Comet 55P/Tempel-Tuttle and the Leonid Meteors

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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 AD 902, enhanced Leonid meteor showers have been recorded around the time of the parent comet's returns to perihelion (Yeomans 1981). However, the parent comet itself has not been seen for more than a few days at any return except during its recent 1997-98 apparition and in late 1865 and early 1866. The perihelion return of comet Tempel-Tuttle in early 1998 again raises the possibility of strong meteor displays in 1998-99 as well as a chance to observe the elusive parent comet.

Until the 1997 recovery observations (Hainaut, 1997), comet Tempel-Tuttle had been observed only during its 1366, 1699, 1865-66, and 1965 apparitions. J.R. Hind (1873) first pointed out that the comet seen by the Chinese in 1366 might have been an earlier apparition of the 1865-66 return of P/Tempel-Tuttle. Rough Chinese observations were used by Kanda (1932) to determine an approximate orbit for the comet's return in 1366. The work of Schubart (1965) allowed the recovery of the comet in 1965. By adjusting the comet's assumed period, Schubart computed an orbit based upon the 1865-66 observations that was also able to represent the 1366 observations. As a result of this process, he also identified a single 1699 cometary observation made by Gottfried Kirch (1737) as being due to comet Tempel-Tuttle. Schubart was able to provide a search ephemeris for the comet's expected return in 1965 and while the observing geometry was very poor, a few successful astrometric observations of the comet were made in mid-1965.

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. Figure 1 illustrates the circumstances of each significant Leonid meteor shower or storm event. Yeomans et al. (1996) improved the comet's orbit by using the 1965, 1865-66 observations as well as the 1699 observation in the solution. In an effort to identify early Chinese observations, they numerically integrated the comet's motion back in time for two millennia. Possible (but not definite) observations of the comet were identified in October 1234 and January 1035.

For the most recent orbit of comet 55P/Tempel-Tuttle, a total of 311 observations over the interval 1865 Dec. 22 through 1998 Feb. 8 were employed. The derived orbital elements are given below.

JPL Solution	53
Planetary Ephemeris	JPL DE405 (J2000)
Epoch	1998 Mar 8.0 (TDB)
Perih. Time	1998 Feb 28.09666 (TDB)
e	0.9055036
q	0.9765849 AU
Arg. Perih.	172.49731 deg.
Lng. Asc. Node	235.25883 deg.
Inc.	162.48614 deg.
A1	5.4 (+/- 2.7) E-10 AU/(day**2)
A2	9.129 (+/- 0.015) E-11 AU/(day**2)

The rms-unweighted residual was 1.8 arc seconds, and while the observation residuals were noisy, no obvious systematic residual trends were evident. The radial and transverse nongravitational parameters (A1, A2) are designed to account for the rocket-like thrusting accelerations introduced by the outgasing cometary nucleus (Marsden et al. 1973). The perihelion passage time differs by only -0.006 day from the prediction by Yeomans et al. (1996). While the radial nongravitational parameter (A1) is not well determined, the transverse nongravitational parameter (A2) has a value within 4% of that found by Yeomans et al. (1996). Our value of A2 and the 1998 orbital elements are also similar to those given by Nakano and Hasegawa (1996); their orbit is based upon 59 observations over the 1366-1965 interval.

The success with which the orbital extrapolations matched the recently computed 1998 perihelion passage time gives confidence in the conclusions reached by Yeomans et al. (1996). No Leonid meteor showers should have been observable prior to the eighth century because the parent comet passed through its descending node well outside the Earth's orbit. It is important to attempt to observe the expected 1998-99 displays because it will be another century after these events before significant meteor displays are once again likely. After the 22nd century, the precession of the comet's orbit will prevent future Leonid meteor displays for several centuries.

THE LEONID METEOR SHOWERS AND STORMS

Rao (1995) and Mason (1995) have provided comprehensive reviews on the history of the Leonid meteor events while Hughes (1982), Kronk (1988) and Yeomans (1991) give a broader historical review of meteor showers in general. Although there are no definitive observations of comet Tempel-Tuttle prior to 1366, the comet's debris has been observable since at least AD 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 a 2000-year backward integration of comet Tempel-Tuttle, we computed the differences between the Earth's heliocentric distance at the time the Earth passes near the comet's node and the comet's heliocentric distance as it passed through its descending node. These distance differences are plotted in Figure 2. The comet can pass within 1 - 2 AU of Jupiter and Saturn and it is primarily these planetary perturbations that alter the comet's nodal distance from one return to the next. 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 2 clearly shows why such impressive meteor storms were seen in 1833 and 1966 and why the 1899 - 1901 events were so disappointing.

