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The 2004 June Bootid meteor shower

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ABSTRACT
The June Bootid meteor shower is known to show irregular activity. We report here the prediction and observations of the 2004 shower. The forecasts were independently performed by three different teams, who all concurred on a broad activity on June 23, though no estimate of the level was done prior to the event. Thanks to these predictions, observations around the world were conducted and gathered by IMO. The broad activity (FWHM $\simeq$ 7 hours) was observed, with a maximum occurring at 14:50 ± 60 min UT. The level of the shower reached a ZHR of 30 ± 10, for a population index of $r = 2.49 \pm 0.15$. Past showers are examined and new associations between the 1916 and 1998 showers and several trails from the early XIXth century are made. An attempt to post-predict the values of the level of all these showers is discussed. New observations of comet 7P/Pons-Winnecke are needed when it is back in 2008.

Key words: meteors; meteoroids — comets: individual: 7P/Pons-Winnecke

INTRODUCTION

A meteor shower occurs when the Earth encounters a meteoroid stream, usually ejected from a comet. Two kinds of showers can be defined: the major and the minor ones. A major one is usually intense (sometimes giving rise to a storm, such as the Leonids. See Arlt et al., 2002) and/or regular (such as the Perseids, see also Jenniskens, 1994). A minor one is usually not intense, with ZHR < 20 (Koschack & Rendtel, 1990), and/or very irregular. The June-Bootids is a minor shower that has sometimes given rise to an unusually high activity in the past. One should keep in mind that several names have been given to this shower, such as 'Pons-Winneckids' or 'ι-Draconids' (Jenniskens, 1995). The annual rate is usually low (ZHR < 10), which sometimes makes it hard to recognize (Arlt, 2000). The first records of a June Bootid meteor shower date back to 1916 (Denning, 1916), and subsequent showers occurred in 1927 and 1998 (Arlt et al., 1999; Spurny & Borovicka, 1998; Spurný, 1999). The ZHR reached the values of $\simeq$ 100, $\simeq$ 30,$\simeq$ 80 in those years respectively. A full description and further details of these showers can be found in Arlt et al. (1999). In particular, they show that there is no regular appearance of the June Bootids, though the parent body is comet 7P/Pons-Winnecke, which is a Jupiter family comet (Denning, 1916). The question of what could cause such unusual increases of activity then arose. Because of the unpredictable nature of the June Bootids, the 1998 observations were only done by the most dedicated observers at that time. Thanks to these people the outburst could be reported (see Arlt et al., 1999). But with the return of the Leonid meteor storms between 1998 and 2002, lots of works were made to predict meteor showers. Several years before these events Kondrateva & Reznikov (1985) were the first to correctly forecast the Leonid meteor showers. They were followed independently and more recently by McNaught & Asher (1999), and subsequent work was done during the Leonid meteor storm period (Brown & Arlt, 2000; Lyytinen & Van Flandern, 2000; Jenniskens, 2001; Vaubaillon, 2002). In the case of the June Bootids, Asher & Emel'yanenko (2002) have shown that the 2:1 resonance with Jupiter causes the stream to remain compact, and then potentially produce an intense meteor shower. Recently, Vaubaillon & Colas (2005) have found the same kind of behaviour for the π-Puppid shower, also associated with a short period comet (26P/Grigg-Skjellerup). Asher & Emel'yanenko (2002) linked the 1998 outburst with the trail ejected during the perihelion passage of the comet in 1825. Reznikov (1983) previously noticed the same kind of association between the 1916 outburst and the trail ejected in 1819.

In 2004, the situation was totally different from 1998, since a June Bootid meteor shower was independently predicted by three teams: Shanov & Dubrovski, Sato, and Vaubaillon. The alert was broadcast on mailing-lists (such as *meteorobs* and *IMO-NEWS*), and the possibility of a meteor shower was already published by Rao (2004). The need

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for meteor shower forecasting resides in the fact that intense meteor showers are rare and precious events. A correct prediction allows scientists to be ready to record the maximum amount of data at a specific time. The results derived by these observations concern the composition of the meteoroid itself and the parent body, the atmosphere, the orbits of individual particles as well as the stream as a whole, the dynamics of small bodies in the solar system etc. (see e.g. Jenniskens, 2002). Thanks to these predictions, professional and amateur astronomers around the world were informed of the imminent shower, and many observations took place. The International Meteor Organization (IMO) gathered and analyzed the data, which are presented here, via R. Arlt. In Section 1, we describe the three different methods used to make the predictions, we present the results of the observations in Section 2, and a discussion then follows in Section 3.

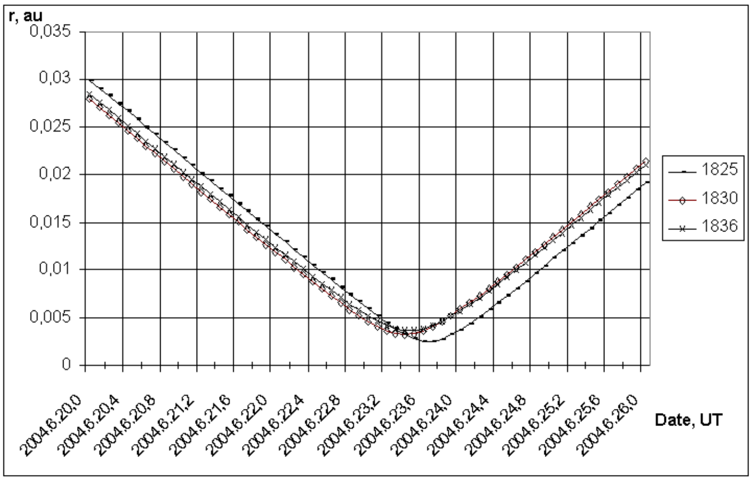

Figure 2. Results by Shanov & Dubrovski: distance (au) of several trails, versus time (UT). Some test particles are close to the Earth on 2004 June 22 and 23, making a meteor shower likely.

