Aurigids

Aurigid predictions for 2007 September 1

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The September 2007 encounter with the 1-revolution dust trail of comet 1911 N1 (Kiess) was modeled to predict the expected peak time, duration, and peak rate of the Aurigid meteor outburst. This event is the only anticipated dust trail crossing of a known long period comet in the next fifty years. With a peak time of 11:36 ± 20 min UT, September 1, 2007, the meteor outburst will be visible from locations in Mexico, the Western states of Canada, and the Western United States, including Hawaii and Alaska.

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1 Introduction

Past encounters with the dust trail of long-period comets were observed only by chance and by few observers. Astrometric measurements were made only during the1995 α-Monocerotid shower (Jenniskens et al., 1997), and to lesser extend during the recent October Camelopardalid outburst (Jenniskens et al., 2005). The α-Monocerotid outburst was predicted based on a similarity in the Sun's reflex position, which mimics the position of a dust trail relative to Earth's orbit (Jenniskens, 1997; Lyytinen & Jenniskens, 2003).

Since the confirmed detection of the 1995 α-Monocerotids (from an unknown comet) and the subsequent Leonid storms, the basic physical principles behind these transient showers is understood: dust ejected from the parent comet is dispersed due to small differences in orbital period from ejection speed and radiation pressure. The dust forms a trail that wanders in and out of Earth's path due to planetary perturbations by the major planets working slightly differently on particles at different positions along the trail (Kondrat'eva & Reznikov, 1985; Kresák, 1993; McNaught & Asher, 1999; Lyytinen, 1999; Jenniskens, 2006). A meteor shower outburst is observed only when the trail is in the Earth's path at the same time of Earth passing the node.

In the case of so-called intermediate long-period comets, with orbital periods of 200 − 10 000 years, the trail is so much perturbed on the way in that the second revolution dust trail is dispersed beyond recognition (Lyytinen & Jenniskens, 2003). Hence, the dust of a long-period comet outburst dates from the last time the comet was near the Sun. All such intermediate long-period comets have a one-revolution dust trail if they completed at least one orbit around the Sun.

2 The 2007 Aurigids

Lyytinen and Jenniskens (2003) investigated when the dust trails of known long-period comets would be in the Earth's path in the next fifty years. They discovered that the most promising case would be that of the α-Aurigids on 2007 September 1, when the position of the trail will be identical to that of three known past outbursts of this shower. In their model, the trail was calculated to be just inside Earth's orbit at all occasions. The past showers make this the only such encounter that can be predicted with enough certainty to warrant a concerted observing campaign, until the 2040/41 AD return of the Lyrid from comet C/1861 G1 (Thatcher).

We investigated the distribution of dust from comet C/1911 N1 (Kiess) using a comet ejection model developed by Crifo & Rodinov (1997) and calculate rigorously the planetary perturbations on the particles from the point of ejection until intersection with Earth's orbit (for a full review of the method see Vaubaillon et al., 2005a, Vaubaillon et al., 2005b).

Some 1 000 000 meteoroids were ejected from the comet orbit in 83 BC, which is the perihelion time of the nominal comet orbit (Minor Planet Center comet orbit database) when integrated backward in time. The calculated Julian day of perihelion passage is 1690869.5, when Julius Caesar was still in the provinces. Forward integration confirms that planetary perturbations occur only on the inward leg. As a result, the precise position of the dust trail is not sensitive to the adopted perihelion time in that previous return.

Figure 1 shows the calculated position of the one-revolution comet dust trail at the time of Earth passing the node in 1935, 1986, and 1994. The graph shows all particles that crossed the ecliptic plane within two months from the time of the observed outburst. The motion of the trail has been removed by fitting simple first or second order polynomials.

Preliminary results were announced at the IAU General Assembly in Prague (Jenniskens & Vaubaillon, 2006) and are summarized in Table 1. Each past shower lasted about 1.5 hours, with a Full Width at Half Maximum = 28 minutes. The width of the trail is not expected to change much from one return to the next, although it will depend on how far we pass from the trail center, based on our experience with past Leonid storms (Jenniskens, 2006). Also, past Leonid dust trails tended to be 0.00025 AU further inward than calculated. If so, the peak time will be up to 21 minutes earlier than calculated.

