Activity Level Prediction for the 2002 Leonids

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We present here a new method to evaluate the level of a meteor storm, and applied it to the 2002 Leonids. By simulating the ejection from the parent comet and the orbit of the particles, and taking the advantage of the measure of $[Af\rho]$, we have computed a "weight" for each of them (that is an indicator of the number each particle is supposed to represent). Looking at impacting particles close enough to the Earth, and calibrating the density computed, we predict that the ZHR of the 2002 Leonids will be 3200 for the 1866 stream, and 3600 for the 1767 stream, with an uncertainty of about 200.

1. Introduction

Today's theories to predict the Leonids storms (McNaught & Asher 1999; Lyytinen et al. 2000) use the fact that 55P/Tempel-Tuttle is the parent body of the streams as a starting point (initial conditions), for numerical simulations, that is, as an astrometric tool. But none of them take into account the photometric information that can be provided. We propose here to see how it can be useful to consider how the comet emits dust to predict the level of the coming 2002 Leonids. The idea here is to simulate the ejection of dust by the comet, and to characterize each of them with a cometary model.

2. Numerical simulations

2.1. Using the cometary informations

The cometary path at each perihelion gives us the initial conditions, whithout which nothing is possible. A point (position and velocity) near each perihelion is given by Rocher (2002, plus personal communication for other perihelions), and allows us to determine the path of the comet, where it is suposed to eject dust: that is as soon as the comet is below 3 AU from the sun (where water ice begins to sublimate. Note that we do not consider here CO emission).

The particles are taken in bins of size (0.1–0.5, 1–5, 5–10, and 10–100 mm) distributed all along the position of cometary orbit, with a time step of one day.

The ejection velocity is that given by Crifo & Rodionov (1997). It takes into account the gravitation of the comet and a hydrodynamical model. To simplify (for further details, see Crifo & Rodionov (1997), Appendix D), we can say that:

$$V = W(T)\Phi\left(\frac{a}{a_\star}\right)$$

with V—ejection velocity; W—factor that depends on T, the temperature of the nucleus of the comet; a—radius of ejected particle; $a_\star$—caracteristic radius, that depends (among other factors) on the angle of ejection (with subsolar point), heliocentric distance and the fraction of nucleus surface that indeed emits gas and dust.

2.2. Stream evolution

The stream simulated with all the particles is then integrated in time. We took into account gravitational and non-gravitational forces (solar radiation pressure and Poynting-Robertson drag (Burns et al. 1979). Note that the seasonal Yarkovsky effect is not considered here, unlike Lyytinen et al.'s (2000) works).

To do fast computations, we used parallelized computers (IBM SP) provided by CINES. Each run was done on 50 processors, 1000 particles per processor, thus in total 50000 particles per size bin. As only the smallest particles (0.1 to 1 mm, for a density of 2000 kg/m^3) are spread in a sufficient way, we will focus on them here.

Some results of the 1866 stream have already been published (Vaubaillon & Colas 2002). We point out here a special feature of the 1767 stream: we can see from Figure 1 that there are some "holes" in the stream. With 50000 particles simulated, this cannot be a statistical artifact. This is rather the effect of close encounters with the Earth at previous perihelions. Such holes can be very important for meteor storms predictions, as we will see further.