1 THE PREDICTIONS FROM DIFFERENT APPROACHES

1.1 Description of the methods

Several methods exist to perform a meteor shower forecast. The best way to date is to do a numerical simulation of the trajectories of test particles released by the parent body. McNaught & Asher (1999) developed a method where an iteration process allows one to look at the closest encounter between a particle and the Earth for a given period of time. The time of the maximum of the shower can thus be determined. We will now sketch the models of the authors of this Paper.

The first team to present forecasts for the 2004 June Bootids was composed of Shanov & Dubrovski. The approach is based on the study of McNaught & Asher (1999): some test particles are released at perihelion in the direction of the comet's motion, as well as in the opposite direction. The modulus of the ejection velocity is first set to a wide range (± 50 m s^{-1}) to find what is the approximate value that brings particles close to the Earth in June 2004. An iteration process then refines this value for a minimum ejection velocity step of 0.01 m s^{-1}.

The predictions made by Sato are based on a similar method. Particles are released at perihelion as well as at different locations of the parent body, in a $[-100; 100]$ days range around perihelion. The minimum ejection velocity step is 0.0001 m s^{-1}.

Finally, a third approach developed by Vaubaillon et al. (2005a) was used to make the 2004 June Bootid forecasts. It is based on a model of the dirty snowball of Whipple (1951). The ejection process occurs as soon as the nucleus reaches a heliocentric distance of less than 3 au. The ejection velocity is computed according to the model developed by Crifo & Rodionov (1997). The modulus of the ejection velocity depends on several parameters, such as the heliocentric distance, the size of the particle and the angle of ejection (*i.e.* the angle between the heliocentric radius vector and the direction of ejection). A total of $1.75 \cdot 10^6$ particles were simulated. The program was run on 10 to 50 parallel processors located at CINES, France.

The technical details and differences between these three approaches are provided in Table 1.

In all three methods, the past perihelion passages of comet 7P/Pons-Winnecke were considered as a starting point, and 35 returns from 1802 to 2002 were considered. Some orbital elements are provided in Table 2, as well as some representations of the orbit in Fig. 1.

1.2 Results

The different models each predicted a June Bootid meteor shower on 2004 June 23. The main contributors to the shower were trails mainly ejected in the first half of the XIXth century. The three models agreed that all the trails from 1813 to 1858 were close to the Earth on 2004 June 23rd (see Figs. 2 to 4). To some extent, the 1875 trail could have also had a contribution to the shower, since it was located very close to the Earth.

Interestingly, these Figures clearly show that some trails overlap. This overlap concerns superpositions of parts of a single trail (Fig. 3), since planetary perturbations make their shape complicated (see also Section 3). There are also overlaps of different trails (Fig. 4). This is the reason why a broad shower was expected. The fact that, despite the overlap, each trail has a different orbit makes the shower not as strong as it could be if all the trails were "exactly" at the same location. Such a configuration happened in 2001 and involved the 1699 and 1866 Leonid trails (McNaught & Asher, 1999; Arlt et al., 2001). That kind of overlap presented here was already reported by Vaubaillon & Colas (2005).

The stream as a whole is divided into several parts. Some of them are close to the Earth, but only one actually intersects the orbit of the Earth. This one is composed of particles ejected mainly from perihelion returns in 1813 to 1836, and to some extent from returns in 1841 to 1858, plus 1875. A broad shower was expected, roughly lasting from 10:00 UT to 17:00 UT on the 2004 June 23. A time of maximum around 14:00 UT ±2 hours was uncertain, because of the large duration of the shower. A plateau was instead predicted from the Shanov & Dubrovski model. The level of the shower was hard to compute, since only a few observations of strong June Bootid showers are available as a

Table 1. Features of the different models used to do 2004 June-Bootids meteor shower forecasts

Model	Shanov & Dubrovski	Sato	Vaubaillon
Ejection Velocity	[-50;50] $\mathrm{m\,s^{-1}}$	[-30;30] $\mathrm{m\,s^{-1}}$	Crifo & Rodionov (1997)'s model
Direction of ejection	$\pm\overrightarrow{V}_{\mathrm{comet}}$	$\pm\overrightarrow{V}_{\mathrm{comet}}$	sunlit hemisphere
Point of ejection	perihelion	±100 days around q	[q; 3 au]
Non-gravitational forces	no	no	Radiation pressure & Poynting-Robertson
Planetary model	Bretagnon & Simon (1986)	DE406	DE406
Planets	☿-♅+☽	☿-♇+☽, Ceres, Pallas, Vesta	☿-♇+☽
Algorithm	Adams	Runge-Kutta-Fehlberg + Encke	Radau 15th order (Everhart, 1985)
Name of the program	Comet's dust	Integrat	Pintem

Table 2. The orbital elements of comet 7P/Pons-Winnecke

Model Reference	Shanov & Dubrovski Marsden & Williams (1999)	Sato Kinoshita (2004)	Vaubaillon Rocher (2004)
a (au)	3.4353750	3.4353791605 ± 0.0000005628	3, 4383219 ± 0, 0000090
e	0.6344237	0.6344242529 ± 0.0000001624	0, 6340814 ± 0, 0000009
i (°)	22.301450	22.3013867021 ± 0.0000330406	22, 2846247 ± 0, 0000164
Ω (°)	93.428080	93.4265774361 ± 0.0000765182	93, 4499831 ± 0, 0000465
ω (°)	172.312690	172.3144729352 ± 0.0000737747	172, 2924087 ± 0, 0000330
T	1996 Jan 2.45304 TT	1996 Jan 2.4515121632 TT	2002 May 15.71977 TT