In 2007, the trail will be at exactly the same position relative to Earth orbit as in prior returns. This confirms

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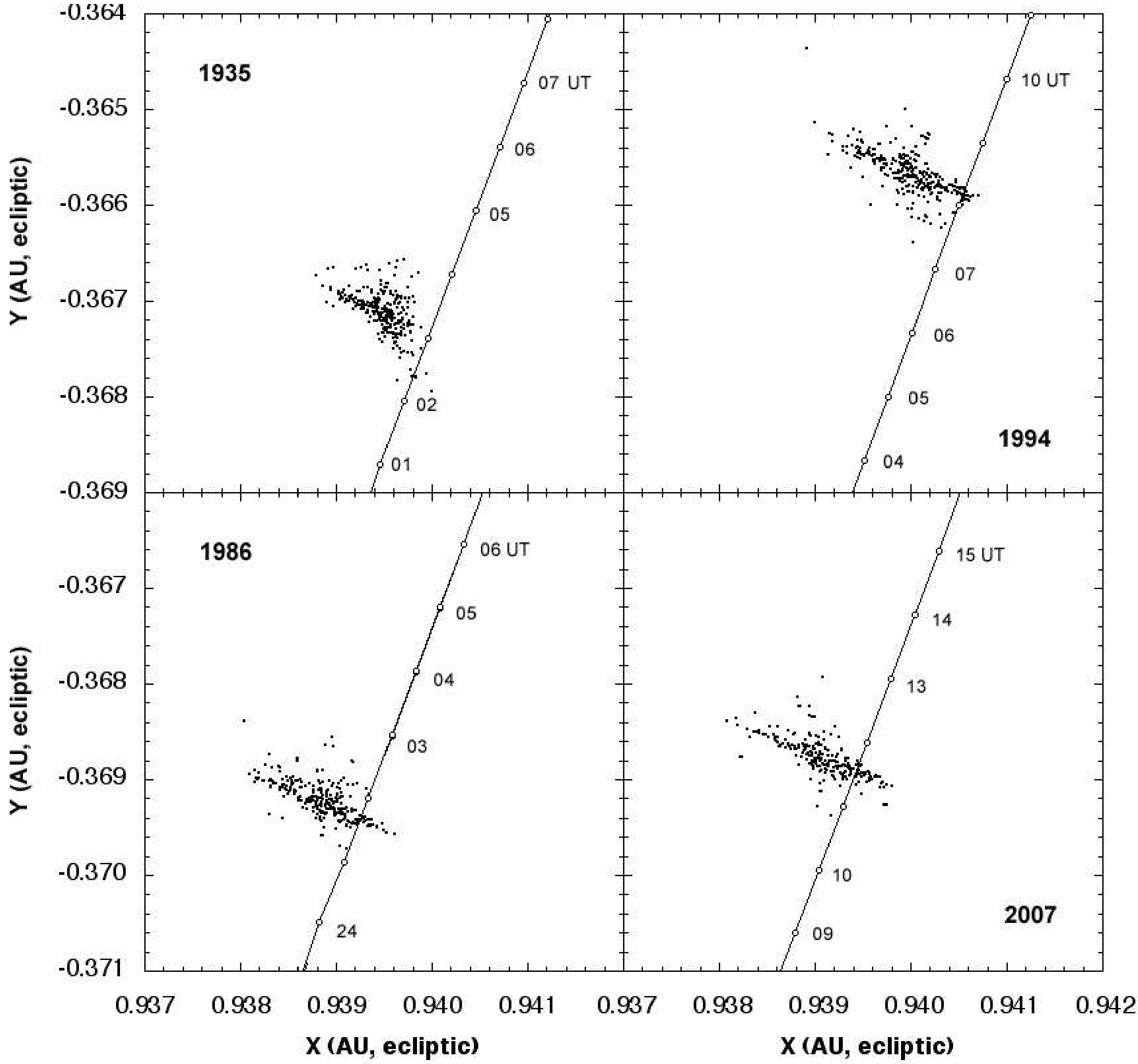

Figure 1 – Position of the node of the model 1-revolution Aurigid stream particles that passed the ecliptic plane within 2 months from the time of past Aurigid outbursts. Only particles are shown that would cause meteors of magnitude −3 to +3. The trail motion over that time period has been removed. The density of points corresponds to the expected intensity of the shower.

