese court because of the astrological uses of the records. The second explanation, however, also depends on the relative importance of appulses to eclipses in Chinese astrological tradition.

Therefore, there is no evidence in the records of close approaches that there are any problems with the current methods of integrating planetary orbits or developing planetary theories. However, with an approximate observational accuracy of 300", this is a weak constraint. In addition, there is no evidence of problems with the ΔT determination of Stephenson and Morrison (1984).

An additional test for systematic errors in ΔT and the mean longitude of the planets was made by plotting the difference between the reported time for a given separation between two objects and the calculated time for that separation. If an error in the mean longitude of a planet existed, it would show up as a systematic trend in time differences between the observed and calculated times of separation for that planet. If there was an error in the parametrization of ΔT, it would show up as a systematic trend in the differences between the observed and calculated times of separation for all the planets. Figure 1(a) shows this plot for Venus. The circles represent recorded occultations by Venus for which the closest approach was calculated to have occurred during the daytime, the triangles represent recorded occultations for which the closest approach was calculated to have occurred during the night, and the $\times$'s represent the records of "fans" or close approaches. Figure 1(b) shows the segment of Fig. 1(a) from JD 1890000 to JD 1910000 so that the detail in the "fan" records around JD 1900000 can be seen. As can be seen, there is no evidence for any systematic errors. However, the daytime conjunctions (circles) have the greatest scatter, while almost all the $\times$'s are on the line for zero observed minus calculated errors, so there is no evidence for systematic problems in either ΔT or mean longitude for Venus. The lack of evidence for systematic error is the same for the other planets observed as well.

V. CONCLUSIONS

There are four main conclusions that can be drawn from the analysis of the Chinese observations of planetary occultations.

First, a large number of the sightings that were reported as occultations are actually records of appulses between the two objects in which the time of closest approach occurred during the daylight hours. In all but two cases, when the

TABLE III. Analysis of records from the Chinese dynastic histories in which the recorded events were characterized as appulses (grazing occultations or near misses).

