Leonids

The unexpected 2004 Leonid meteor shower

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In 2004 the Earth will encounter meteoroids released around the 1333 and 1733 returns of comet 55P/Tempel-Tuttle (respectively 20 and 8 orbital revolutions ago). The resulting enhancements in the Leonid ZHR profile will only be of the order of 10 (for the 20-rev) and a few tens (for the 8-rev) above the Leonid background ZHR, and will be rather diffuse, but should be observable. The 20-rev trail will be encountered in the early hours of November 19 and the 8-rev in the late hours of the same date (UT). In this paper we compare details of the predictions from our three dynamical models.

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1 Introduction

The task of making meteor shower predictions has been attempted since the XIXth century, but significant success was achieved only in the late XXth (Kondrat'eva & Reznikov, 1985; Lyytinen, 1999; M^c^Naught & Asher, 1999). Several studies (e.g., Lyytinen & Van Flandern, 2000; Vaubaillon, 2002) indicate that the great Leonid meteor storm period is now over until at least 2033, although noticeable outbursts will occur in 2006 and 2007.

However, as in 2003 (Vaubaillon et al., 2003) we announce here an unexpected Leonid meteor shower in 2004 November. The 2003 shower was unusual in the way that an earlier than normal shower was predicted, i.e. on November 13. This enhancement of activity was observed (Arlt, 2003), as well as the other predicted shower, on November 19. Generally speaking, expected and observed ZHR values were low ($\lesssim 100$). Combined with the existence of gaps in the observational coverage, this makes it harder to define a maximum, and indeed no clear peak was found.

Though nothing was previously expected for 2004, as the time of the Leonid shower approaches, we once again examined our results. It was found that Leonid trails will approach the Earth. The most surprising thing is that no 2004 prediction has been published yet, though models are now correctly predicting the different showers. We present in the following the details of the results from our 3 different models (M^c^Naught & Asher, 1999; Lyytinen & Van Flandern, 2000; Vaubaillon, 2002).

2 Predictions for 2004 Leonids

The model of Vaubaillon (2002, 2003) follows the orbital evolution of millions of particles (50 000 meteoroids ejected at each perihelion return of comet 55P/Tempel-Tuttle since 1300 A.D., plus several streams back to 604 A.D., in each of various size bins). In this way 1333 and 1733 are identified as the only returns of the comet from which there are significant concentrations of meteoroids (leading to meteors superimposed on the normal Leonid background) near the Earth's orbit in 2004 November.

Figure 1 provides the position of the 1333 and 1733 trails relative to the Earth. A different part of the same 1333 trail is thought by several authors to have been the main component of the great 1998 Leonid fireball storm (Asher et al., 1999; Vaubaillon, 2003), although other results suggest large contributions from other trails (Lyytinen, 1999; Brown & Arlt, 2000). This is a very perturbed trail, and substantially dispersed particles are found in the plot of Figure 1.

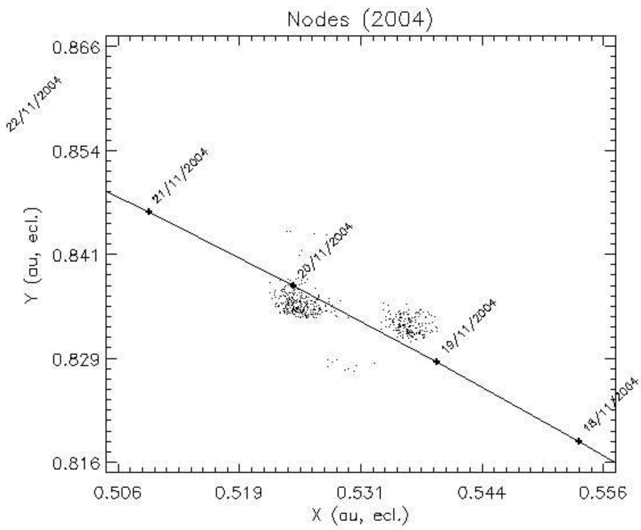

Figure 1 – General circumstances of the encounters in 2004 November with meteoroid streams ejected from 55P/Tempel-Tuttle in 1333 (the earlier encounter) and 1733 (the later encounter). The particles away from the two main concentrations are from 1333.