Table 1 – Calculated circumstances for the encounter with the 1-revolution (83 BC) trail of C/1911 N1 (Kiess) at the time of Aurigid outbursts. $\Delta r_\Omega(D-E)$: difference in the the heliocentric distances of the nodes between Earth and dust. Δa: difference in orbital element a between comet and meteoroid immediately after ejection. f_M: mean anomaly factor, describing the dilution of dust density in the trail relative to that of the 1-revolution trail (in the absence of planetary perturbations). FWHM: Full-Width at Half Maximum, describing the broadness of a distribution by specifying the width at a level half that of the peak.

Year observed	Year ejected	$\Delta r_\Omega(D-E)$ (AU)	Δa (AU)	f_M	Sol. Long. (J2000)	Day	Time (UT)	FWHM	Phase of Moon
2007	−82	−0.0003863	6.9726	0.005810	158°561	Sep. 01	11^h36^m	25^m	0.8
1994	−82	−0.0008137	6.0279	0.004612	158°738	Sep. 01	08^h01^m	33^m	0.1
1986	−82	−0.0003673	5.4497	0.016433	158°530	Sep. 01	01^h38^m	27^m	0.6
1935	−82	−0.0005241	1.7459	0.031045	158°656	Sep. 01	03^h05^m	35^m	0.6

Table 2 – Observed parameters of past Aurigid outbursts. FWHM: Full-Width at Half Maximum, describing the broadness of a distribution by specifying the width at a level half that of the peak. $< m >$: average magnitude.

Year	Sol. Long.	Day	Time (UT)	ZHR (/hr)	FWHM (min)	RA (J2000)	DEC	$< m >$
1994	158°.733	Sep. 01	07^h54^m	200 ± 25	~ 30	—	—	+1.13
1986	158°.519	Sep. 01	01^h22^m	200 ± 25	28 ± 7	90.5	+34.6	+0.54
1935	158°.656	Sep. 01	03^h04^m	≥ 100	31 ± 13	86.3	+40.5	+2.62

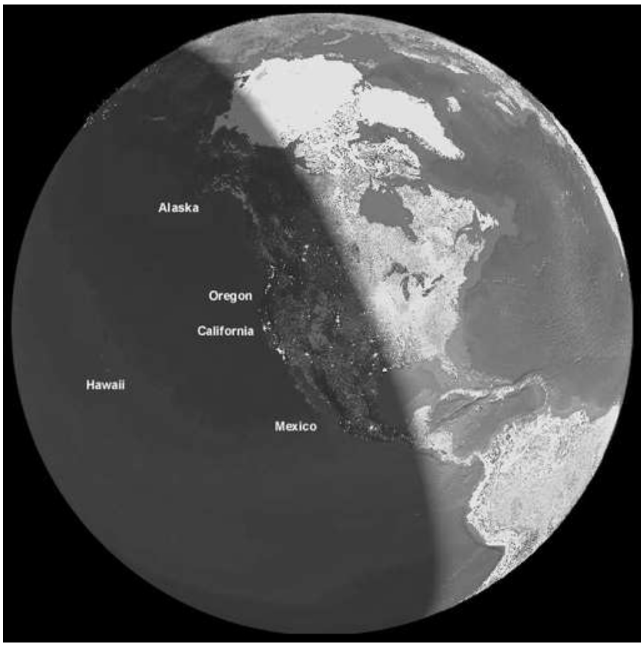

Figure 2 – View of the Earth from the perspective of the approaching meteoroids. Best locations for viewing the outburst are at the dark side of the Earth, somewhat away from the civil twilight border, and closest to the center of the image.

earlier results by Lyytinen and Jenniskens (2003). However, the observed peak time in past encounters was 1, 16, and 7 minutes earlier than calculated (Table 2). Our best estimate for the peak time, therefore, is 11:36 UT on September 1, 2007, with an uncertainty of about ± 20 minutes.

As it happens, the predicted encounter time makes the shower favorable for viewing from the California, where the radiant will be high in the sky just before dawn. A bad Moon, four days past full Moon, will be high in the sky ($\sim 69°$ at San Francisco), which will hamper ground-based observers. Fortunately, the Moon will not dampen the display much, because past Aurigid outbursts were rich in −3 to +3 magnitude meteors, with few faint ones.