No.	Recorded Julian Date	Obj. Involved. Planet	Object	Rec. Time (JD+T)	Rec. Dist.	Rec. Dir.	Closest Dist.	Dist Obs. R.A.	Dec.	Calculated Julian Date	Closest Dist.	Approach R.A.	Dec.	Delta T days	d/n	y/n	Comments
					″		″	s	″		″	s	″				
1	1668077	Mercury	Venus		400					1668051.06	5925	160.9	5446	0.19	d		a(26).
1a	1668077	Mercury	Venus		400					1668126.29	1727	-61.8	1481	0.19	n		b(39).
2	-1711042	Mars	Jupiter		200	NE	257	-6.2	242	1711046.39	257	-6.2	242	0.17	n		g. k.
3	1742164	Mars	σ Leo	0.35	700		599	-34.0	-343	1742164.27	479	-10.6	-454	0.15	n	n	
4	1899195	Venus	σ Leo	0.36	1800	SW	2469	-145.0	-1278	1899195.63	1892	-41.8	-1791	0.09	d		f.
5	1899208	Venus	η Vir	0.38	1400	NW	1781	-103.0	911	1899208.68	271	11.1	225	0.09	d		f.
6	1899222	Mars	γ Cap	0.03	200	E	78	-1.0	76	1899222.86	78	-1.0	76	0.09	n	y	
7	1899246	Jupiter	α Lib	0.40	2500	N	2059	57.3	1875	1899249.07	2056	49.4	1919	0.09	d		a(3), f, k.
8	1899428	Venus	Mars	-0.01	1000	N	1278	-14.8	1262	1899428.10	1278	-14.8	1262	0.09	n	y	
9	1899496	Venus	β Vir	-0.01	1400	SE	1341	86.0	-426	1899495.57	149	3.8	139	0.09	d		c.
10	1899624	Mars	α Lib	0.38	2500	N	1346	-36.1	1235	1899625.69	938	21.1	868	0.09	d		a(1), f.
11	1899652	Mars	β Sco	0.38	2100	S	2300	-50.4	-2181	1899652.45	2300	-50.4	-2181	0.09	n	y	
12	1899652	Mars	ω Sco	0.38	1800	NW	2242	-131.6	1181	1899653.18	508	10.8	484	0.09	d		f.
13	1899785	Mars	σ Aqr	0.30	2500	NW	3078	54.4	-2979	1899786.47	3078	54.4	-2979	0.09	n	y	
14	1900183	Mars	η Cnc	0.00	700	SE	610	2.8	-609	1900182.86	601	-5.3	-596	0.09	d		c.
15	1900287	Venus	α Leo	0.34	2500	S	3343	-139.9	-2683	1900287.61	3021	-40.7	-2964	0.09	d		f.
16	1900328	Venus	θ Vir	0.37	1800	W	1639	83.2	-898	1900328.84	351	-8.2	-328	0.09	d		a(1), c.
17	1900362	Mars	ω Sco	0.41	1100		1008	-66.2	-313	1900362.64	603	-12.7	-575	0.09	d		f.
18	1900365	Venus	β Sco	0.40	400	NE	1308	30.0	1233	1900365.37	1308	30.0	1233	0.09	n	y	
19	1900365	Venus	ν Sco	0.40	2500	SW	1789	118.7	-606	1900366.53	1072	-25.7	-1005	0.09	d		a(1), f.
20	1900469	Jupiter	Saturn	0.38	2500	W	2916	-205.0	242	1900476.89	981	-18.1	947	0.09	d		f, j, k, l.
21	1900481	Mars	Saturn	0.36	2500	E	1789	118.7	-606	1900480.56	1018	19.6	-980	0.09	d		f, j, l.
22	1900481	Mars	Jupiter	0.36	2100	S	2012	40.6	-1929	1900481.18	2012	40.6	-1929	0.09	n	y	
23	1900597	Venus	σ Leo	-0.01	1400	N	1268	7.0	-1264	1900596.77	1139	-29.1	-1056	0.09	d		c.
24	1900617	Saturn	ι Aqr	0.16	2500	NE	2756	81.1	2509	1900624.00	2103	-39.8	2026	0.09	d		c, j, k, l.
25	1900628	Jupiter	42 Aqr	0.14	1800	N	2266	-36.7	2206	1900624.41	2263	-44.5	2173	0.09	n	n	b(4), g, k.
