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An Unusual Meteor Shower on 1 September 2007

Around 83 B.C., give or take a century, comet Kiess (C/1911 N1) passed by the Sun, ejecting a cloud of dust particles. The comet returned in 1911, after completing one orbit. The dust particles were pushed by solar radiation pressure into slightly wider orbits and have been returning ever since, forming a thin ongoing stream of dust that usually passes just outside Earth's orbit. On occasion, the combined gravity of the solar system's planets moves this dust trail into Earth's path. Earth encountered this 2000-year-old dust in 1935, 1986, and 1994, causing a meteor shower known as the Aurigids.

This very rare shower will occur again on 1 September 2007. A brief shower of tens of meteors will radiate from the constellation of Auriga, many as bright as the brighter stars in the sky. The Earth will be in the thick of it during the 1 hour centered on 0436 PDT. The shower will be visible with the naked eye from locations in the western United States, including Hawaii and Alaska, from Mexico, and from the western provinces of Canada (Figure 1).

This unique encounter could provide insights into how long-period comets lose large dust grains and about how to translate the observed dust trail crossing into physical data about the parent comet, and even provide more evidence for the hypothesized "pristine crust" of a comet [e.g., *Cooper et al.*, 2003; *Stern*, 2003]. This crust would be the product of cosmic ray bombardment during the years when the comet was in cold storage in the Oort cloud.

Long-Period Comets and Their Dust Trails

Long-period comets spend the majority of their time in the Oort cloud, a region of ice, rock, and dust that surrounds the solar system. These comets travel in highly elliptical orbits, and they take more than 200 years to return to the inner solar system. They can approach the Earth from all possible directions, typically at high velocity (56 kilometers per second is the most probable speed), and, because they can be bigger than asteroids, they are thought to be responsible for some of the largest impact craters on Earth [e.g., *Zimbelman*, 1984; *Weissman*, 2007]. Long-period comets offer little advanced warning, except for a trail of dust particles released during their previous return to the Sun.

The formation of these dust trails is well understood ever since the first detection of a dust trail from an unknown long-period comet in 1995, which caused the alpha-Monocerotid meteor shower [*Jenniskens et al.*, 1997] and the later 1999–2002 Leonid meteor storms from short-period comet 55P/Tempel-Tuttle [*Kondrat'eva and Reznikov*, 1985]. The three most recent returns of comet Kiess to the inner solar system occurred in 1911, 83 B.C., and about 2000 years prior. The oldest dust trail has now been perturbed beyond recognition [*Lyytinen and Jenniskens*, 2003], while the dust from 1911 still surrounds the comet as a cloud of dust. The 83 B.C. dust cloud has completed one orbit and is now a thin and very long stream of dust particles, dense enough at its core to create a noticeable shower on the rare occasion that Earth and dust trail meet.

The dust of long-period comets can be very unusual as well. The 1995 alpha-Monocerotid meteors were extremely low in sodium [*Borovicka et al.*, 2005] and penetrated 5 kilometers deeper into Earth's atmosphere than other meteoroids of similar size and speed [*Jenniskens et al.*, 1997]. It is theorized that this difference occurs because these meteoroids were crumbs of the comet's pristine crust. While long-period comets have not frequented the inner solar system enough to completely lose their pristine crust, short-period comets have long lost this crust.

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Predictions for the 2007 Aurigid Shower

The expected September 2007 encounter was modeled using a comet ejection model developed by *Crifo and Rodionov* [1997], and planetary perturbations on the particles from the point of ejection until intersection with Earth's orbit were rigorously calculated (for a full review of the method, see *Vaubaillon et al.* [2005]).

One million meteoroids ranging in size from 0.2 millimeters to 20 centimeters were ejected from the comet orbit in 83 B.C., which is the time of closest passage to the Sun of the nominal comet orbit listed in the Minor Planet Center comet orbit database, when integrated backward in time.

In 1935 and 1994, the trail moved rapidly from outside to inside Earth orbit in the days around the time of the outburst. In 1986, the trail moved from inside to outside Earth orbit. In contrast, the trail will be nearly stationary in 2007. To determine the trail position and cross section at the time of encounter, we corrected for this motion and considered all particles that passed by Earth orbit over a time interval of 2 months. This is justified, because the trail is not much distorted during that time interval.

The model puts the dust trail on 1 September 2007 at the exact same distance from Earth's orbit as when Aurigid showers were seen in past years (Figure 2). However, the calculated trails are always just inside Earth orbit, as first noticed by *Lyytinen and Jenniskens* [2003]. This discrepancy is thought to be due to ejection conditions being slightly different from those in the Crifo model. New observations of the upcoming Aurigid shower will help calibrate the ejection model.

