The Upcoming Approach of Cored Tempel-Tuttle and the Leonid Meteors

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ABSTRACT

Using the available observations in 1699, 1865-66, and 1965, an orbit has been re-computed for periodic comet 55P/Tempel-Tuttle, the parent body of the Leonid meteors. The comet's motion has been numerically integrated back in time for two millennia and ephemerides computed for each perihelion return. Chinese observations of the comet in 1366 are well represented and we have identified possible (but not definite) observations of the comet in October 1234 and January 1035. The Leonid meteors have been observed since A.D. 902. Prior to the eighth century, no Leonid meteors should have been visible because the comet's orbit passed too far outside that of the Earth. Using previously recorded accounts of the Leonid meteor showers and storms as a guide, we have provided predictions for the upcoming Leonid displays in November of 1996- 1999. The 1998 and 1999 events hold the most promise for a Leonid meteor storm although there seems little likelihood that the great storms of 1833 and 1966 will be repeated in the coming yews.

INTRODUCTION

The field of meteor astronomy began during the spectacular Leonid meteor shower witnessed in eastern North America during the early morning hours of November 13, 1833. Observers were stunned by a storm of meteors with an approximate rate of 50,000 per how. Denison Olmsted, a Yale College professor, was among the first to note the celestial nature of the phenomena by pointing out the location from which the meteors seemed to emerge was stationary in the neck of the constellation Leo (Olmsted, 1834). Using historical accounts of the Leonid showers from A.D. 902 to 1833, Hubert A. Newton (1864) established a time of 33.25 years between major shower events and predicted the next major Leonid event would occur in November 1866. Although it did not compare with the great storm of 1833, the anticipated meteor display on November 13, 1866 was impressive with a recorded rate of approximately 5,000 meteors per hour (Olivier, 1925). It was also in 1866 that the parent comet of the

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Leonids was discovered by Ernst W. L. Tempel at Marseille and Horace P. Tuttle at Harvard. This comet's orbit was soon identified with an orbit for the Leonid meteor particles themselves: the connection between comets and meteor stream particles was made clear in the 1860's (Yeomans, 1991). However the disappointment when the predicted 1899 Leonid meteor storm failed to materialize severely set back the science of meteor astronomy. In 1925, Charles Olivier recalled that in the face of great public anticipation and substantial press coverage, "the failure of the Leonids to return in 1899 was the worst blow ever suffered by astronomy in the eyes of the public" (Olivier 1925). After disappointing displays in 1932 and 1933, many feared the Leonid storms were only of historical interest. However, the extraordinary storm on November 17, 1966 dramatically demonstrated that the Leonid displays were far from dead.

The annual November Leonid meteor showers and the occasional Leonid meteor storms (e.g. 1833, 1966) are far better known than is the Leonid parent body, comet 55P/Tempel-Tuttle. Since A.D. 902, enhanced Leonid meteor showers have been recorded around the time of the parent comet's returns to perihelion. The parent comet itself, however, has not been seen for more than a few days at any apparition except in late 1865 and early 1866. The coming perihelion return of comet Tempel-Tuttle again raises the possibility of strong meteor displays in 1998-99 as well as a chance to observe the elusive parent comet. The January 1998 perihelion return of the comet offers the best observing opportunity since late 1865. On January 17, 1998 the comet will pass within 0.36 AU of the Earth and less than 8 degrees from the north celestial pole. It should be an easy target for northern hemisphere observers.

In an earlier work, Yeomans (1981) used 1865-66 and 1965 astrometric data to compute an orbit for comet 55P/Tempel-Tuttle and then numerically integrated the comet's motion back to the early tenth century. By comparing the orbital circumstances of the parent comet near the times of the observed Leonid displays over the 902-1969 interval, criteria were established for significant Leonid displays to occur: displays are possible roughly 2500 days before or after the comet reaches perihelion but only if the comet passes closer than 0.025 AU inside or 0.010 AU outside the Earth's orbit.