26	1900721	Saturn	ι Aqr	-0.01	1800	NW	2806	-149.2	1859	1900726.57	2357	-45.4	2268	0.09	d		c, j, k, l.
27	1900692	Venus	φ Sgr	-0.06	700	N	2157	15.8	2147	1900692.03	2157	15.8	2147	0.09	n	y	
28	1900694	Venus	σ Sgr	-0.05	400	W	171	0.0	171	1900694.08	171	0.0	171	0.09	n	y	
29	1900847	Mars	ε Gem	0.04	700	W	908	60.1	-395	1900847.55	454	2.5	-453	0.09	d		a(1), c.
30	1900890	Mars	η Cnc	0.03	2500		847	-58.7	272	1900892.33	174	1.3	174	0.09	n	n	a(2), g.
31	1900947	Venus	μ Gem	0.34	2100	E	1344	94.6	268	1900946.84	64	-0.3	63	0.09	d		c.
32	1900992	Venus	α Leo	0.37	2800	E	2914	-109.4	2466	1900991.75	2021	33.7	1953	0.09	d		c.
33	1901175	Venus	Jupiter	-0.05	2100	NW	1869	-112.1	817	1901175.28	1467	-43.0	1318	0.09	n	n	g.
34	1901217	Mars	Saturn	0.37	2100	NW	2137	-126.9	1075	1901217.84	1671	-40.7	1562	0.09	d		f.
35	1901255	Venus	χ Gem	0.01	2100	NW	2202	-116.9	-1542	1901255.41	1564	-2.1	-1564	0.09	n	n	g.
36	1901268	Venus	γ Cnc	0.02	1400	SW	2428	-26.2	-2402	1901268.26	2428	-26.2	-2402	0.09	n	y	
37	1901284	Mars	Jupiter	0.31	2100	SW	2508	-165.2	-984	1901285.54	11	0.4	-9	0.09	d		f, l.
38	1901433	Venus	θ Vir	0.36	1400	SW	1357	38.6	-1227	1901433.92	956	-20.8	-903	0.09	d		a(1), c.
39	1901464	Mars	χ Gem	0.19	1400	N	1180	11.3	1170	1901465.18	1180	11.3	1170	0.09	n	y	
40	1901475	Venus	υ Sco	0.39	2100	NW	2437	136.5	1413	1901474.86	1967	33.5	1910	0.09	d		c.
41	1901600	Mars	M44	0.06	2500	NE	1700	5.6	1698	1901600.57	1472	16.7	1454	0.09	d		f, h.
42	1901686	Mars	β Vir	0.01	700	N	784	-24.8	693	1901686.29	496	13.4	455	0.09	n	n	
43	1904165	Saturn	η Gem	0.02	700		634	-37.5	359	1904166.14	433	-4.8	428	0.08	n	y	k, l.
44	1907251	Jupiter	β Vir	0.37	1800		1555	48.8	1378	1907250.93	1545	37.7	1441	0.08	d		l.
45	1907539	Jupiter	η Vir	0.02	400		660	-18.8	-598	1907540.15	660	-18.8	-598	0.08	n	y	a(1).
46	1908076	Jupiter	β Sco	0.37	400		640	-37.1	-345	1908077.12	488	-11.0	-461	0.08	n	n	a(1), i, j.
47	1908163	Jupiter	ω Sco	0.23	1800	E	2895	60.8	2757	1908169.14	2895	60.8	2757	0.08	n	n	a(6).
48	1908163	Jupiter	ν Sco	0.23	1100		2204	-46.0	-2102	1908160.12	2204	-46.0	-2102	0.08	n	y	b(3).
49	1911780	Jupiter	η Vir	0.20	1400		962	38.8	770	1911780.71	935	24.7	860	0.08	d		f.
50	1912382	Venus	σ Sgr	-0.04	1100		713	-1.8	-713	1912381.98	713	-1.8	-713	0.08	n	y	c.
51	1912437	Jupiter	β Sco	0.40	700		832	-20.0	-780	1912437.29	831	-17.0	-794	0.08	n	n	i, j.
52	1914130	Venus	α Vir	0.01	1400		882	26.7	786	1914130.04	881	28.8	769	0.08	n	y	c.
53	1916024	Mars	Jupiter	0.38	400		522	13.8	480	1916024.33	522	13.8	480	0.08	n	y	
54	1916041	Venus	Mars	0.38	2500		1787	113.7	226	1916040.38	694	14.4	660	0.08	n	y	