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 likely that the major 1966 Leonid storm will be repeated in either 1998 or 1999, the possibility cannot be ruled out. Significant displays should be looked for in both years. The predicted times in each year when the Earth passes through the comet's orbital plane are presented in Table 1. The most recent significant cometary perturbation by Jupiter or Saturn was in 1732, so that particles released from the parent comet subsequent to that year would be relatively unaffected by differential planetary perturbations.

Table 1. Predicted Leonid Shower Circumstances. Although slightly enhanced meteor shower activity was evident in 1995 - 97, impressive meteor showers are most likely in 1998 and/or 1999.

Earth passes through Comet's orbit plane Date (UTC)		Observed time of shower maxima	IAU Circ Reference	ZHR meteors/hr	Earth follows (+) or leads (-) comet (days)
1995	Nov. 18.054	Nov. 17.9-18.4	6268	25-35	-838
1996	Nov. 17.306	Nov. 17.2-17.4	6505	60	-473
1997	Nov. 17.566	Nov. 17.5-17.6	6772	40	-108
1998	Nov. 17.822			200 – 5000?	+257
1999	Nov. 18.075			200 – 5000?	+623

The range in the Zenith Hourly Rates (ZHR) for 1998 – 1999 are predictions based upon the rates observed in 1931-32 (ZHR ~ 200) and 1866-68 (ZHR ~ 5000), when the geometric circumstances were similar to the 1998 – 1999 circumstances.

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. Brown and Jones (1993) provide shower maxima predictions for 1995-99 that are slightly earlier than those given here, Jenniskens (1996) predicts that these showers will be significantly later than those presented here while Mason's (1995) predictions are similar to those given here. From Figure 2, we emphasize that because of planetary perturbations, it will be another century after the 1998-99 events before significant Leonid meteor displays are once again likely.

While there have been efforts to predict the intensity of a meteor shower by modeling the stream of particles released by the parent comet, this is an extremely complex process fraught with many unknowns and assumptions. For the Leonid meteor displays, the only real data available are the historical records of when strong Leonid meteor events took place and a knowledge of the geometric circumstances under which these events too place. Hence, history has provided a reality check upon the existing models and in fact, these historical circumstances can be used to provide predictions for the 1998-1999 events. In the past, the times of the shower intensity maxima have been very close to the time when the Earth passes through the comet's orbital plane near its descending node. As noted in Table 1, these types of prediction for the times of the 1995, 1996, and 1997 maximum shower events have been rather accurate and there is no obvious reason to doubt that the 1998 and 1999 predictions will be seriously in error. What sort of Leonid meteor rates can we expect in 1998 and 1999? The geometric circumstances in 1866-67 and 1931-32 were most similar to those expected in 1998 and 1999. Since the observed meteor rates in 1866-67 and 1931-32 were approximately 5000 and 200 per hour respectively, we can anticipate a zenith hourly rate in 1998 and 1999 bounded by the rates witnessed in the earlier events – between 200 and 5000 meteors per hour.