In the current work, the comet's orbit has been improved by including the 1699 data in the solution and the comet's motion has been numerically integrated back in time for two millennia. Ephemerides were computed at each of the comet's returns to perihelion and searches were conducted for observed apparitions prior to 1699. Leonid meteor shower predictions have also been updated for the 1996-1999 period

THE ORBIT OF THE PARENT COMET 55P/TEMPEL-TUTTLE

Astrometric data exist for periodic comet Tempel-Tuttle from the 1699, 1865-66, and 1965 apparitions. There is only a single 1699 observation by Gottfried Kirch and only three useful observations in mid-1965. The remaining 48 observations cover the interval from December 25, 1865 through February 9, 1866. In addition, rough Chinese observations were used by Kanda (1932) to determine an approximate orbit for the comet's return in 1366. In an earlier work, Yeomans (1981) computed an orbit based upon the most recent two apparitions. When this orbit was integrated back to 1699, the single observation of that year indicated that a correction of -17.3 days was required to bring the computed time of perihelion passage into accordance with the observed position. Using the 1865-66 and 1965 data, various values for the transverse nongravitational parameter (A2) as defined by Marsden et al. (1973) were iteratively input until the orbit residuals for the single 1699 observation reached a minimum. The optimum value for the A2 nongravitational parameter was $+9.3 \times 10^{-11}$ AU/(day)^2 and the mean residual for the 1865-66 and 1965 observations was a rather large. 15.4 arc seconds. There were also systematic residual trends to one arc minute suggesting that the dynamical model was not entirely successful.

In the current work we used the JPL comet and asteroid orbit determination program maintained by Paul W. Chodas since the mid 1980's. This program uses a linearized, weighted least-squares estimation algorithm in which observational data are used to improve an existing orbit. The dynamical model includes all planetary perturbations at each time step. The numerical integrator employs a variable step, variable order Adams method (Krogh 1972), and the step size varies to ensure that the estimated local velocity error at each time step is less than 10^{-13} AU/day. The equations of motion include relativistic terms (Shahid-Saless and Yeomans 1994) to be compatible with the employed planetary ephemeris DE404 (Standish et al 1995) and the partial derivatives necessary for adjusting the initial renditions are integrated along with the comet's equations of motion. This program has been used to generate accurate orbits for spacecraft targets (Yeomans et al. [illegible]) as well as for the three millennial investigation into the motion of comet 109P/Swift-Tuttle (Yau et al., 1994)

For comet 55P~J’cmpcl-Tuttle, we have employed the observations from 1699, 1865-66, and 1965 to obtain an orbital solution, solving for the orbital elements as well as for the radial and transverse nongravitational parameters (A1, A2). Except for the single observation in 1699 for which the residuals were 11 .?’ and 6.6’, therms unweighed residual was 3.8 arc seconds, and while the observation residuals were noisy, no obvious systematic residual trends were evident. The radial nongravitational parameter (A1) is not well determined and the transverse nongravitational parameter (A2) has a value within 6% of that found by Yeomans (1981). Table 1 gives the nongravitational parameters and the orbital elements for all the observed apparitions as well as the predicted orbital elements for 1998. Jupiter and Saturn are the major perturbing bodies for comet Tempel-Tuttle; Table 2 notes the times and minimum separation distances when the comet passed within 1 AU of these planets.

The considerable improvement over the orbit published by Yeomans (1981) results from including nongravitational parameters in the orbital solution. in the previous work, various test values of the transverse nongravitational parameter (A2) were input and solutions were made for the six orbital elements until the 1699 observation could be represented approximately. Because they did not employ nongravitational effects and used only observations from the two most recent apparitions, the 1998 perihelion passage time given by Marsden and Williams (1995) is 0.52 days earlier than the result given here.