3 Past Aurigid outbursts

In 1935, Cuno Hoffmeister and Artur Teichgraeber at the Sonneberger Sternwarte in Germany and visual observers from the Štefanik Observatory in Prague reported an outburst of meteors in the predawn hours of the morning of September 1 during regular observations (Teichgraeber, 1935; Guth, 1936). A large number of bright meteors radiated from a point in the constellation of Auriga. The German and Czech observers nicely confirmed each others' reports and, together, documented the event well. Teichgraeber immediately realized that the radiant of the Aurigid stream was not far from that of comet C/1911 N1 (Kiess) at 91.3°, +39°.2, which passed Earth's orbit unusually close in 1911. However, it was long unknown how, 24 years after the return of the comet, there could still be a sudden meteor outburst.

The cause of this outburst came into focus when in 1986 another outburst was observed by Hungarian amateur meteor astronomer Istvan Tepliczky of the *Magyar Meteor- és Tüzgömbészlelö* (MMETH). He saw a flurry of bright meteors radiating from the constellation Auriga, which was in many respects similar to the event in 1935 (Tepliczky, 1987). These were again predominantly bright meteors, +0.54 magnitude on average, all leaving a wake lasting 1–3 seconds. There was no independent observation that year, but the fact that the Aurigids had returned was quickly accepted on account of Teplickzky's experience as a visual meteor observer. Again, the peak of the outburst was close to the comet orbit node. The position of the radiant was derived from plotted trails was close to the theoretical position of Kiess (Table 2).

When the shower returned in 1994, it was observed by only two experienced visual observers under marginal conditions. N.A.M.N. observers Bob Lunsford and George Zay, located near San Diego, California, observed the outburst very shortly after the radiant came above the local horizon (Zay & Lunsford, 1994). These grazing meteors were very slow and made long 60 degree tracks on the sky, lasting 2 seconds. Most were of magnitude 0 and +1. Forward meteor scatter observations by Ilkka Yrjölä of Kuusankoski, Finland, confirmed the outburst and placed the peak some time before Bob and George saw the first Aurigids (Jenniskens, 1997).

Rates continued to rise when twilight interfered during the 1935 outburst. In 1986, Tepliczky derived an average ZHR $= 39.6 \pm 8.1$ from the period between the first and last Aurigid (00^h47^m – 02^h12^m UT), during which 24 Aurigids were seen. He only saw two sporadic meteors in an hour prior to the outburst (limiting magnitude $\sim +5.2$?), and the faintest Aurigid was +4 magnitude, which suggests that observing conditions were not ideal. Jenniskens (1995) calculated a peak ZHR $= 250 \pm 30$/hr, based on 10-minute intervals, but used an exponent of 1.4 to account for the radiant

Table 3 – Observed magnitude distributions (Zay & Lunsford, 1994). Observer VR is Vrátnk (first name unknown) of the MČAS (Chechian Astronomical Society), who saw the shower in 1935 from the Štefanik Sternwarte in Prague (Guth, 1936).

	−4	−3	−2	−1	0	1	2	3	4	5	Observer
Aurigids:											
1994	0	0	1	0	1	8	6	2	0	0	LUNRO
1994	0	0	1	0	1	9	3	3	2	1	ZAYGE
1986	1	0	0	5	7	3	6	1	1	0	TEPIS
1935	—	—	—	—	2	2	14	9	4	1	VR
Sporadics:											
1994	0	1	1	0	3	3	18	24	10	2	LUNRO
1994	0	1	0	2	6	5	16	21	8	6	ZAYGE

altitude correction. For a simple geometric correction $\sim 1/\sin(h_r)$, the ZHR $= 200 \pm 25$/hr.

The rate measurement in 1994 was hampered by the low radiant elevation and a rising radiant during the observations. Lunsford and Zay observed 20 and 17 Aurigids that night. For the hour between 07^h22^m and 08^h22^m UT, with the radiant being at 13° elevation at 07^h49^m UT, they calculated a ZHR = 37/hr and 55/hr, respectively. Again, the rate varied strongly during that interval. In small 10-minute intervals, Jenniskens (1997) had a peak ZHR = 400±50 per hour. For a simple geometric dilution correction, this rate would be a factor of 2 lower.

We can use these past activity estimates to guess how intense the 2007 Aurigid meteor shower will be. Based on these calculations, the rates in 2007 are expected to be of similar intensity as in 1986 and 1994, with a peak ZHR of about 200 (Figure 1).