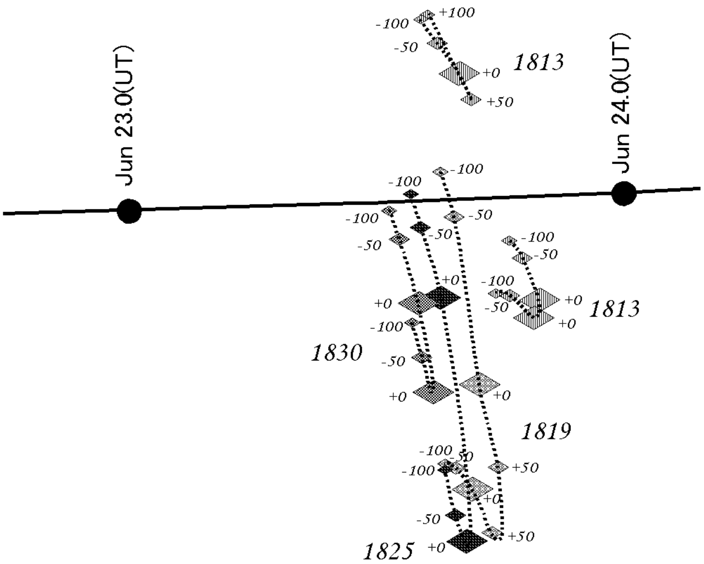

Figure 3. Results by Sato: location of the streams in the ecliptic plane. The continuous line represents the path of the Earth. The large diamond marks (with +0 labels) are the position of the nodes of the meteoroids ejected at pelihelion. There may be more than one node for a given trail, since meteoroids were ejected at different values of ΔV. Small diamonds are the nodes of meteoroids ejected before or after passage. The labels indicate the time of ejection of the particle, in terms of number of days before (< 0) or after (> 0) the perihelion passage of the parent body. A long-duration meteor shower is expected on June 23, from particles ejected before perihelion.

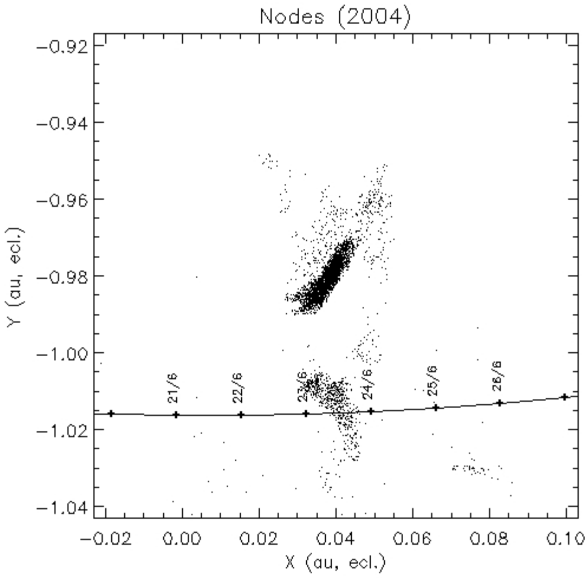

Figure 4. Results by Vaubaillon: nodes of the particles ejected from 1813 to 1875, in the vicinity of the Earth's orbit (continuous line), in June 2004. Again, a long-duration shower is expected on June 23.

calibration (Arlt et al., 1999). Moreover, comet 7P/Pons-Winnecke was poorly documented in terms of physical data. Fink & Hicks (1996) provide a water production rate of $\simeq 3.10 \cdot 10^{27}$ $\mathrm{mol\,s^{-1}}$ at $r_{\mathrm{h}} = 1.42$ au. The only $[Af\rho]$ measurement was done by Lowry & Fitzsimmons (2001) when the comet was far from the Sun ($r_{\mathrm{h}} = 5.58$ au). They only derived an upper value of 20.0 cm, which prevented us from fully applying the model developed by Vaubaillon et al. (2005a). As a first step, only the simulation of the generation and evolution of the stream, as well as the computation of the position of the node of the meteoroids was done. This was performed in order to examine the possibility of a meteor shower in June 2004, but no activity level prediction was made. Figure 4 showing the configuration of this

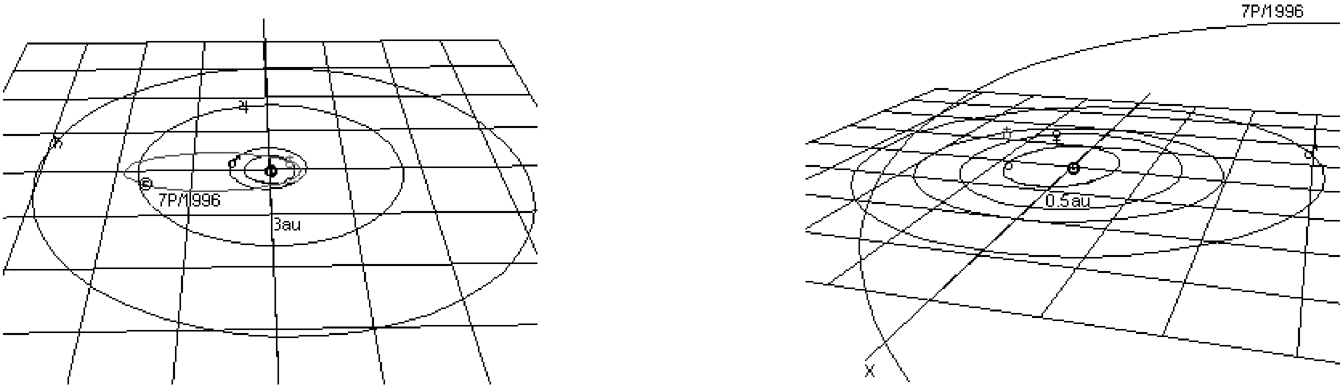

Figure 1. Large (left) and close view (right) of comet 7P/Pons-Winnecke's orbit. Its inclination is small and its aphelion is located close to the orbit of Jupiter. Hence any encounter perturbs a lot the orbit. In particular, the Position of the comet's perihelion distance is powerfully modified by the planet. During the XIXth century the comet's perihelion was located inside the Earth's orbit, whereas in the XXth centuary it was moved outside the Earth's orbit. June Bootids meteor showers (and especially the 2004 one) were caused by particles ejected in the XIX century. Some of them are trapped into the jovia 2:1 resonance.