The 1733 trail was encountered in 2000 (M^c^Naught & Asher, 1999; Arlt & Gyssens, 2000; Lyytinen & Van Flandern, 2000), i.e. only two years after the comet's perihelion return. In 2004 the situation is different, since six years separate the comet's return and the time of the shower. A more dispersed trail is expected, resulting in a lower ZHR value than in 2000.

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Table 1 – Trail encounter parameters, times and ZHR forecasts for 2004 Leonids (excluding normal Leonid background). Negative $r_{\rm E} - r_{\rm D}$ means Earth is closer than the trail to the Sun.

Model	Trail	Δa_0	$r_{\rm E} - r_{\rm D}$	f_M	Peak time (UT)	ZHR
M & A	1333	+0.15	−0.0019	0.02	Nov 19, $06^{\rm h}40^{\rm m}$	
Lyytinen	1333	+0.15		0.02	Nov 19, $01^{\rm h}30^{\rm m}$	5–10
Vaubaillon	1333				Nov 19, $06^{\rm h}42^{\rm m}$	$\simeq 10$
M & A	1733	+0.22	+0.0024	0.10	Nov 19, $21^{\rm h}20^{\rm m}$	
Lyytinen	1733	+0.22		0.11	Nov 19, $19^{\rm h}00^{\rm m}$	$\simeq 30$
Vaubaillon	1733				Nov 19, $21^{\rm h}49^{\rm m}$	65

Table 1 gives the details of the encounters with the two trails, on 2004 November 19. Vaubaillon's predictions are based on past observations, with a higher statistical weight given to the 2000 data for the 1733 trail. Thus these calibrations from past observations lead to moderate ZHR enhancements, as shown in the Table.

Alternatively, some idea of the meteor activity level can be obtained from the trail encounter parameters Δa_0, $r_{\rm E} - r_{\rm D}$ and f_M (McNaught & Asher, 1999). The first of these, defined as the difference in semi-major axis from the cometary value at the time when a meteoroid is released, is equivalent to the orbital period (which evolves under planetary perturbations). Therefore Δa_0 specifies the distance along the trail during the following orbital revolutions, and determines when the meteoroid reaches the ecliptic. Conversely the constraint that a meteoroid reaches its node in mid-November, so as to produce a Leonid meteor, determines Δa_0 (values in Table 1).

Most meteoroids experience significant solar radiation pressure, which increases the period. The above definition of Δa_0 is for the case of no radiation pressure, when Δa_0 for any given meteoroid is determined entirely by its ejection location on the comet's orbit and by the ejection velocity; we define meteoroids with the same period (experiencing different amounts of radiation pressure) as having the same Δa_0. Greater values of Δa_0 tend to be associated with smaller particles because these are more affected by radiation pressure. The Δa_0 values in Table 1 (McNaught & Asher model) are compatible with visual meteors (i.e., the number of meteoroids, of sizes corresponding to visual Leonids, is a maximum near such values of Δa_0). The particle size ranges simulated in other models agree with this conclusion.

For young enough trails, orbital evolution due to planetary perturbations is essentially a function only of Δa_0. Moreover, ejection at perihelion tangential to the comet's orbit, varying only the ejection speed, can generate any value of Δa_0. This idealisation, with a 'trail centre' defined by tangential ejection at perihelion, vastly reduces the required computation and has been shown to successfully predict any meteor storm (e.g., Kondrat'eva et al., 1997). Ejection over an extended arc of the comet's orbit and in directions other than tangential can be related to trail cross sections (Kondrat'eva & Reznikov, 1985; McNaught & Asher, 1999). The Table 1 (M & A model) values of the peak time are for the Earth's closest approach to the trail centre; the values of $r_{\rm E} - r_{\rm D}$ are the 'miss distance' in AU of the Earth from the trail descending node. The miss distance of storm level Leonid displays has been within a few × 0.0001 AU and so the 2004 trail encounters are a long way below storm level, even with the favourable values of Δa_0.