Because the position of the trail is the same as in prior returns, we can use past experience to forecast the upcoming shower. Given that the calculated and observed peak times in past encounters were off by 16 minutes in 1986 and by 1 minute in 1994, our best estimate for the peak time, 1136 UT, has an uncertainty of about ±20 minutes. The predicted encounter time makes the shower visible over the dark part of the globe shown in Figure 1. The meteors will radiate with a speed of 67 kilometers per second from the direction (called the shower radiant) right ascension = 92° and declination = +39° (J2000) in the constellation Auriga. Especially in California, the radiant will be high in the sky just before dawn in the early morning of 1 September.

In the past, observed showers lasted about 1.5 hours, with the rate being above half that of the peak (full width at half maximum, or FWHM) during approximately the middle 28 minutes. Our model predicts FWHM is 25 minutes for 2007, but the actual width will depend on where the Earth crosses the trail. On the basis of past Leonid storm observations, we expect that the width of the trail will be wider when the Earth passes farther from the trail center [*Jenniskens*, 2006], thus causing a longer shower.

Depending on the exact position of the trail crossing, meteor rates in 2007 are expected to increase to a level similar to those in 1935, 1986, and 1994, when the zenith hourly rate (ZHR) rose to approximately 200 per hour in a short 10-minute time interval at the center of the outburst. That is about 3 times the peak rate of the annual Perseid shower. ZHR is the rate of meteors observed by a typical visual observer under clear-sky conditions with the radiant in the observer's zenith and the faintest stars visible in the sky being of magnitude +6.5. The estimate is uncertain, because the shower was observed under nonideal circumstances by only one observer in 1986 and two in 1994 [*Tepliczky*, 1987; *Zay and Lunsford*, 1994].

All previous Aurigids seen in 1935, 1986, and 1994 were predominantly bright -2 to +3 magnitude meteors, with few faint ones. The model correctly explains the lack of fainter meteors by having the smaller meteoroids disperse more along the comet orbit

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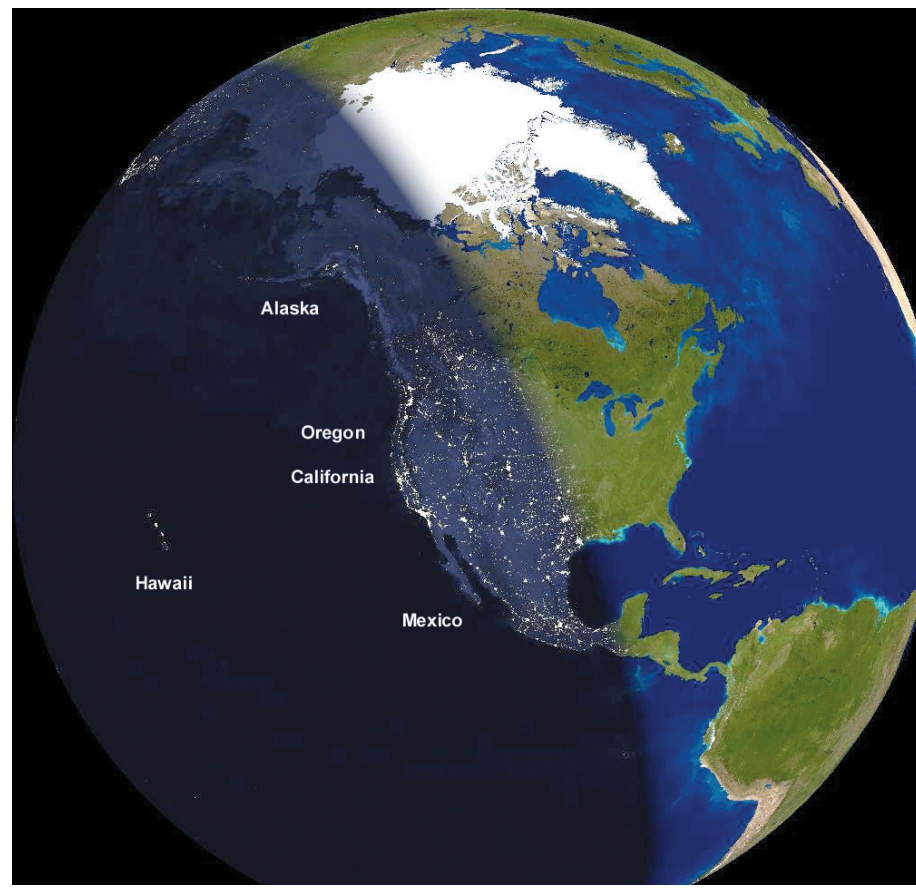

Fig. 1. Earth as seen from the perspective of the approaching dust grains at the peak of the predicted 1 September meteor outburst.