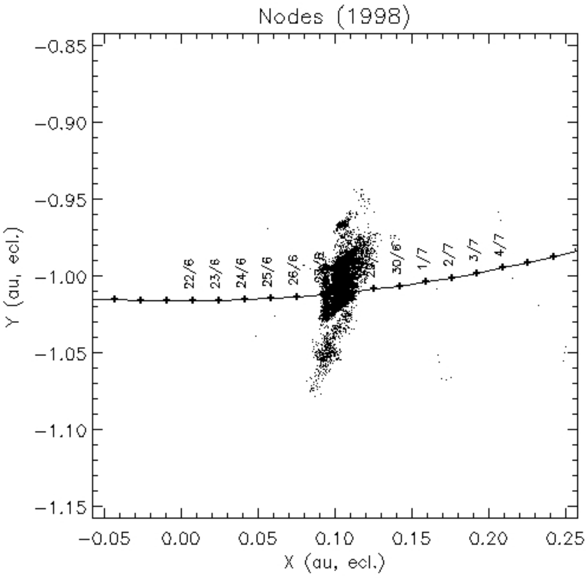

Figure 5. The 1998 June Bootid meteor shower: same as Fig. 4.

shower has to be compared to the 1998 case, represented in Fig. 5. It is clear that the 2004 shower was expected to be much lower than in 1998, but at that time (*i.e.* before the shower) no ZHR estimation was computed. An attempt to give a post-prediction of the ZHR is presented in Section 3.

The properties of test particles approaching the orbit of the Earth (geocentric velocity, coordinates of the radiant etc.) are provided in Table 3. From this Table, we can predict a position of the radiant at $\alpha = 223^{\circ}\!.2 \pm 0^{\circ}\!.7$, $\delta = 47^{\circ}\!.2 \pm 0^{\circ}\!.3$, and $V_{\rm g} = 14.11 \pm 0.03$ km/s. The June Bootid meteors are among the slowest meteors, making them hard to observe, since only the biggest particles will produce enough light to be detected.

2 RESULTS FROM VISUAL OBSERVATIONS

The complete set of visual observations covering the 2004 June Bootids collected by the International Meteor Organization comprises 157 observing periods with a total of 439 shower meteors. The observing conditions are evaluated in terms of a stellar limiting magnitude, thereby including the observer's perception qualities. We are very grateful to the following observers who sent in their observing reports:

Anna Astashonok (Belarus), Igor Balyuk (Belarus), Sergey Dubrovski (Belarus), Shlomi Eini (Israel), Gunnar Glitscher (Germany), Sylvie Gorkova (Czech Republic), Lew Gramer (USA), Robin Gray (USA), Valentin Grigore (Romania), Daniel Grün (Germany), Takema Hashimoto (Japan), Roberto Haver (Italy), Javor Kac (Slovenia), Richard Kramer (USA), Jakub Koukal (Czech Republic), Anna Levina (Israel), Robert Lunsford (USA), Pierre Martin (Canada), Mikhail Maslov (Russia), Sirko Molau (Germany), Minoru Muraki (Japan), Masataka Nomura (Japan), Kouji Ohnishi (Japan), Grigoriy Polinovskiy (Belarus), Aleksandr Prajenik (Belarus), Sarka Psikalova (Czech Republic), Yuriy Rojin (Belarus), Koetsu Sato (Japan), Mikiya Sato (Japan), Tomoko Sato (Japan), Sergey Shanov (Russia), Wesley Stone (USA), Kazumi Terakubo (Japan), Shigeo Uchiyama (Japan), Martin Ulehla (Czech Republic), Jan Verfl (Czech Republic), Masayuki Yamamoto (Japan), and Kim Youmans (USA).

The observational measure for meteor shower activity is the Zenithal Hourly Rate (ZHR) which is corrected for a limiting magnitude of +6.5 and a radiant elevation of 90° above the horizon. The individual correction for an observing period i is

$$C_i = \frac{r^{6.5-\mathrm{lm}} F}{T_{\rm eff} \sin h_{\rm R}}\,, \tag{1}$$

where r is the shower's population index describing the exponential increase of meteor numbers towards fainter magnitudes (see below). The individual limiting magnitude given for each observing period is abbreviated by lm, possible obstructions of the field of view are expressed by F, the effec-

Table 3. Properties of particles approaching the orbit of the Earth, by Shanov & Dubrovski (upper part) and Sato (lower part). ^{1}: perihelion return of the comet when the test particle was ejected; ^{2}: ejection velocity; ^{3}: Time difference between particle node crossing and closest approach of the Earth to this node (Shanov & Dubrovski) OR time before comet perihelion (at ejection, Sato); ^{4}: Time of the shower (closest approach to the Earth); ^{5}: distance between particle node and Earth trajectory; ^{6}: coordinate of the radiant; ^{7}: geocentric velocity.

