Draconid meteor storms

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Outbursts and storms in the October Draconid meteor shower occur because meteoroids from the parent periodic comet, 21P/Giacobini-Zinner, are not dispersed uniformly around the stream. The comet's orbital evolution has allowed meteoroidal material to be fed into the stream for the past few centuries and to be supplied for the next thousand years or more, but this depends on the nucleus continuing to be physically active. Various shower outbursts can be linked to the comet's observed activity during the past century.

1 Comet Giacobini-Zinner and the October Draconids

The *Giacobinids* or *October Draconids* (0009 DRA in the IAU list of established showers) are alternative names for a well-known meteor shower associated with 21P/Giacobini-Zinner, which was first observed in 1900 and later became the first comet to be visited by a space probe (the *International Cometary Explorer*, in 1985 September). While of low activity in most years, the Draconid shower displays occasional meteor storms or outbursts (see Chapter 8 of Rendtel and Arlt, 2008) associated with passages of the Earth through filaments or trails of meteoroids that are yet incompletely dispersed since liberation from the parent comet within the past few centuries. The prediction of the 1998 display (Reznikov, 1993; 1998) remains one of the most impressive demonstrations of the precision with which meteor outbursts can be forecast.

One of the main reasons that the prediction of Draconid meteor storms is complicated is the fact that the parent comet has one node near the Earth (i.e., the descending node, which results in the showers/storms) and its other node near Jupiter, the giant planet's gravity causing spreading of the comet-derived meteoroids into different filaments dependent upon when (i.e., on which perihelion passage) they were ejected/liberated by the comet. The comet itself had approaches to Jupiter in 1898, in 1815, and in earlier years. The accumulated effect of the deflections due to each approach progressively increases the uncertainty in the orbit. The orbit's chaotic nature means that we have very little idea of the comet's location even 300 years ago. Trends in the comet's Minimum Orbit Intersection Distance (MOID) over this time can, however, be known reliably. The MOID, presently around 0.25 AU (Figure 1), was even smaller in the past, reaching zero approximately 400 years ago. A near-zero MOID in general increases the frequency of close approaches, and the comet cannot dynamically survive that epoch (beyond 300 or so years ago) of nodal crossings with Jupiter. Comet 21P/Giacobini-Zinner was probably therefore captured into a Draconid-like orbit during the 18th century.

It follows that the October Draconid stream has been formed since that time, although the parent comet's activity may not have been constant, with indeed no observations known before the 20th century. Prior to the 1898 Jovian approach, Giacobini-Zinner's perihelion distance had been approximately 0.2 AU higher than at present, which could affect the activity. Moreover, Watanabe and Sato (2008) indicated how varying activity within the 20th century alone may explain the relative intensities of different storms and outbursts.

Dynamical modeling indicates that the comet's MOID will increase for several centuries and that the orbit's size and shape will remain basically the same for at least the next thousand years. If there is enough mass (observations of Comet 21P/Giacobini-Zinner at around 4 AU from the Sun imply a nuclear diameter of the order of 2 km: Lamy et al., 2004) of a suitable composition to continue generating meteoroids then the Draconid stream will remain supplied with new material. Knowing whether the material hits Earth and produces meteors requires more detailed calculations; this has been done by Maslov (2011) for the 21st century.

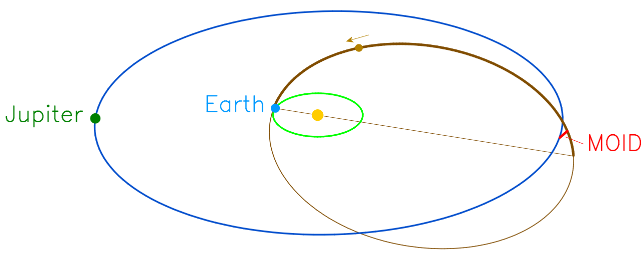

Figure 1 – Orbit of 21P/Giacobini-Zinner showing the comet's position on 2011 October 8, and also the Minimum Orbit Intersection Distance between the cometary and Jovian orbits. The ellipse representing the comet's orbit is drawn as a thicker/thinner line above/below the ecliptic.