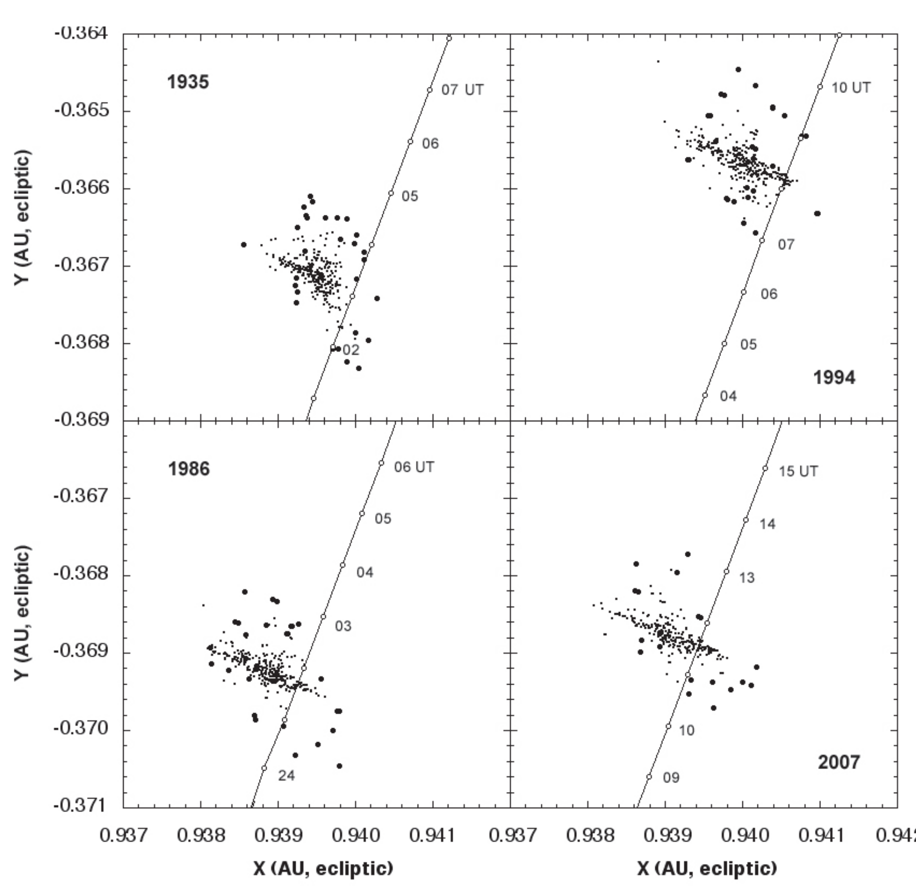

Fig. 2. Modeled location of the dust trail on 1 September 1935, 1986, 1994, and 2007. The scatter diagrams show where, in our model simulation, individual meteoroids crossed the ecliptic plane at the time of past Aurigid showers. The position of Earth is marked in intervals of 1 hour. Small dots show the large meteoroids (0.2–2 centimeters in size) that cause visible meteors (+3 to -3 magnitude), while bold dots show the smaller (0.1–0.2 centimeter diameter) meteoroids that cause faint approximately +6 magnitude meteors.

Meteor Shower

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due to higher ejection velocities. In 2007, the Earth will be only 15% farther from the comet than in 1994. Hence, the particle size distribution will be much the same. Outside hazy areas, the Moon (4 days past full) should not diminish the display much.

The meteors also may be very unusual. George Zay and Bob Lunsford of San Diego, Calif., described the 1994 Aurigids meteors as greenish or bluish [*Zay and Lunsford*, 1994]. This suggests that the meteoroids produced unusually strong iron and magnesium atom line emissions from ablating metal atoms, and it points to a different particle morphology of outburst Aurigids than other fast meteoroids of similar size. We do not know if that is because comet Kiess shed some of its pristine crust in 83 B.C.

The use of modern instruments is warranted to take full advantage of this rare opportunity. Over the next 50 years, the dust trail of Kiess will continue to move in and out of Earth's orbit, but the model shows that it will not hit the Earth itself again. In fact, no other known long-period comet has predicted dust trail crossings with a similar track record of past outbursts to be able to anticipate small discrepancies in the predicted trail positions. At present, the 1 September Aurigid shower seems to be the only sure deal in the next 50 years.

For more information on the Aurigid shower observing campaign, visit the Web site: http://aurigid.seti.org.

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