Trail^1	V_{ej}^2 (m s^{-1})	δ_t^3 (days)	Time^4 (UT)	$r_{\mathrm{D}-\mathrm{r}_{\mathrm{E}^5}}$ (au)	α^6 (°)	δ^6 (°)	V_{g}^7 (km s^{-1})
1863	+09.64	−3.0	Jun 23 07:28	+0.0015	222.5	+46.8	14.13
1858	+09.09	−3.5	Jun 23 08:32	+0.0006	222.6	+46.7	14.12
1852	+08.48	−3.2	Jun 23 09:34	0.0000	222.6	+46.7	14.12
1847	+07.96	−2.7	Jun 23 10:32	0.0000	222.6	+46.7	14.12
1841	+07.15	−3.5	Jun 23 11:10	0.0000	222.7	+46.6	14.11
1841	+07.14	−1.9	Jun 23 11:21	0.0000	222.6	+46.7	14.12
1836	+07.02	−3.7	Jun 23 11:42	0.0000	222.7	+46.6	14.11
1836	+07.00	−1.4	Jun 23 12:03	0.0000	222.6	+46.7	14.12
1830	+07.12	−4.6	Jun 23 12:12	0.0000	222.7	+46.5	14.09
1819	+08.58	−11.4	Jun 23 12:17	0.0000	222.8	+46.2	14.05
1825	+07.53	−6.2	Jun 23 12:42	0.0000	222.7	+46.4	14.07
1830	+07.08	−1.2	Jun 23 12:56	0.0000	222.6	+46.6	14.11
1836	+07.01	0.0	Jun 23 13:05	+0.0031	223.5	+46.5	14.16
1830	+07.09	0.0	Jun 23 13:39	+0.0025	223.4	+46.3	14.14
1825	+07.48	−1.0	Jun 23 14:43	0.0000	223.6	+46.4	14.13
1819	+08.52	−0.9	Jun 23 14:00	0.0000	222.5	+46.6	14.10
1825	+07.49	0.0	Jun 23 14:43	+0.0025	223.6	+46.4	14.13
1819	+08.52	−0.9	Jun 23 15:28	0.0000	222.5	+46.5	14.10
1819	+08.53	0.0	Jun 23 16:06	+0.0033	223.3	+46.4	14.14
1813	+10.85	−2.2	Jun 23 18:10	0.0000	222.6	+46.4	14.07
1813	+10.86	0.0	Jun 23 19:08	+0.0035	222.8	+46.4	14.12
1830	+8.155	0	Jun 23 13:45	+0.0033	223.0	+47.1	14.14
1830	+8.169	0	Jun 23 14:17	+0.0064	223.5	+47.3	14.12
1830	+13.807	−104.8	Jun 23 12:30	0.0000	222.5	+46.8	14.14
1825	+8.834	0	Jun 23 14:46	+0.0031	223.0	+47.0	14.13
1825	+8.859	0	Jun 23 15:36	+0.0115	224.2	+47.6	14.08
1825	+12.720	−74.7	Jun 23 13:45	0.0000	222.4	+46.8	14.13
1819	+10.377	0	Jun 23 16:32	+0.0062	223.4	+47.2	14.10
1819	+10.388	0	Jun 23 16:29	+0.0098	224.0	+47.6	14.09
1819	+13.570	−60.1	Jun 23 15:31	0.0000	222.5	+46.7	14.12
1813	+13.166	0	Jun 23 16:09	-0.0040	221.6	+46.7	14.17
1813	+13.290	0	Jun 23 19:32	+0.0034	223.1	+46.9	14.10
1813	+13.291	0	Jun 23 19:15	+0.0045	223.1	+47.0	14.10

tive duration of the period is T_{eff}, and the radiant elevation is h_{R}.

The geometrical radiant height is altered by the gravity of the Earth. If the incoming stream has a low geocentric velocity, the deviations from the geometrical position can amount to several degrees towards the zenith. This zenithal attraction is taken into account in (1). Another effect is the vectorial addition of the motion vector of the meteoroid and the rotational velocity on the surface of the Earth and is called diurnal aberration. It can be as much as 1° towards the east for the June Bootids, but is not taken into account here.

The population index r is described as the increase in shower meteor numbers n from magnitude class m to magnitude class $m+1$, $r = n(m+1)/n(m)$. It does not only tell us something about the mass distribution in the meteoroid stream, but is necessary for the correction of individual observations to the standard limiting magnitude of +6.5. Before computing the actual ZHRs, we have to determine the value of r.

The magnitudes of 258 June Bootids were used to compute r using the average magnitude distance from the limiting magnitude (Arlt, 2003). A population index of $r = 2.49 \pm 0.15$ was obtained which is significantly higher than typical r-values of major meteor showers such as the Perseids or Geminids. The population index is expected to be a function of time, but the relatively small number of June Bootids recorded does not allow a time-resolved r-profile.

Having r at hand, one can compute the individual corrections C_i for the observing periods. The average ZHR for certain given intervals of time is then found by

$$\mathrm{ZHR} = \left(1 + \sum\nolimits_i N_i\right) \Big/ \sum\nolimits_i C_i^{-1} , \tag{2}$$

where N_i are the June Bootid numbers seen in the individual periods. The average (2) weights observing periods with their total correction C_i. The additional '1+' results

Table 4. Numerical results for the activity profile of the 2004 June Bootids as derived from visual meteor observations. The solar longitude $\lambda_\odot$ refers to equinox J2000.0; $N_{\rm obs}$ is the number of observing periods involved in the average, $N_{\rm JBO}$ is the number of June Bootids contributing.