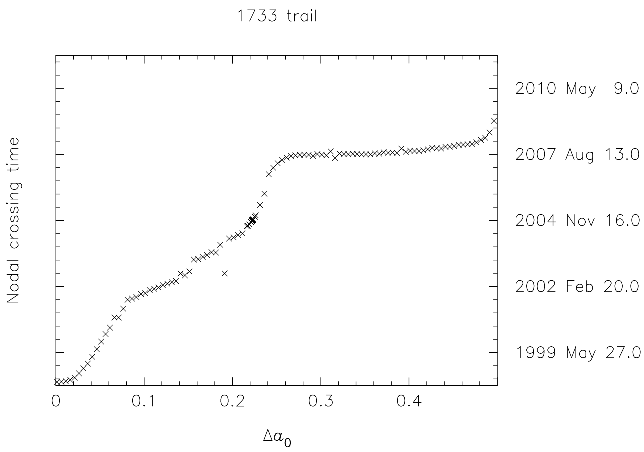

Figure 2 – Nodal crossing time around present day of particles ejected tangentially at perihelion in 1733, as a function of orbital period at ejection time (equivalently Δa_0).

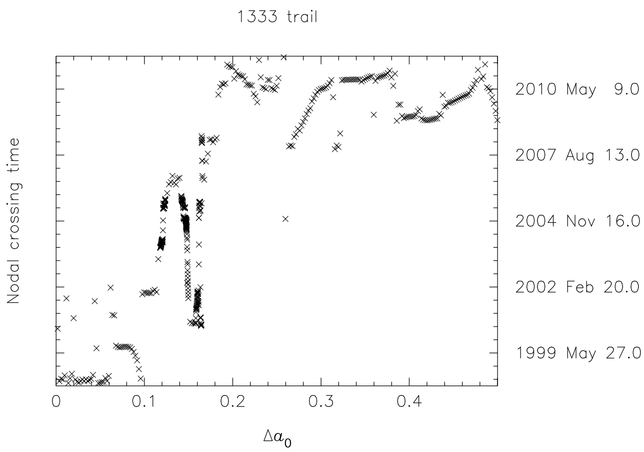

Figure 3 – Nodal crossing time around present day of particles ejected tangentially at perihelion in 1333, as a function of orbital period at ejection time (equivalently Δa_0).

The third parameter f_M measures how 'stretched' any given part of a trail is in the along-orbit direction. When nodal crossing times (Figures 2 and 3) are more spread out, f_M and the spatial density of particles are lower. In the 8-rev trail, the nodal crossing time is a (moderately) smooth function of Δa_0 (Figure 2), and f_M can easily be evaluated from the tangential ejection at perihelion model. For this trail, $f_M \approx 0.10$ (Table 1) and the particle density is $10\times$ down on that for a 1-rev trail (additional to any dependence of the density on Δa_0 and $r_{\rm E} - r_{\rm D}$).

The 20-rev trail is old enough to be more scattered (Figure 3). Although the tangential ejection at perihelion model successfully identifies parts of the trail near the Earth (i.e., where $|r_{\rm E} - r_{\rm D}|$ is small), resulting values of f_M cannot be relied on (essentially, the curve in Figure 3 is not smooth enough). Indeed, at finer resolution (not shown here), Figure 3 shows multiple Earth encounters with the idealised trail centre (not listed separately in Table 1 since $r_{\rm E} - r_{\rm D}$ and especially Δa_0 are quite similar). The value of $f_M \approx 0.02$ in Table 1 was derived by following the orbital evolution of particles ejected along the comet's orbital arc and with different velocities (all particles having Δa_0 that placed them at or near the appropriate part of the trail). This simulation with multiple particles also allows cross sections to be plotted but these are not shown here as they show similar features to Figure 1; in any case Figure 1 relates to a fuller model (which has been calibrated by past observations). The low f_M and fairly high $r_{\rm E} - r_{\rm D}$ suggest quite a low ZHR.