2 Past Draconid outbursts

The period of the comet's heliocentric orbit being 6.5–6.6 years, a cyclicity of 13 years might be anticipated, as exemplified by the storms observed in 1933 and 1946, when the naked-eye meteor activity peaked at several thousands per hour, compared to non-outburst years. The former great storm was observed at the Armagh Observatory by the Director, the Rev. W.F.A. Ellison, who wrote the following (King, 1934):

> *Between 7 and 7.35 p.m. I counted 300 meteors. The majority were small objects of the 3rd and 4th magnitudes, but brighter ones were frequent, and occasionally there were brilliant flashing fireballs [...] Called indoors for the evening meal at 7.35, I was out again at 7.58. Then it was apparent that a really great meteoric storm was in progress. I counted 200 meteors in two minutes, and then counting became impossible.*

The spectacular storms of 1933 and 1946 resulted from Earth's passages through the ultra-high-density cores of trails generated in the early 20th century (see Reznikov, 1993; Vaubaillon et al., 2011). The geometry of the 1946 encounter with the trail that was created through the liberation of meteoroids released during the comet's 1900 perihelion passage is shown in Figure 2; in fact other trails overlapped with this one.

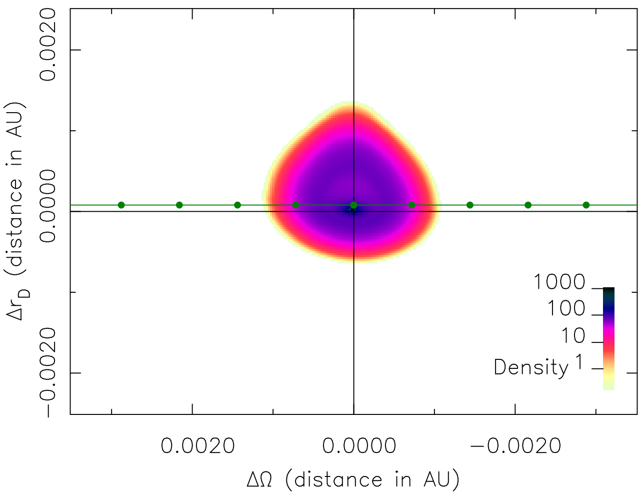

Figure 2 – Earth's encounter in 1946 with the high density core of the 1900 (7-revolution) Draconid trail. The trail's ecliptic cross section in nodal longitude (x-axis) and heliocentric distance (y-axis) directions is shown, with the shading giving the spatial density of meteoroids in arbitrary units. The Earth is plotted as circular symbols of the correct size in the units shown on the two axes, at 1-hour intervals, moving right to left, with $\Delta\Omega = 0$ at 1946 Oct 10.17 UTC. In reality, the trail density profile depends on the ejection velocity distribution of meteoroids from the comet nucleus; to create this plot (cf. Asher, 2010), radiation pressure parameter $\beta = 0.0001$ and mean meteoroid ejection speed $15/r$ m/s (r being the heliocentric distance in AU) were used.

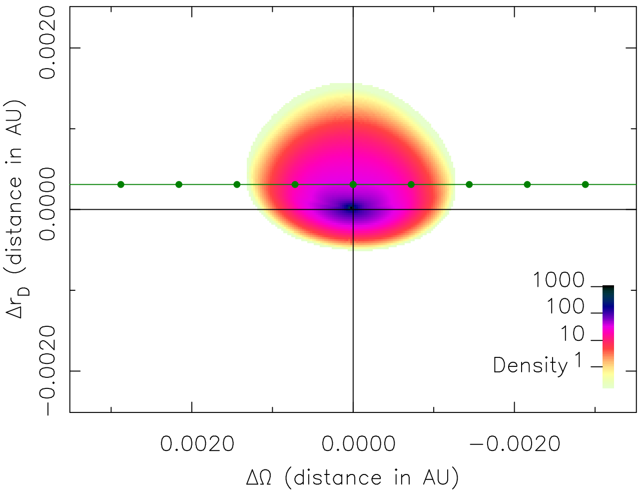

Figure 3 – Encounter in 1998 with 1926 (11-rev) trail. Earth reaches $\Delta\Omega = 0$ at Oct 8.55. Parameters $\beta = 0.0002$, mean ejection speed $20/r$.