TABLE III. (continued)

No.	Recorded Julian Date	Obj. Involved. Planet	Object	Rec. Time (JD+T)	Rec. Dist.	Rec. Dir.	Closest Dist Obs. Dist.	R.A.	Dec.	Calculated Julian Date	Closest Approach Dist.	R.A.	Dec.	Delta T days	d/n	y/n	Comments
					″		″	s	″		″	s	″				
55	1916207	Jupiter	η Vir	0.15	400	N	747	16.4	711	1916206.86	746	17.0	702	0.08	d		c.
56	1916251	Jupiter	η Vir	0.10	200	W	197	-9.5	137	1916253.91	60	1.8	54	0.08	d		c, l.
57	1920769	Venus	η Vir	0.38	1100	SE	263	17.4	43	1910769.15	134	3.8	122	0.08	n	n	g.
58	1927486	Venus	Mars	-0.03	700		702	-21.2	628	1927487.10	702	-21.2	628	0.08	n	y	
59	1928396	Venus	α Leo	0.38	2600		1419	78.8	868	1928396.00	1111	18.8	1079	0.08	d		c.
60	1928606	Mars	ω Sco	0.41	2100		468	-0.6	467	1928607.39	441	10.6	413	0.08	n	y	
61	1930192	Mercury	Venus	0.39	2600		2008	-61.3	-1819	1930193.76	1162	30.5	-1082	0.08	d		f.
62	1932487	Mars	η Vir	0.36	1100		1265	3.6	1263	1932487.50	1191	30.0	1104	0.08	d		f.
63	2001436	Jupiter	1 Gem	0.31	2600		1056	-14.9	-1034	2001440.08	1001	8.9	-993	0.05	d		f.
64	2001495	Mars	λ Sgr	-0.02	1800		1762	20.3	1740	2001493.88	1757	8.4	1753	0.05	d		a(1), c.
65	2001660	Venus	ν Tau	0.02	2800		2326	75.3	2067	2001659.58	1644	-38.5	1551	0.05	d		c.
66	2001866	Venus	η Vir	0.38	2100		1947	-34.7	-1877	2001866.20	1944	-39.4	1853	0.05	n	n	g.
67	2001877	Mars	η Vir	0.37	1800		1725	-83.3	1199	2001878.08	629	14.8	590	0.05	d		f.
68	2001878	Venus	θ Vir	0.38	1400		1556	-102.4	245	2001878.71	315	-8.6	-287	0.05	d		f.
69	2002959	Mars	δ Cap	0.05	700		1200	-72.3	645	2002959.44	892	-21.9	838	0.05	n	n	
70	2002867	Mars	ι Aqr	0.04	1400		1439	-101.6	-28	2002967.68	448	-10.6	422	0.05	d		f.
71	2018316	Mars	σ Leo	0.34	1400	NW	806	21.7	741	2018317.16	804	17.0	765	0.05	n	n	
72	2021002	Venus	Pleiades	0.03	1800	SE	1333	35.6	-1235	2021001.01	1333	35.6	-1235	0.05	d		h.
73	2021037	Venus	β Tau	0.02	2600		2084	-94.5	-1653	2021038.91	1428	-30.6	-1367	0.05	d		c, k, l.
74	2021212	Venus	η Vir	0.40	700		1427	-78.3	821	2021212.67	326	9.0	298	0.05	d		f.
75	2021331	Mars	Jupiter	0.42	2600	S	2481	-82.0	-2211	2021331.95	2202	1.7	-2202	0.05	d		f.
76	2021592	Venus	φ Sgr	-0.03	2600	W	2290	-169.2	-397	2021592.74	495	-1.5	-495	0.05	d		c,l.
77	2022662	Venus	δ Sco	-0.03	3200		3212	166.8	2162	2022661.57	2825	5.9	2665	0.05	d		c.
78	2022730	Venus	δ Cap	-0.02	3200		2591	-167.6	1089	2022730.50	1745	-38.8	1658	0.05	d		f.
79	2022747	Saturn	36 Gem	0.18	2600		2273	97.8	1824	2022752.02	1819	-0.4	1819	0.05	d		j, k, l.
80	2023011	Venus	σ Leo	0.40	2800		1622	-76.6	-1170	2023011.50	1485	-36.7	-1384	0.05	d		f.
81	2024538	Mars	φ Vir	0.35	1800	NW	1916	-9.6	1910	2024538.75	1715	43.9	1586	0.05	d		f.
82	2081517	Mars	σ Leo	0.31	1800	N	1937	90.1	1414	2081516.78	1769	38.9	1674	0.03	d		f.
83	2082096	Saturn	π Sgr	0.18	1800		4508	-2.4	-3403	2082085.57	3306	8.0	-3304	0.03	d		b(8), c.

Explanation of Columns in Table III:
Column 1: The number of the observation in chronological order.
Column 2: The observed date of observation converted to a Julian Day Number.
Column 3: The planet involved in appulse.
Column 4: The other object involved in the appulse.
Column 5: The approximate time of the observation in fractions of a Julian Day.
Column 6: The recorded separation between the two objects converted to seconds of arc.
Column 7: The recorded direction from the object to the planet at the recorded time.
Column 8: The calculated least separation between the planet and the object either within 0.10 days of the recorded time, after the sun had set, or the object had risen above the horizon.
Column 9: The calculated separation in Right Ascension at the separation given in Column 8.
Column 10: The calculated separation in declination at the separation given in Column 8.
Column 11: The calculated time of least separation.
Column 12: The calculated separation in Right Ascension at the time of least separation.
Column 13: The calculated separation in declination at the time of least separation.
Column 14: The value of Delta T in fractions of a Julian Day.
Column 15: Closest approach occurred during (d) the daytime or (n) the nighttime.
Column 16: y/n: If closest approach occurred during the nighttime, (y) it occurred in the recorded time period, or (n) it did not occur during the recorded time period.
Column 17: Comments, see the Footnotes.

Footnotes:
a(n): Recorded date was n days early.
b(n): Recorded date was n days late.
c: Closest approach occurred before sunset.
d: Closest approach occurred during evening twilight.
e: Closest approach occurred during morning twilight.
f: Closest approach occurred after sunrise.
g: Closest approach occurred while objects were below the horizon.
h: Extended object.
i: Member of Jupiter-β Sco group of 'occultations.'
j: Planet is moving very slowly across sky (<2′ /day).
k: Date recorded is only approximate.
l: Least separation is given for the given time of observation on the recorded date of the phenomenon.