Date (UT)	Time	$\lambda_\odot$	$N_{\rm obs}$	$N_{\rm JBO}$	ZHR
Jun 20.270	06:29	89°214	7	0	0 ± 0
Jun 21.097	02:20	90°004	7	2	1 ± 1
Jun 22.120	02:53	90°980	6	10	3 ± 1
Jun 22.842	20:12	91°669	11	6	2 ± 1
Jun 22.999	23:59	91°819	17	32	3 ± 1
Jun 23.356	08:33	92°159	10	112	12 ± 1
Jun 23.545	13:05	92°340	10	157	26 ± 2
Jun 23.615	14:46	92°406	4	10	33 ± 10
Jun 23.658	15:48	92°447	5	18	25 ± 6
Jun 23.706	16:57	92°493	5	5	12 ± 5
Jun 24.032	00:46	92°804	14	17	2 ± 0
Jun 24.947	22:44	93°677	14	25	5 ± 1
Jun 25.877	21:03	94°564	11	12	3 ± 1
Jun 26.967	23:12	95°603	20	10	2 ± 1
Jun 27.755	18:07	96°354	8	19	3 ± 1
Jun 28.985	23:38	97°527	7	4	2 ± 1

from the skewness of the distribution of observed numbers around the expectation value of the distribution which is the rate we are looking for. An observed number of meteors can be produced by a variety of rates with varying probability. The average of all these possibilities, assuming a Poissonian distribution, leads to the expectation value in eqn. 2. The difference to the usual Gaussian-based average is only relevant if (just as with the June Bootids here) meteor numbers are rather small.

The peak time of the 2004 June Bootid maximum was observed to occur at 14:50 ± 60 min UT on June 23. The uncertainty results from the small number of observing reports going into the average at 14:46 UT. Observing conditions faced by the four observers covering the peak average were far from ideal; the average limiting magnitude was a poor +4.82. Given the symmetry of the profile around this average, it is likely that the peak occurred in the two hours around 14:50 UT, even if we omit the actual peak average. The full width at half maximum (FWHM) is roughly 7 hours. Because of the uncertainties in the observations nearest to the peak, the maximum ZHR is not very precise either. A level of ZHR = 30 ± 10 appears to be a fair estimate.

The population index of $r = 2.49 \pm 0.15$ as derived from the 2004 observations converts into a differential mass index of $s_M = 1 + 2.5 \log r = 1.99 \pm 0.07$. The only ingredient to this conversion is the assumption that magnitude differences are naturally related to intensity ratios, and intensities uniquely to the energy of the meteoroid. At a fixed pre-atmospheric velocity, magnitude thus refers to mass M, and the distribution is a power law such as $n(M) \propto M^{s_M}$.

Photographic observations showed that the fraction of kinetic energy converted into luminosity varies as a function of M, and the resulting mass index would be lower by a factor of about 0.92, here $s_M = 1 + 2.3 \log r = 1.91 \pm 0.06$ (see Koschack & Rendtel, 1990).

A background component of activity may also be detected in the visual data. The ZHR level is between 2–5. This is not much above the typical detection threshold of ZHR $\sim$ 1 for visual observations. Because of the peculiarly low pre-atmospheric velocity of only $\simeq$ 18 km s^{-1}, the shower meteors are distinct from most sporadic meteors. Accidental alignment with a radiant as close to the antapex as the one of the June Bootids is highly unlikely. Although it is hard to assess the reliability quantitatively, we conclude that there was a background activity level of ZHR $\sim$ 3 for the period 91°–99° in solar longitude (J2000.0), with a maximum of ZHR = 5 near 94°.

3 DISCUSSION

Comparing the predictions and observations in 2004, we can say that the June Bootid meteor shower occurred as expected. Also the long duration of the shower (*i.e.* several hours) is in agreement with the theoretical results. The low activity level of the shower made the maximum hard to determine, giving rise to large uncertainties in the peak time as derived from the observations. The models show how the whole stream was spread out and the difficulties in defining a maximum were more or less expected. Moreover, the Earth only encountered the "end" of the stream, as shown in Fig. 7. From the top to the bottom, we can see that the trailet encountered in 2004 was a perturbed one, resulting in the split of a trail by the Earth. The existence of such a split was already reported by McNaught & Asher (2002) and Vaubaillon & Colas (2002). This again illustrates the need for accurate numerical simulations in order to provide meteor shower forecasts, since any purely Keplerian view of the dynamics of such a stream (*i.e.* not perturbed by planetary perturbations) is unable to address that point. Considering earlier apparitions, we studied the past June Bootid meteor showers, following the method developed by Vaubaillon et al. (2005a,b). Comet 7P/Pons-Winnecke had some close encounters with Jupiter in the past 3 centuaries. Reznikov (1976) already mentioned the one occuring around in 1800 A.D. We found that there were 4 encounters in the 18th century: 1705, 1716, 1788 and 1800. Table 5 provides some orbital elements of the comet before and after the 1800 encounter. These data are to be compared to the ones provided in table 2. Because of the proximity of the 2:1 resonance the comet had many relatively close encounters with Jupiter between 1871 and 1954. Each of these made the inclination higher, up to the actual value. The next close encounters are expected in 2025 and 2037.

As mentioned in the Introduction, the 1916 shower was linked to the 1819 trail by Reznikov (1983), and the 1998 one to the 1825 trail by Asher & Emel'yanenko (2002). Moreover, a shower was suspected in 1927, but is uncertain (Arlt et al., 1999). We examined the circumstances for each of these years, for particles ejected at each perihelion, back to 1703. The total amount of particles involved considering these additional simulations is $2.55 \cdot 10^6$. The plots of the orbital nodes of the particles in these years are shown in Figs. 8, 9, and 5.