In an effort to determine if there were any earlier observations of comet Tempel-Tuttle, the orbital solution given in Table 1 was numerically integrated backward in time for two millennia. The computed time of perihelion passage in 1366 is within 0.14 days of the value. determined by Kanda (1932) using the 1366 observations alone. The success with which the orbital extrapolation matched the observed 1366 perihelion passage time, coupled with the knowledge that no major planetary perturbations took place (see Table 2), gives us confidence in the accuracy of the 2,000 year integration. Using software developed to investigate close Earth approaches of comets and asteroids (Yeomans and Chodas 1994), we also kept track of the positional uncertainties associated with each planetary encounter. Each time the comet passed close to a perturbing planet, the minimum separation distance and the three-sigma uncertainty associated with this distance was output. In our backward integration, it was not until the second century A.D. that these 3-sigma uncertainties approached the values of the close approach distances themselves. Figure 1 presents the orbital characteristics for comet Tempel-Tuttle. Ephemerides were computed for a number of potential apparitions and searches into the literature were then undertaken to determine whether early apparitions of the comet were recorded. We assumed that the comet's apparent magnitude can be represented using the expression:

$$m = 9.0 + 5 \log (d) + 20 \log (r)$$

where d and r are the geocentric and heliocentric distances in AU's. This expression, which was taken from a data tape provided by the Minor Planet Center, gives a fair representation of the comet's reported behavior in 1866. To facilitate the search for earlier apparitions, we have made the crude assumption that the comet's intrinsic brightness has remained relatively constant over two millennia. In Figure 2, we have plotted the minimum geocentric distance and brightest apparent magnitude for each of the comet's returns since A.D. 17. At least since 1366, the comet has been intrinsically faint and achieved naked eye visibility only for a few days when it approached very close (< 0.1 AU) to the Earth. Stephenson and Yau (1985) noted that the active comet Halley does not reach obvious naked-eye visibility until its apparent magnitude is between 3.5 and 4.0 while Yau et al. (1994) pointed out that the less active comet 109P/Swift-Tuttle reached naked eye visibility only when its apparent magnitude was brighter than 3.4. As is evident from Figure 2, comet Tempel-Tuttle might have reached a magnitude brighter than 3.4 in 1699, 1366, 1234, 901, and 17. Identified observations have been recorded only in 1699 and 1366.

A possible early sighting of comet Tempel-Tuttle concerns a guest star recorded by Japanese observers on 1234 Oct. 30 (Ho Peng Yoke, 1962). At this time, comet Tempel-Tuttle came within 0.1 AU of the Earth with a solar elongation angle of about 75 degrees. For Japanese observers, it should have been a naked-eye object in the northeast morning sky. Despite these favorable circumstances, no records of this comet were located in either Chinese or Korean historical texts. Only a brief sighting concerning a guest star observed on October 30, 1234, was found in a Japanese work. Under 1234 October 30, a listing by Kanda (1935) included a report extracted from Borusho (a work compiled around AD 1260, which records the activities of the imperial court during the period from AD 967 to 1259). The Japanese record states that "On the seventh day, day jen-shen (of the 60-day cycle) in the tenth month of the first year of the Bunryaku reign-period (= 1234 October 30), a guest star appeared, but the astronomers did not see it. A court official's daughter-in-law saw it." Despite the brevity of the Japanese account and Hasegawa's (1980) dismissal of this sighting, this Japanese observation during the few days during which the comet would have achieved naked-eye brightness suggests that this might have been an observation of the comet.

There is also a possibility that the Chinese observed the comet on January 15, 1035. According to Ho Peng Yoke (1962), the Chinese noted that a star appeared at night at the Wai-Phing asterism (in Pisces) and that it had vaporous rays. At the time, comet Tempel-Tuttle would have been in Pisces at distances of 1.33 and 0.96 AU from the Earth and sun respectively and at a solar elongation of 46 degrees. However, if the comet had the same outgassing characteristics as it has had more recently, it would have been several magnitudes fainter than a naked eye object. Conceivably, the comet may have undergone a strong outburst at that time, raising its brightness considerably. Either comet Tempel-Tuttle was anomalously bright in January 1035 or it was not the comet noted by the Chinese in that year. We could locate no observations of the comet during its close Earth approach on October 12, 901 despite the fact that the comet reached its closest Earth approach (0.008 AU) within a few days of a new moon. For Chinese observers, the comet should have been an easy naked-eye object in the eastern morning sky. In summary, we cannot claim that comet Tempel-Tuttle was definitely observed prior to 1366.