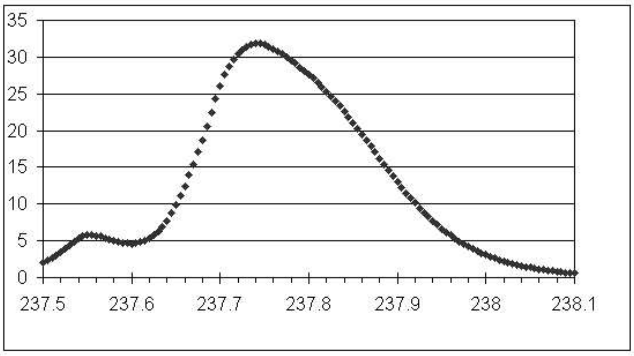

Figure 4 – ZHR due to 8-rev trail, as function of $\lambda_\odot$, taking into account the A2-effect.

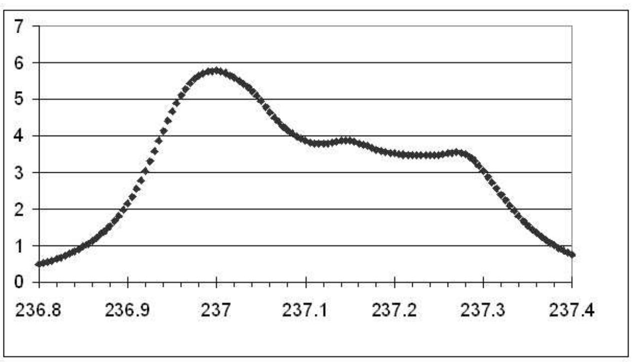

Figure 5 – ZHR due to 20-rev trail, as function of $\lambda_\odot$, taking into account the A2-effect.

Because perturbations are a function of orbital period, any systematic change to the period can affect particles' perturbation histories. We use the term 'A2-effect' to refer to systematic changes in the period due to radiative (i.e. nongravitational) forces. The size of the A2-effect is different for different meteoroids, as they experience radiative forces to differing extents. The overall A2-effect results from the range in the individual effect on different particles. It can firstly cause trail cross sections to spread over time, and also modifies the density profile encountered by the Earth along its orbit. A complete nongravitational model was calculated with the technique of Lyytinen & Van Flandern (2000) and Lyytinen et al. (2001). The model has been somewhat updated, taking into account the data from the years 2001 and 2002, but the main principles are the same. The derived ZHR plots are shown in Figures 4 and 5. The peak times that are evident as solar longitudes in these Figures are listed as UT in Table 1.

It appears that the nongravitational A2-effect (also called continuous acceleration) will bring particles closer to the Earth's orbit with positive values (that increase orbital period at each revolution) in the 8-rev encounter and with negative values in the 20-rev encounter. This effect may increase to some degree the total amount of meteors seen, but because these will be distributed over an extended time interval, the ZHR seems actually to be lower than would be expected without the effect. The times of maximum will be shifted earlier by some hours in each case, because of the effect. In the trail from 1733, this shift is expected to be about two or three hours and in the 1333 trail maybe as much as five hours (Table 1). The given times are not expected to be very accurate. The observations are expected to be valuable in studying this nongravitational effect, although the relatively small rates will probably not allow the observational results to give very accurate ZHR plots.

3 Comments and conclusion

The best estimates for this year's Leonids, excluding the normal Leonid background, are in Table 1. The background is traditionally associated with the Earth's passage through the comet's orbital plane; using the value of the comet's longitude when it last reached its node gives a time of 2004 November 17, $08^{\rm h}$ UT. The 20-rev and 8-rev trail encounters are two days later.

In general, the longer the time since the meteoroids were released from the comet, the harder it is to make precise quantitative predictions: we note that the majority of spectacular Leonid storms have been due to younger trails. Also, in the observations, lower level showers are harder than storms to separate quantitatively from the background. However, as in 2003 we can see that the Leonid meteor shower time is still not over now. Observers are therefore encouraged to gather data on November 19. We recall that IMO reports are the basis for constraining models of evolution of meteoroids and predictions of meteor showers.

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