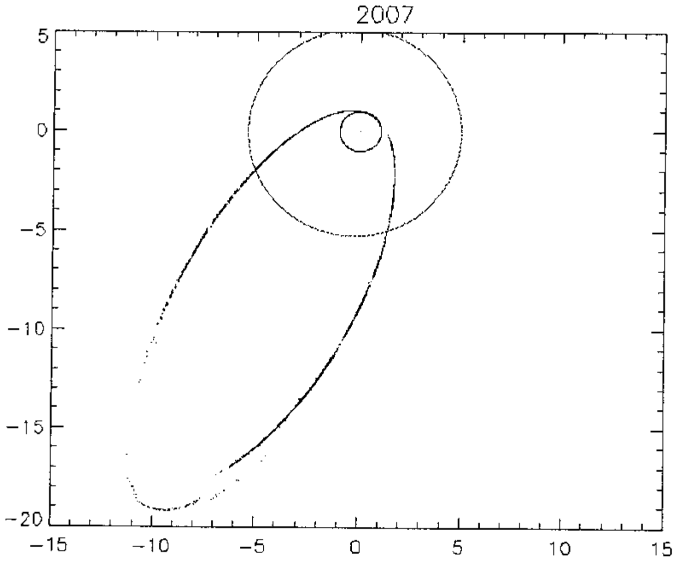

Figure 1 – Stream ejected in 1767. The two circles are the orbits of the Earth and Jupiter. The begining of the stream is situated in (−5; −15) (approx. x and y ecliptic coordinates, in AU). It almost joins the end of the stream (−19; −10) Note the "holes" along the stream (approx. coordinates : (1;0), (1; −8), (0; −10)). They result from close encounters with the Earth.

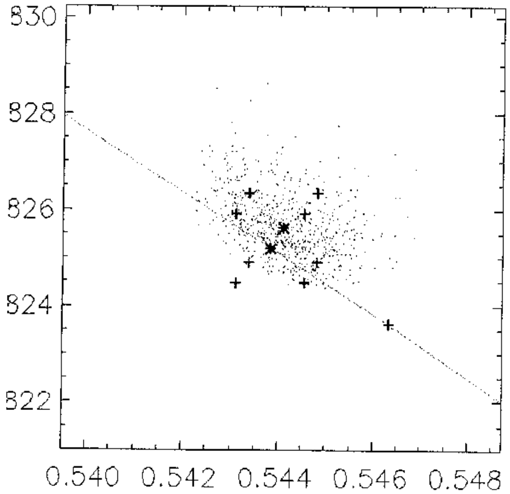

Figure 2 – Particles from the 1767 stream impacting the Earth. The line is the orbit of the Earth. The first cross at $x = 0.546$ is the position of the Earth on November 19, 2002, 0:00 UT. The second one (on the same line) is positioned at the expected time of the maximum. The one just upper right is the center of the stream. Around these 2 points, the 2×4 crosses represent the space criterion ΔX.

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2.3. Collision with the Earth

In any simulation of this sort, the amount of simulated particles is some orders of magnitudes less than the real amount ejected by the comet. So there is quite no possibility for a given simulated particle to encounter the Earth. To predict meteor showers we have to define an impact criterion much larger than the Earth's diameter. Brown (2000) considered also a time criterion (centered on the time of the maximum). We have prefered to keep only a space criterion, as, in a long-time simulation, we do not always know when the shower occured. It is also a simple way to do predictions over a large range of time with a single run. The space criterion is defined as :

$$\Delta X = \Delta T \, V_\mathrm{e}$$

with ΔX—space criterion; ΔT—time criterion (here 6.5 days); V_e—velocity of the encounter. We consider that there is an impact if the particle reaches its (descending) node at the next integration time step, and is in the space criterion.

2.4. Time of the maximum

The estimated time of the maximum of the storm encountered is established by computing the median value of the positions of the nodes, and by deducing the closest point on the orbit of the Earth. Of course, this method can be improved by considering only the node close to the orbit of the Earth, instead of the entire set, but first results are in good agreement with previous works (Asher 2000) (see Table 1).

3. Photometric considerations

The parameter which is important to consider here is $[Af\rho]$, because it takes into account the light scattered by the dust. It has been introduced by A'Hearn et al. (1995), and its advantage is that it is independent of the instrument with which it has been measured. Indeed, ρ is the aperture of the telescope. A is the albedo and f the filling factor, that is, the proportion of dust in the image, in terms of effective area. A and f are known with a large uncertainty, but the parameter $[Af\rho]$ can be measured.

As annouced by Vaubaillon & Colas (2002), this parameter has been measured. Imre Toth (Konkoly Observatory, Budapest) has provided it, from measurements done by Lamy (1998) with HST. We thank here these two astronomers for having provided these measurements. We have deduced $[Af\rho] = 78.91$ cm at perihelion, considering $[Af\rho]_r = [Af\rho]_q(q/r)^\gamma$, with r being the heliocentric distance, q the perihelion distance, and $\gamma = 2$.

In order to derive some information from $[Af\rho]$, a certain number of assumptions are of necessity. We consider here that:

- The dust production rate is proportional to gas emission rate: $Q_\mathrm{d} = K \, Q_\mathrm{g}$, and K is constant with heliocentric distance.
- the grain size distribution index s is taken between 2 and 6 (range deduced from cometary results (Fulle et al. 2000) and meteor observations (Gural & Jenniskens 2000)).