THE LEONID METEOR SHOWERS AND STORMS

Although there are no definitive observations of comet Tempel-Tuttle prior to 1366, the comet's debris has been observable since at least A.D. 902. Enhanced meteor displays were recorded on several dates since 902 and major Leonid meteor storms were often recorded as well (e.g., 934, 1238, 1566, 1833, and 1966). Twentieth century observations of the Leonids suggest that the normal observed rate, adjusted to the zenith, is about 15 per hour. However, during the few years before or after the parent comet's return to perihelion, the Leonids can produce extraordinary storms of several thousand meteors per hour. Comet Tempel-Tuttle passes close to the Earth's orbit at its descending node. Using the 2000-year backward integration of comet Tempel-Tuttle, we have computed the differences between the Earth's heliocentric distance at the time of the comet's nodal passage and the comet's heliocentric distance as it passed through its descending node. These distance differences are plotted in Figure 3. The comet can pass within 1-2 AU of Jupiter and Saturn (see Table 2) and it is primarily these planetary perturbations that alter the comet's nodal distance from one return to the next. It is evident that no Leonid meteor showers could have been observed prior to the eighth century because the parent comet passed through its descending node well outside the Earth's orbit. Radiation pressure would be expected to push the small dust particles back behind the comet and outside its orbit so that major Leonid meteor storms are most likely when the Earth trails the comet to, and passes just outside of, the comet's descending node. For example, the great Leonid storms of 1833 and 1966 occurred because the Earth followed the comet to its descending node and passed just outside this point by 0.0012 and 0.0031 AU respectively. Figure 3 clearly shows why such impressive meteor storms were seen in 1833 and 1966 and why the 1899 - 1901 events were so disappointing.

What can be said about the likelihood of a significant meteor shower or storm in 1998 or 1999? In 1998-99, the Earth will pass nearly three times as far from the comet's orbital path as it did in 1966 and more than six times further than it did during the great storm of 1833. The 1998-99 circumstances are most like those for the 1866-68 and 1931-32 returns. For the former period, hourly rates of up to 5,000 were reported while in the latter period, about 200 was the maximum reported rate. By simulating particle ejections from the parent comet in the previous two perihelion returns, Wu and Williams (1996) predict that while the 1999 shower will be unimpressive, the 1998 shower may be similar to those seen in 1899 or 1932. While it does not seem too likely that there will be a major Leonid storm in either 1998 or 1999, the possibility cannot be ruled out. Significant displays should be looked for in both years. Table 3 gives the predicted times in each year when the Earth passes through the comet's orbital plane. Table 2 lists the comet's close approaches to its primary perturbers, Jupiter and Saturn. The most recent significant cometary perturbation was in 1732 so that particles released from the parent comet subsequent to this date would be relatively unaffected by differential planetary perturbations.

In January 1866, comet Tempel-Tuttle was the second comet to be observed spectroscopically (Huggins 1866; Secchi 1866). Both continuum radiation and the C_2 Swan bands were observed (though not recognized as such at the time). These crude observations were made more than 130 years ago and there were no observations of this comet's physical behavior at its next observed return in 1965. As a result, very little can be inferred concerning its dust production rates at any time in the past. The extraordinary Leonid storm of 1966 suggests that, despite the unimpressive past apparitions of the comet, it is still losing substantial amounts of' dust. Because of solar radiation pressure. and planetary perturbations, the Leonid meteor stream particles most distant from the parent comet will have the largest deviations from the parent comet's orbit. As a result, the predicted times of the 1996-97 shower maxima given in Table 3 could be in error by several hours. If history is any guide, even the predictions in 1998 and 1999 could be in error by a few hours (Kresak 1993). Brown and Jones (1992) and Jenniskens (1996) provide shower maxima predictions that are slightly earlier and significantly later than those provided here. The approximate right ascension and declination of the radiant point (J2000) are 153.6 and +21.8 degrees respectively and moonlight should be a problem only in 1997. Meteor observers at various longitudes are advised to coordinate observing programs so that observations of a marked meteor rate increase could be transmitted to aid subsequent observations by others in more westerly locations. The International Leonid Watch program is one such coordination effort (Brown 1991). However uncertain the Leonid events may be in 1998 and 1999, they are well worth an observational effort. From Figure 3, we note that because of planetary perturbations, it will be another century after the 1998-99 events before significant Leonid meteor displays are likely once again.