We found that there were several trails responsible for these showers. The 1927 level of the shower was very low, with ZHR $\simeq$ 30 (Arlt et al., 1999). Figure 9 shows that the major part of the stream was located outside the orbit of the Earth. However, a few particles from old trails are found very

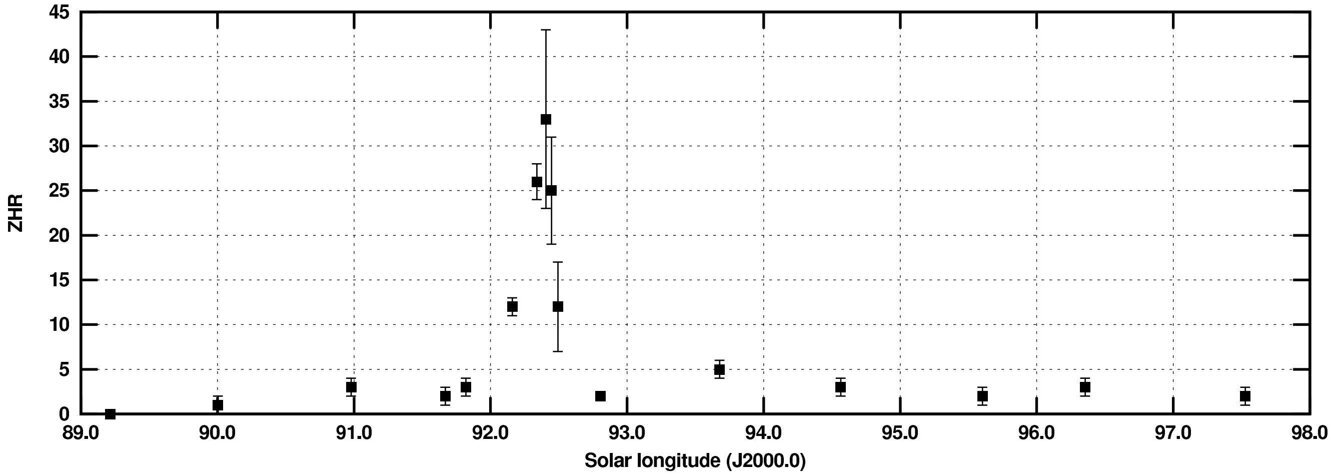

Figure 6. Activity profile of the 2004 June Bootids. The data plotted are identical to the data given in Table 4.

Table 5. The orbital elements of comet 7P/Pons-Winnecke between 1700 and 1910 A.D (from P. Rocher initial conditions). The very low inclination of the comet in 1751 makes Ω and ω to vary a lot.

a (au)	3.1404576750	3.4324267213	3.1965720703	3.2627299142
e	0.7528833271	0.7048761129	0.7426185958	0.7017633191
i (°)	8.3841371193	2.7142859986	10.4559706960	18.2846120258
Ω (°)	68.9389275423	270.1287677364	115.7828535902	100.5724951144
ω (°)	200.6318241585	3.5414675507	160.9213623753	172.3170935150
T (0:00:00 UT)	01/06/1703	31/08/1751	04/08/1802	11/10/1909

close to the Earth, and could have been responsible for the observed rate. Arlt et al. (1999) mention that Dole observed an active radiant located in constellation of Ursa Major, at RA = 215°, DEC = +57°. The location of the expected radiant was computed from the average orbital elements of these particles, by the use of the program provided by L. Neslusan (Neslusan et al., 1998). We find: RA = 208°, DEC = +56°, a value close to the one reported by Dole, and also located in the constellation of Ursa Major. The orbital elements of the particles considered here are similar to the cometary ones in 1927. Due to the change of orbit of the comet, the actual radiant is located at: RA = 224°, DEC = +47° (according to IMO, see: www.imo.net/calendar/cal04.htm).

The results for all the showers are summed up in Table 6. The difference from previous results comes from the fact that the model developed by Vaubaillon et al. (2005a) uses many more particles than other simulations. The possibility of an encounter between meteoroids and the Earth is more easily found in the larger sample.

An attempt to retro-actively predict the level of the different showers was conducted. As shown in Section 1.2, comet 7P/Pons-Winnecke suffers from the lack of an accurate determination of physical parameters. From several studies and following the model developed by Vaubaillon et al. (2005a), we adopted or derived the following values:

– radius of the cometary nucleus: $r_{\mathrm{n}} = 2.6$ km, from Lowry & Fitzsimmons (2001), assuming $A = 0.04$,

– perihelion distance: $q = 1.25$ au (Rocher, 2004),

– absolute magnitude: $m_{\mathrm{H}} = 11.0$, from S. Yoshida (see http://www.aerith.net/comet/catalog/0007P/2002.html),

– water production rate at perihelion: $Q_{\mathrm{H_2O}}(q) = 8.32 \cdot 10^{27} \mathrm{mol\,s^{-1}}$, using m_{H} and Jorda's equation (Jorda et al., 1992)

– $[Af\rho]$ at perihelion: $[Af\rho](q) = 42$ cm (taking the highest permitted value of $[Af\rho]$ provided by Lowry & Fitzsimmons (2001)).

– best fit value of the size index of population: $s = [3.0; 3.5]$.

Table 6. Association between past June Bootid meteor showers and different trails. The associations made by Reznikov (1983) and Asher & Emel'yanenko (2002) are indicated in bold face. The trails are listed by order of contribution to the shower.

Shower	Associated trail
1916	**1819**, 1813
1927	1714, 1720, 1727
1998	**1825**, all from 1819 to 1852, 1813, 1858 to 1875
2004	1813 to 1858

We tried to fit the size index of population s, based on observations of the June Bootids in 1916, 1998, and 2004 (this paper and Arlt et al., 1999). The details of the results are provided in table 7. The best value lies in the range $s = [3.0; 3.5]$. A value of $s = 3.5$ corresponds to $s_M = 1.83$, or $r = 2.3$. These values are close to the ones observed by visual observers (see Section 2). A value of $s = 3.0$ leads to