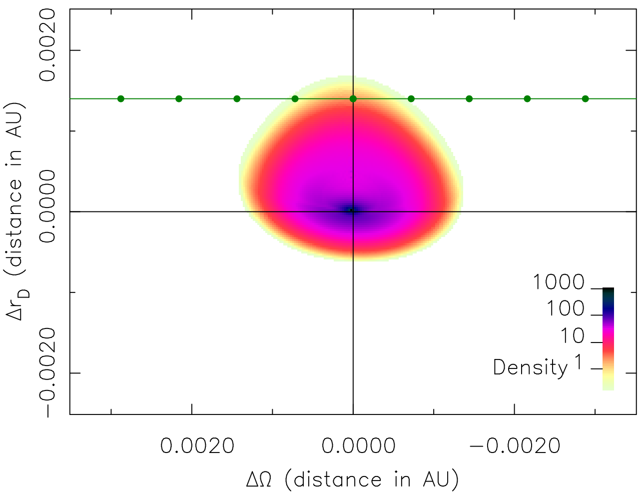

Figure 4 – Encounter in 2011 with 1900 (17-rev) trail. Earth reaches $\Delta\Omega = 0$ at Oct 8.84. Parameters $\beta = 0.0002$, mean ejection speed $20/r$.

The 1998 outburst occurred (Arlt 1998; Koseki et al., 1998) at the time calculated by Reznikov (1993), with a Zenithal Hourly Rate of several hundred. This was primarily due to the 1926 trail, other trails being several tens of Earth diameters away (see Sato, 2003). The encounter (Figure 3) was not quite as central as in Figure 2.

Among other outbursts, the 2005 event was well below the 1998 level and contained a substantial proportion of faint meteors (Campbell-Brown et al., 2006; McBeath 2007). This resulted from a much more distant trail encounter (Campbell-Brown et al., 2006). There can also be some heightened activity in years away from the main (6.5–6.6 or 13 year) cycle (see Langbroek, 1999; Sato, 2003).

3 Draconids 2011

Various analyses (e.g., Cooke and Moser, 2010; Maslov 2011; Vaubaillon et al., 2011) led to an expectation that a series of peaks might be observed on 2011 October 8 between 17^{h} and 21^{h} UTC, corresponding to distinct trails of meteoroids released by Comet 21P/Giacobini-Zinner during its perihelion passages in the 19th and 20th centuries. As the anticipated main peak near 20^h UTC would be due to meteoroids released during an observed return of the comet (Figure 4), the prediction of noticeable activity was well determined. Despite the unfavorable lunar phase, the peak was very clear in the observations (e.g., see Barentsen, 2011, for visual observations; and Molau et al., 2012, for video data).

The earlier predicted activity around 17^h UTC from generally brighter meteors was due to trails generated in the late 19th century (e.g., Maslov, 2011) when no known observations of the parent comet exist and thus its activity level is uncertain. Our tests with different initial orbits (from Marsden and Williams, 2008) show that locations in 2011 of these late 19th century trails can be displaced by a few Earth diameters depending on the orbital solution used. For 20th century trails, when the comet's position is constrained by observations, the accuracy is good to Earth diameter level.

4 Implications for spacecraft operators

Averaged over many years the *overall* meteoroid influx to the Earth amounts to about 100 tonnes per day (Love and Brownlee, 1993), mostly being held in particles around 1 mm in size which ablate in the upper atmosphere and so do not reach the ground intact. During an intense storm, however, much more than a normal day's influx is received over a period of just a few hours. Being forewarned of this has benefits in that satellite operators can be ready for possible malfunctions, or may orient their platforms so as to minimise the possibility of damage (e.g., tilt large solar cell arrays away from the meteor radiant). The Leonid outbursts in 1998–2003 are an example: the Hubble Space Telescope's optical axis was directed to point away from the Leonid radiant for a few hours. HST and other satellites were similarly oriented in 1993 August, when an intense Perseid meteor shower was forecast, linked to the perihelion passage of the parent comet 109P/Swift-Tuttle in the preceding year. One functioning geostationary communications satellite, ESA's Olympus, suffered an end-of-life anomaly during that Perseid outburst (Caswell et al., 1995), and other spacecraft have also been suspected to have received damaging meteoroid impacts at other times. The 2011 Draconid meteor outburst was of significance with regard to the satellite collision hazard, the storms of 1933 and 1946 having occurred before the start of the Space Age. The threat to satellites was taken seriously (see, e.g., Cooke and Moser, 2010) but, in this regard, the Draconids' relatively slow speed mitigated the rather high flux levels encountered.

Acknowledgements

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