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Figures

1. Orbital Diagram, in ecliptic plane. projection, for Comet P/Tempel-Tuttle. Planetary positions are given for the time of the comet's 1998 perihelion passage (1998 Feb. 28). The innermost orbit is that of the Earth.

2. The minimum geocentric distance and the predicted brightest magnitudes are plotted for each return of comet P/Tcnq~cl-Tuttle over a period of two millennia. For each apparition, the plotted apparent magnitude represents the brightest value achieved when the comet's solar elongation angle is larger than 40 degrees. The horizontal dashed line represents the approximate naked-eye limit for an active periodic comet

3. Minimum Distances Between Comet and Earth Orbits at the Time of Comet's Nodal Crossing

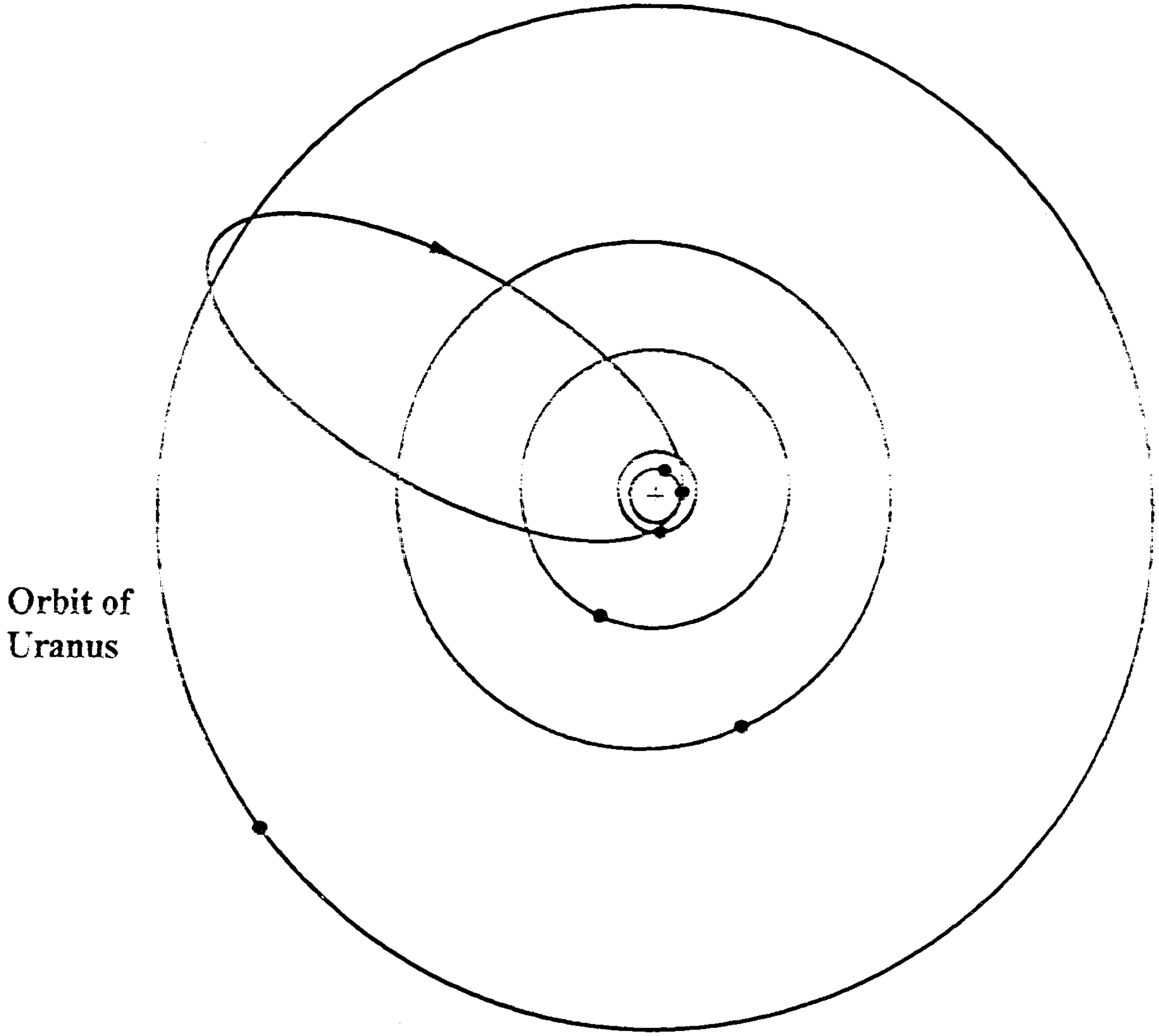
Tables

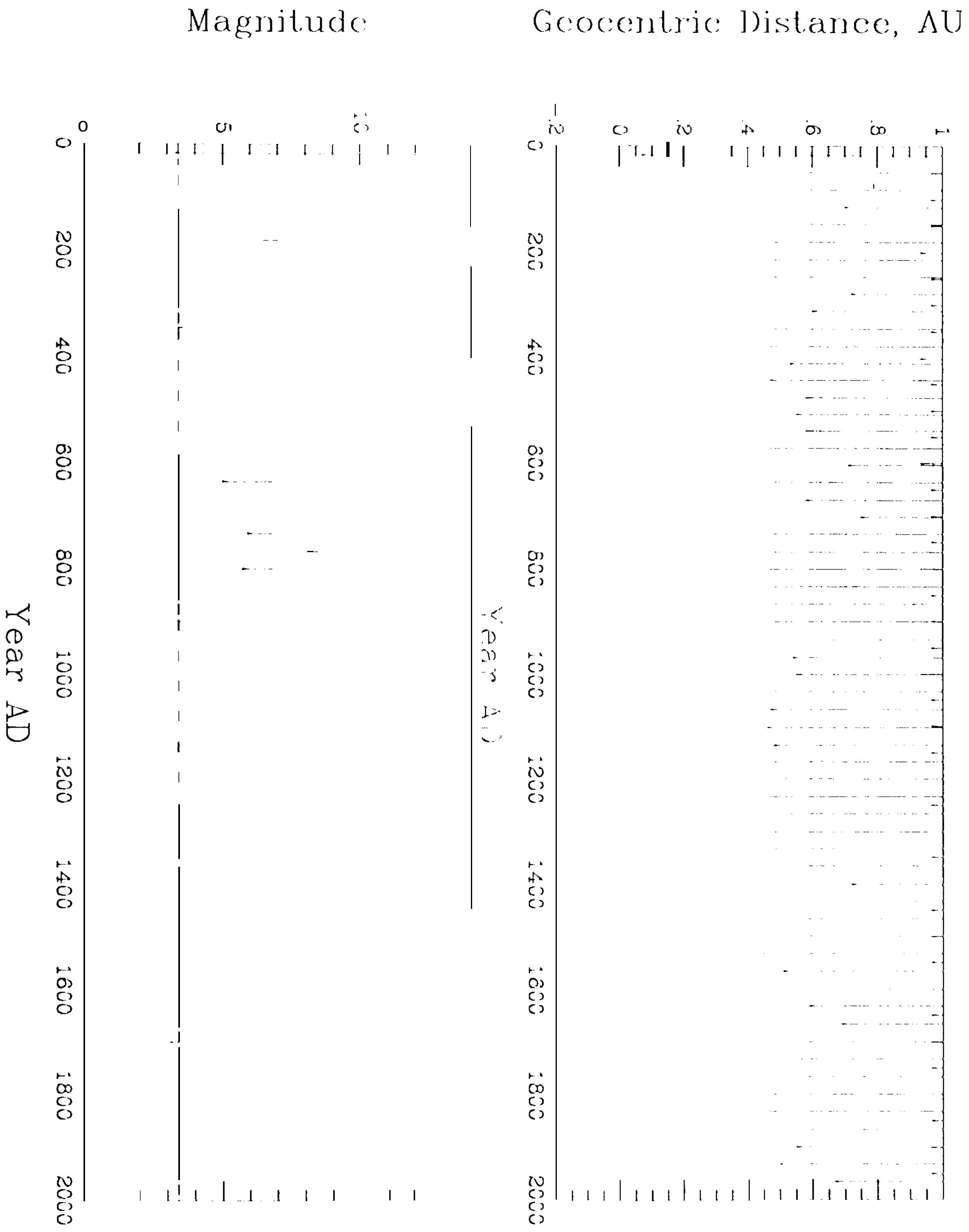
1. Orbital elements and nongravitational parameters for P/Tempel-Tuttle