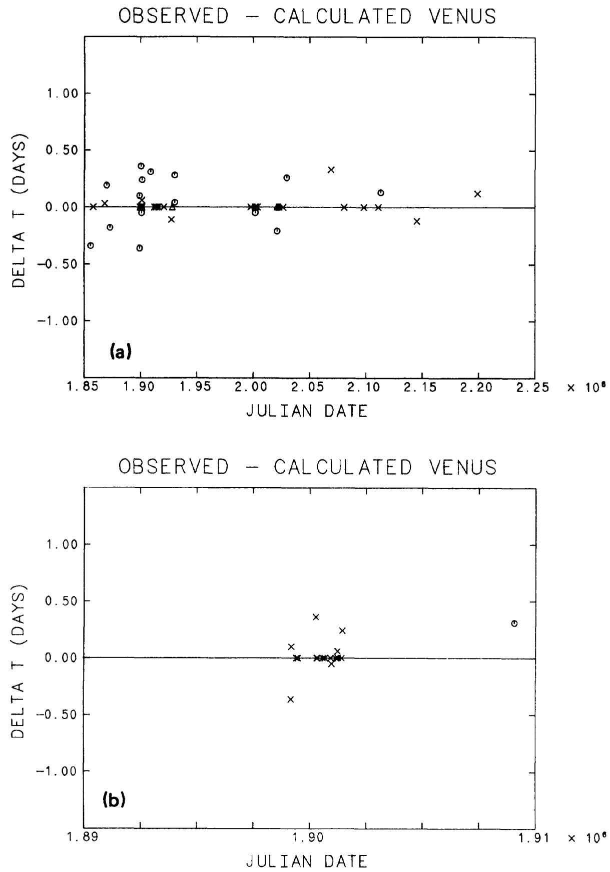

FIG. 1. (a) Observed minus calculated time for a given separation for Venus. The circles represent the observations recorded as occultations for which the closest approaches occurred during the daytime. The triangles represent the recorded occultations where the closest approaches occurred during the night. The ×'s represent the records of "fans" or appulses. (b) This is the same as (a) but shows the detail from JD 1890000 to 1910000.

closest approach was observed, the distance was less than 15′. For a few of the observations, an actual occultation occurred when the occulted object was extended, and in a few cases the two objects were actually observed to come close enough together that they were not separable by the naked eye. Additional problems that might have resulted in the recording of an occultation are poor weather conditions and irradiation. However, all of the records are of real events, in agreement with Bielenstein's hypothesis that portents were common enough that, rather than manufacturing them for the record, they would be ignored when they were not needed politically. This means that the Chinese records should not be used for statistical purposes because an event may have been ignored not only because it may not have been observed but also because it may not have been politically useful.

Second, the observations appear to be used as markers in the sky for various aspects of the motions of the planets. Examples of these markers: (1) the series of observations of Jupiter and β Scorpii, which were all made when Jupiter was in retrograde motion in the area, and (2) the two observations from the "poor" observations, which consisted of a date, a planet, and two objects occulted several weeks apart. In the latter example, it was shown that the planet actually made close passes to both the objects, and the date was the time for the planet to pass the first of these "markers."

Third, there is no evidence within the accuracy of these observations to make us think that there are any inherent difficulties in present planetary theories with periods of about 2000 yr. This constitutes the first check of the planetary theories against this large body of Chinese observations. However, this evidence is weak.

Finally, from the observed very close approaches that occurred during the nighttime hours, the time that was recorded for their closest approach and the time that was calculated verify the ΔT correction derived by Stephenson and Morrison (1984). This confirmation of ΔT is important because the observations do not depend on the position of the Moon, as do previous determinations of ΔT. However, the errors involved in the timing of the individual events make it impossible to distinguish betwen the ΔT value of Stephenson and Morrison (1984) and that of Newton (1984).

In general, this study verifies the reliability of ancient Chinese records of planetary occultations and gives an example of how these records can be used in modern astronomy. The Chinese records of celestial events include many different kinds of events such as planetary positions, lunar occultations, comets, and eclipses. These records have only been sparingly used by people such as Morrison and Stephenson (1977) and Newton (1984), mainly because most of the records exist in Chinese only and have difficulties inherent in translation and interpretation. Therefore, the best method of attacking these records is as a collaboration between astronomers and historians knowledgeable in the language and traditions of Chinese astronomy.

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