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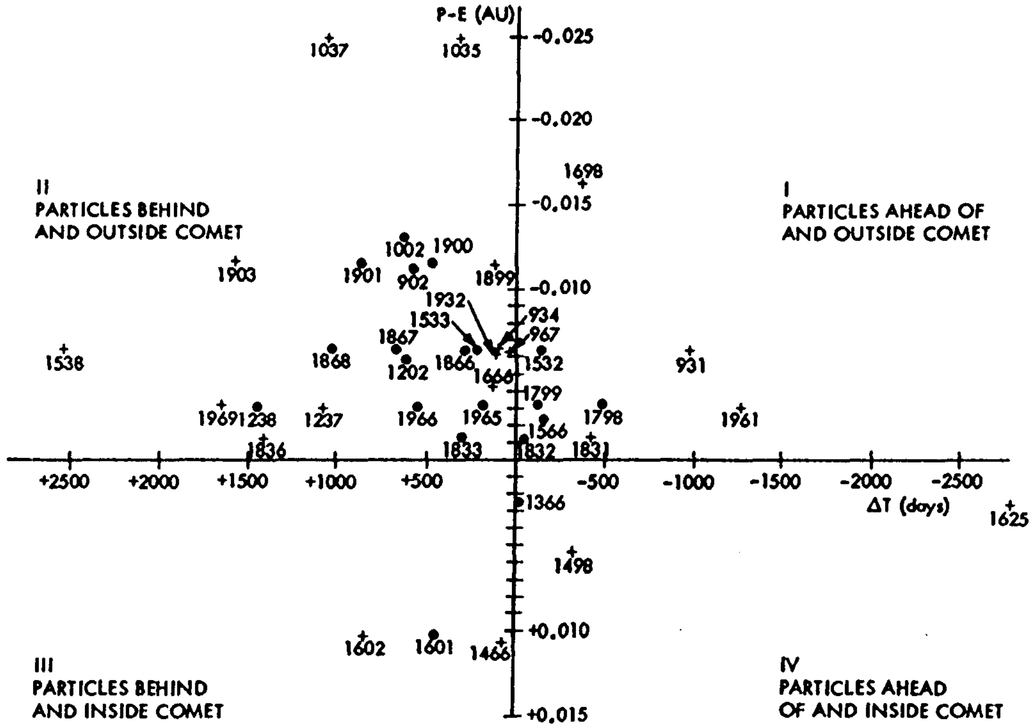
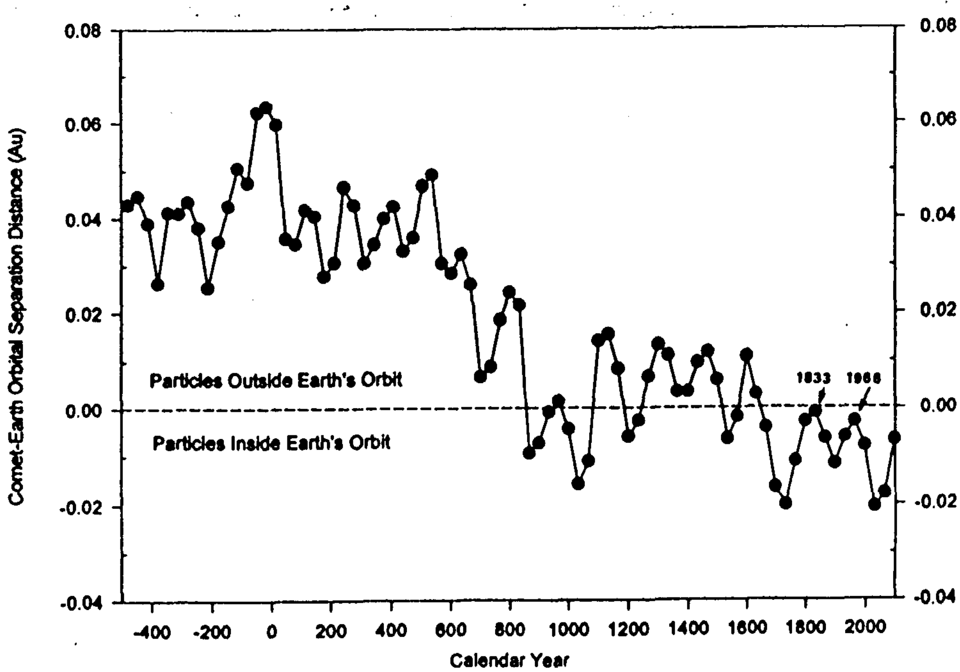


Dust particle distribution surrounding comet Tempel-Tuttle as deduced from Leonid meteor shower data. The ordinate represents the distance (in AU) that Leonid shower particles were inside or outside the orbit of the parent comet and the abscissa gives the time (in days) these particles either lag or lead the parent comet to the comet's descending node.



Minimum distances between comet Tempel-Tuttle and Earth orbits at the time of the comet's passage through its descending node.