2. Minimum separation distances and times for comet's approaches to within 1 AU of Jupiter and Saturn

3. Predicted Leonid Meteor Shower Circumstances

Comet 55P/Tempel-Tuttle




Geocentric Distance, AU
Magnitude
Year AD
Year AD
-.2
0
.2
.4
.6
.8
1
0
5
10
0
200
400
600
800
1000
1200
1400
1600
1800
2000

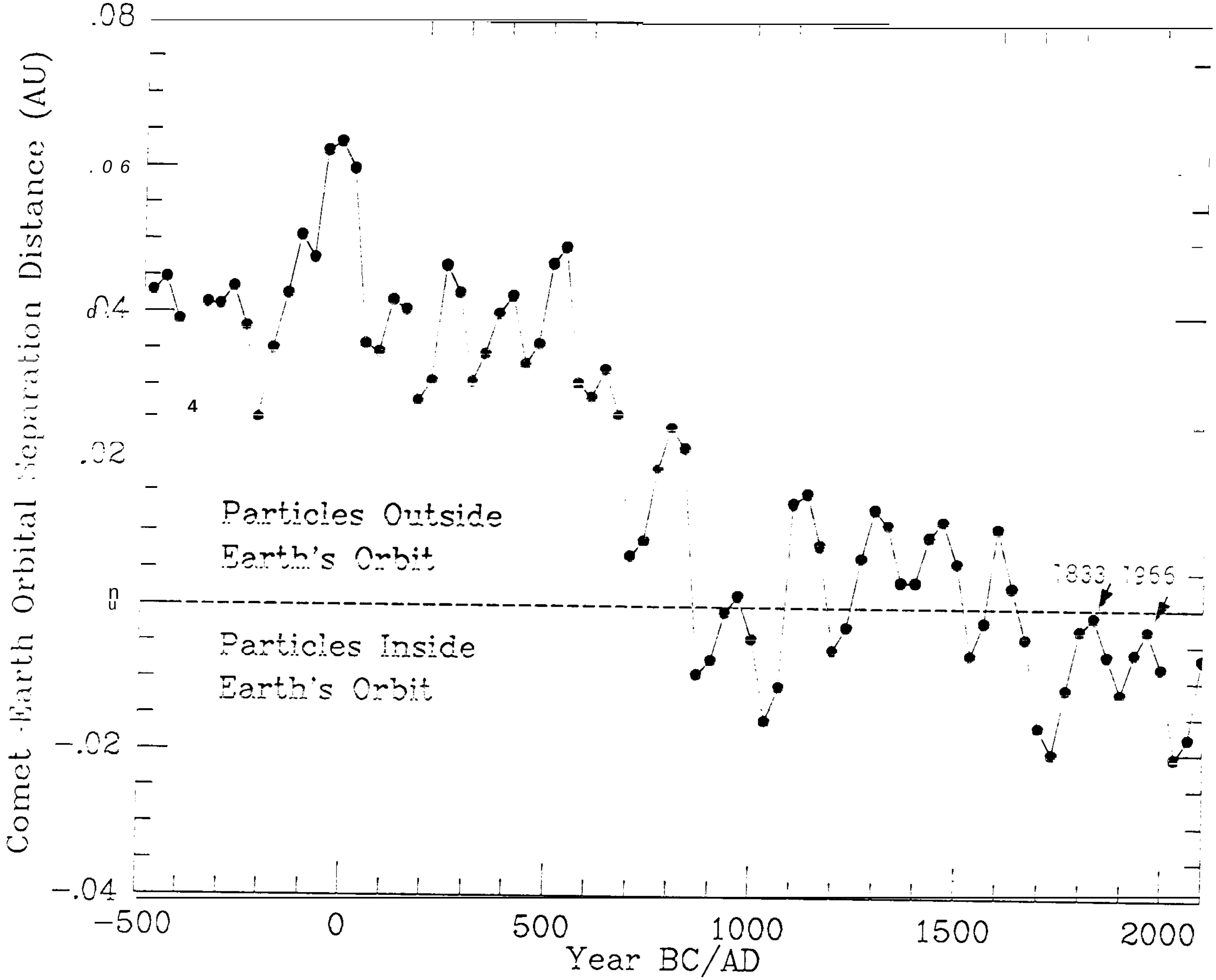

.08
.06
.04
.02
0
-.02
-.04
Comet -Earth Orbital Separation Distance (AU)
Particles Outside
Earth's Orbit
Particles Inside
Earth's Orbit
1833
1966
-500
0
500
1000
1500
2000
Year BC/AD

Table 1. Orbital elements for P/Tempel-Tuttle. These orbital elements are referred to the ecliptic and J2000 equinox

Ref. Solution: 23
Planetary Ephemeris: DE404
No. Observations: 52
Observation Arc: 1699 Oct 26 - 1965 Jul 26
Weighted rms = 3.8"

A1	-0.4799×10^{-9}	(1.8302×10^{-9})
A2	8.7910×10^{-11}	(0.0575×10^{-11})

Epoch (TDB)	e	q (AU)		Arg. Perih.	i	Tp
1366 Oct. 19.0	0.90635303	0.97636837	225.426903	164.467487	162.231802	1366 Oct. 18.404265
1699 Oct. 1.0	0.90803727	0.96411299	230.703748	168.900160	162.549820	1699 Oct. 10.932568