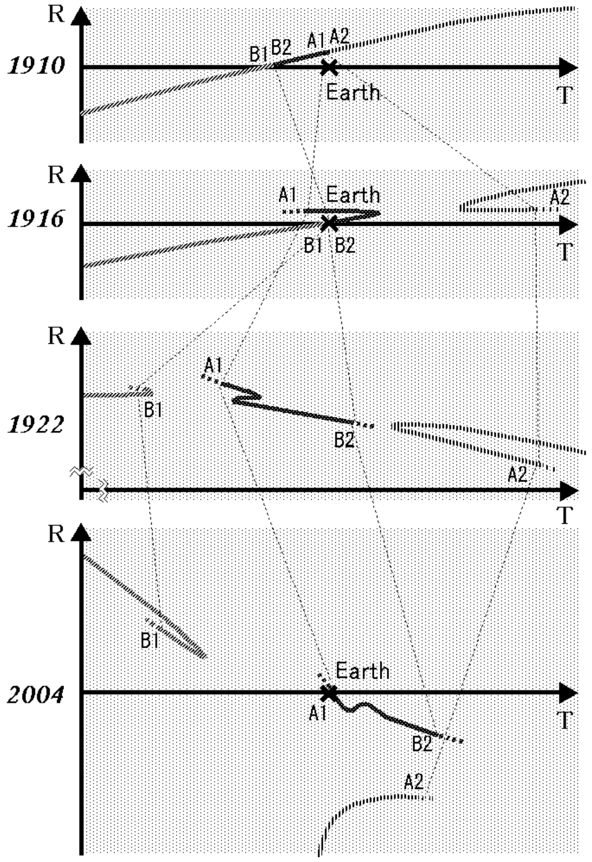

Figure 7. Illustration of the perturbation of the June Bootid meteoroid stream by the Earth (this figure shows the 1819 stream, but other ones are almost similar). T is the time and R the nodal distance to the Earth's orbit (upper is outside of the orbit). The first close encounter between the Earth and the stream occurred in 1910, causing the first gap (i.e. the points A1 and A2 which were coincident prior to 1910, became separated). Subsequently, the 1916 close encounter caused the points B1 and B2 to separate and the trail to be divided into three parts, one (shown as the darker section of the trail, from A1 to B2) being smaller than the others. This is the one encountered in 2004.

$r = 1.95$, which seems way too low. The apparent variation of s can be explained by the fact that the model uses the $[Af\rho]$ parameter to compute the amount of dust emitted by the nucleus. This value is measured from the scttering of light produced by small particles of radius in the range [0.1-10 μm], *i.e.* not in the size range of the particle responsible for the meteors. We also have to stress that the value of the cometary nucleus radius was derived when the comet was far from the Sun ($r_{\mathrm{h}} = 5.58$ au; see Lowry & Fitzsimmons, 2001). A variation of the cometary parameters can allow a better fit.

CONCLUSION

The 2004 June Bootids were predicted two months before the event by three independent models. They all predicted that a meteor shower would occur on June 23, from trails ejected in the early XIXth century. Thanks to the dissemination of this information, observations could be conducted all around the world. The scientific benefits were immediate: Kasuga et al. (2004) for example, published the first spectrum of a June Bootid meteor, followed by Jenniskens (2004). Ueda et al. (2005) from video observations computed the radiant and the orbital elements of several June-Bootids meteors, in agreement with the results presented in table 3. We were also able to associate past June Bootid returns to several trails hitherto unknown. The derivation of the peak activity of such a low-level shower was complicated by the fact that the size index of population s does not seem to agree with the observations. However, considering a lower value makes predictions possible. Therefore, we call for observations of comet 7P/Pons-Winnecke, and especially

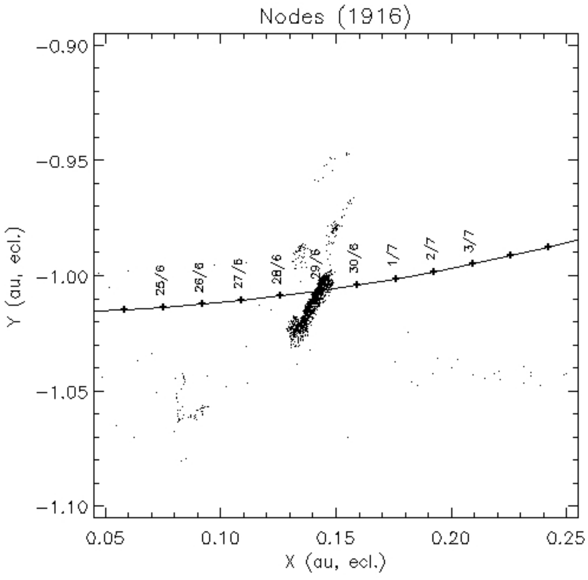

Figure 8. The 1916 June Bootid meteor shower: same as Fig. 4.

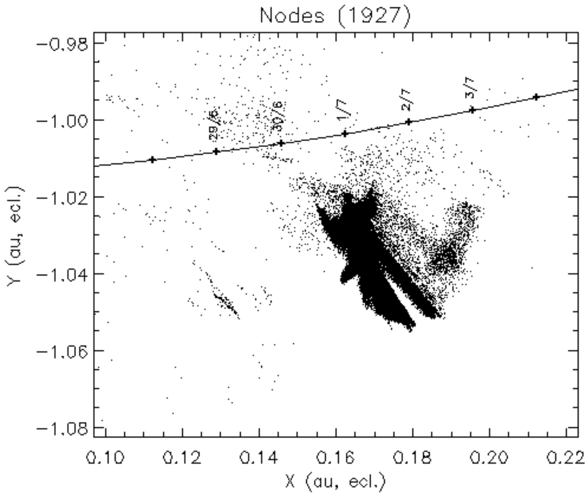

Figure 9. The 1927 June Bootid meteor shower: same as Fig. 4.

Table 7. Fit of the size index of population s of the meteoroids ejected from comet 7P/Pons-Winnecke, by using June Bootids meteor showers observations and the model developed by (Vaubaillon et al., 2005a).

Year	Observations	s	Predictions
1916	100	3.00	124
		3.25	91
		3.50	42
1998	81	3.00	207
	(peak: 250?)	3.25	158
		3.50	75
2004	30	3.00	29
		3.25	22
		3.50	10

a derivation of the parameter $[Af\rho]$ for its next perihelion return in 2008.

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