These showers were very dramatic because of their brief duration and the abundance of bright meteors. These past Aurigid showers contained as many meteors with negative magnitudes as the recent Leonid storms. The 2007 return is not much further from the position of the comet than that of 1994 and we expect again relatively bright meteors of magnitude −3 to +3 magnitude (Table 3) with a low magnitude distribution index $\chi \sim 1.5 \pm 0.3$. The trail does not contain many small particles. In our model, this is because the smaller grains are ejected in wider orbits (Whipple, 1951) and become quickly more dispersed.

The α-Monocerotid magnitude distribution was truncated with an upper mass cut-off, presumably because large grains can not make it this far out in the trail. Our model, however, shows that large particles can make it out to this position in the trail and we are interested in knowing what will be the brightest Aurigid observed in 2007.

4 Importance of this rare shower

From the 1994 return of the Aurigids, it was clear that there was no simple periodicity as expected for a clump of dust in a shorter orbit. Instead, the solar reflex motion was nearly the same in each year, giving birth to the hypothesis that the outbursts were caused by a wandering dust trail (Jenniskens, 1995). This was confirmed the next year, when the 1995 α-Monocerotid outburst was observed and proven to be due to dust grains in a long-period orbit (Jenniskens et al., 1997) and not a dust cloud from a comet fragment orbiting in a 10-year orbit as thought before.

Until now, the α-Monocerotids are the only dust trail crossing with the trail of a long-period comet observed by modern instrumental techniques. Interestingly, these meteoroids were very unusual. They were found to be almost completely lacking in sodium (Borovička et al., 2002; Borovička et al., 2005) and penetrated relatively deep in Earth's atmosphere (Jenniskens et al., 1997), presumably because material was sampled that came from a pristine crust exposed to cosmic rays at the time of cold storage in the Oort cloud.

C/1911 N1 Kiess is an *Intermediate Long-Period comet*, which means that it has survived a few orbits since first entering the inner solar system. This makes it representative of a large number of such comets that appear at Earth very infrequently but betray their presence by a dust trail. We do not know for certain if the debris lost in 83 BC contains any grains from its pristine crust. However, it is very enticing to attempt to detect such meteoroids as they represent the only direct evidence for cosmic-ray induced crusts of comets.

In this context, it is interesting that Bob Lunsford and George Zay described the outburst Aurigids as having a greenish or bluish look to them (Zay & Lunsford, 1994), while being more white outside this interval. That suggests that the meteoroids produced a strong iron and magnesium signature from ablating metal atoms, more so relative to air plasma emissions during the outburst than by meteors from the annual Aurigids. This could point towards a different particle morphology of outburst Aurigids.

Another important reason for observing the 2007 Aurigid outburst is that long-period comets are responsible for some of the largest impact craters on Earth. Dust trail crossings from unknown comets are sometimes observed, which betray the presence of an Earth-threatening long-period comet. A recent example is the 2005 October Camelopardalid outburst (Jenniskens et al., 2005). A study of the imminent dust trail crossing may teach us how to translate observed dust trail crossings into physical data on the parent comet. The duration of such outbursts, for example, depends on how fast the meteoroids are ejected, which can teach us how massive the parent comet is. The results can be compared to observations of comet Kiess itself.

The expected meteor outburst is not a great immediate threat to satellites in orbit. The meteoroids are an impact hazard for satellites because of the high impact speed of the meteoroids (Beech & Brown, 1993). However, the impact probability will be less than that of past Leonid storms due to a lack of small meteoroids in the trail. Fast sporadic meteoroids are more likely to hit, because they are present over longer time intervals. Even so, the chance of impact of fast meteoroids in the mass range of $0.01 - 0.1$ gram will increase a hundred fold at the peak of the brief Aurigid outburst.

More important is the fact that long period comets can break and produce dense dust streams (e.g., Sekanina 2002). If the comet breaks while rounding the Sun and the dust cloud (the zero-revolution trail) moves into Earth's path at the wrong moment, the rate of meteoroid impacts can rise above ZHR = 1 000 000 /hr. The likelihood of this occurring is higher than the chance that the comet itself will hit the Earth. The study of the Kiess dust trail can help future mitigation efforts by calibrating prediction models that determine the exact location of such debris clouds.

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