Q_g is deduced from the comet's magnitude (Beech et al. 2001), with Jorda's equation (cited by Crifo & Rodionov 1997).

4. Estimation of ZHR

This model allows us to give a "weight" to each ejected particle, that is the number of particles that it is supposed to represent, if the model is totally right. Indeed, thanks to Jorda's equation and Crifo & Rodionov model, we can compute the amount of gas emitted in the sunlit hemisphere (with a dependence on the angle from the subsolar point), and then deduce the "real" number of particles ejected, by unit of time.

As, of course, we cannot be "totally right" because of the assumptions we had to do, these "weights" computed is more an indicator rather than a real value.

By considering the impacted particles and the weight of each of them, we have an indicator (again) of the amount of dust encountered by the Earth. Now care must be taken from these results, because the center of the trail does not inevitably coincide with the orbit of the Earth. So we have defined a criterion to take into account only the impacting particles, close enough to the Earth. This space criterion is set to corespond to a time criterion of one hour, at the orbital speed of the Earth. To have relevant results, we have to simulate a large number of particles. By this way, we also take into account the holes in the stream (see Section 2.2).

Then, a density of weighted particles is computed. To predict leonids storms, we have calibrated the data with past observed showers. The results are shown in Figure 3.

A very (too?) simple linear fit allows us to give some predictions of the 2002 Leonids (see Table 1).

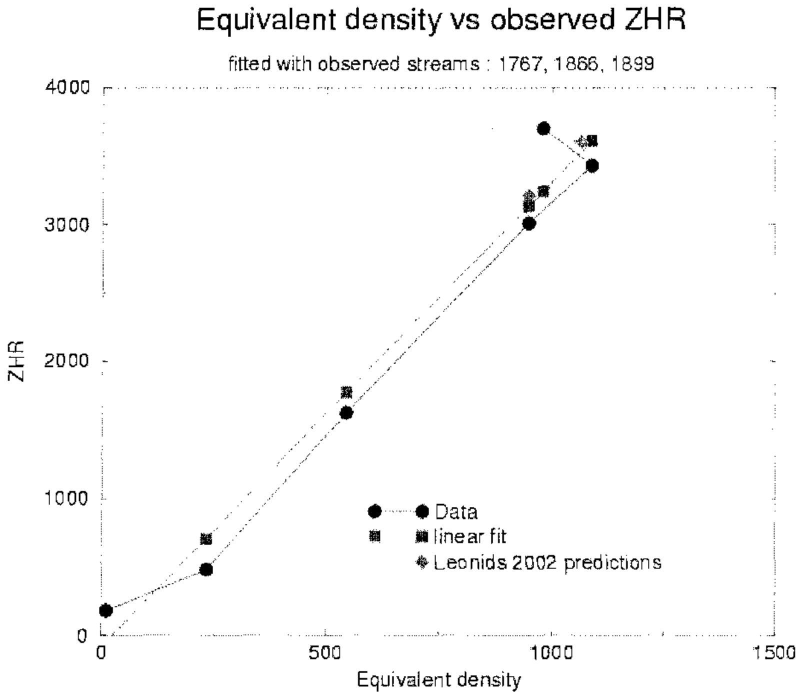

Figure 3 – Computed density of weighted particles versus observed ZHR. The observations are those done from 1999 to 2001, and reported by the *IMO* (Arlt et al. 1999, 2000, 2001). They concern the streams of: 1866, 1767, 1733, and 1699

Table 1 – Predictions for the maxima of the 2002 Leonids.

Stream	Time of maximum	Expected ZHR
1767	November 19, 2002, 04:04 UT	3600
1866	November 19, 2002, 10:47 UT	3200

As a result of this fit, the uncertainties are about 200 for the ZHR. Although our method is different in many ways from others (McNaught & Asher 1999; Lyytinen et al. 2000), we have found very similar results here, which is encouraging.

5. Conclusion

We have performed some numerical simulations to reproduce the emission of dust from comet 55P/Tempel-Tuttle. By considering impacting particles with the Earth and taking into account some measurements done for the comet, we have estimated the activity level of the 2002 Leonids. This gives a new method to make some predictions of meteor storms.

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