1865 Dec. 30.0	0.90606785	0.97655455	233.252358	170.900782	162.689907	1866 Jan. 11.623019
1965 Apr. 30.0	0.90443918	0.98163646	235.114939	172.561614	162.706015	1965 Apr. 30.004825
1998 Mar. 8.0	0.90550549	0.97659782	235.258084	172.493457	162.485875	1998 Feb. 28.090556

Table 2. Minimum separation (All) distances and times for comet's approaches to within 1 AU of Jupiter and Saturn

Date		Jupiter	Saturn
48	April	0.81	
344	June	0.54	
570	Mar.	0.54	
700	Oct.	0.88	
864	June		0.78
866	Sep.	0.52	
1068	Jan.	0.86	
1099	July		0.57
1630	Mar.		0.34
1732	July	0.83	

Table 3. Predicted Leonid Shower Circumstances. Although enhanced meteor shower activity is likely in 1996 and 1997, a meteor storm is most likely in 1998 and/or 1999.

Earth passes through comet's orbit plane Date (UTC)	HH:MM	Earth follows (+) or leads (-) comet (days)	Moon's age (days)	Representative observing sites
1996 Nov. 17	7:20	-473	6	Eastern U.S.
1997 Nov. 17	13:34	-108	17	Western U. S., Hawaii
1998 Nov. 17	19:43	+257	28	Japan, Asia
1999 Nov. 18	1:48	+623	9	Europe, North Africa