Orbit and cometary origin of the 2004 June 3 Washington bolide

An early June Bootid from comet 7P/Pons-Winnecke?

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Abstract – an approximate orbit for the 2004 June 3 fireball over Washington is derived from trajectory and speed data. The approximate orbit suggests a cometary origin. The possibility is discussed that the fireball was an early member of the June Bootid meteor stream, which have their origin in comet 7P/Pons-Winnecke.

Introduction

On 2004 June 3 at about 9:40:10 UTC, a brilliant meteoric fireball lit up the skies over Washington state, USA and British Columbia, Canada. It was captured by an all sky video camera operated by Ed Majden from Courtenay, BC (Majden, contribution on this website). A strong sonic phenomenon registered on several seismic stations in British Columbia and Washington state (Tatum, contribution on this website). The event was witnessed visually by eyewitnesses on Mt. Rainier, Washington (Matson, contribution on this website and *priv. com*.).

1. Entry angle and entry direction

A combination of data including the Courtenay all sky video, the explosion point as determined from the seismic data, and the apparent angle of the meteor as estimated from Mt. Rainier, allowed Rob Matson to derive values for the entry angle and entry azimuth of the meteoroid, and its initial entry speed (Matson, contribution to this website and *priv. com*). These data have been used by this author as a starting point for computing an approximate orbit for the meteoroid; and to search for a possible parent body candidate.

2. From radiant and speed data to an orbit

Methods and equations to derive orbital parameters from a radiant position and speed can be found in for example Whipple and Jacchia (1957), Ceplecha (1987), and Jenniskens and de Lignie (1987). This author incorporated equations from these sources into a MS Excel spreadsheet, that can be downloaded at *http://home.wanadoo.nl/marco.langbroek/metsoft.html*. The spreadsheet needs input of the (geocentric) speed and radiant coordinates of the meteor, and the heliocentric X, Y, Z position and speed of the Earth at the moment of the meteor's appearance, and then provides the meteor's orbital elements as output. The spreadsheet has been extensively tested on a high number of professionally computed meteor orbits, and performs well. With regard to the computed approximate orbit for the 2004 June 3 bolide discussed below, it should however be noted that the validity and accuracy of the computed orbit strongly depends on the validity and accuracy of the entry angle and azimuth, and notably the speed, as derived by Rob Matson.

3. From entry angle and direction to radiant position

The basis for the computation was the following information provided by Matson:

Flight azimuth: towards 114°.5 *(= coming from 294°.5)*
Entry angle: 51° *(with respect to the horizontal)*
V_∞ *: 17.9 km/s*

The entry azimuth of 294°.5 and entry angle of 51° for the given time instance and location correspond to a point of origin at the following sky position (Meeus 1991), which is the apparent radiant:

Table 1: Apparent radiant

RA 214° (= 14h 16m)
δ +49°
V_∞ 17.9 km/s

This is in the constellation of Bootes, just north of *λ Bootis* and just east of the extremity of the tail of Ursa major. This is an interesting position for a June meteor, as we will see later in this contribution.

The position of the apparent radiant is influenced by the phenomena of *zenith attraction*: the gravitational pull on the meteoroid's movement in the last part of its orbit, just before entering the earth's atmosphere. This results in the radiant position shifting slightly towards the zenith: the effect is largest for slow meteors, and low entry angles. While for a typical shower meteor with a velocity of 60 km/s (e.g. a Perseid meteor) the effect is only a fraction of a degree, the effect is considerable for a slow meteor with a velocity of 18 km/s. The following equation from classic meteor physics describes the effect:

$$\tan (0.5\, Za) = ((V_\infty - V_{geo}) / (V_\infty + V_{geo})) * \tan (0.5\, Zd)$$

In which *Za* is the zenith attraction (in degrees), and *Zd* is the zenith distance of the radiant. V_∞ is the initial speed with which the meteoroid enters the atmosphere, and V_{geo} is the geocentric speed, the speed corrected for the gravitational pull of the earth. The latter relate as:

$$V_{geo} = \sqrt{(V_\infty^2 - 11.2^2)}$$

(this ignores a small contribution by the earth's rotation).

For a speed (V_∞) of 17.9 km/s and an apparent entry angle of 51° as determined for the 3 June fireball by Matson, the zenith attraction amounts to 5°.8. The *true* entry angle (the velocity vector of the orbit), without gravitational pull, hence is 45°.2. The resulting *true radiant* (or *geocentric* radiant) is:

Table 2: Geocentric radiant:

RA 207° (= 13h 48m)
δ +46°
V_{geo} 14.0 km/s

With these data as input, the orbit can be computed. For above geocentric radiant parameters, the following orbital elements result:

Table 3a: Orbital elements:		*Table 3b: Heliocentric radiant:*	
q	1.01 AU	β	16°.3
a	4.3 AU	λ	166°.5
e	0.76	V_{helio}	39.3 km/s
i	16°.3		
ω	187°.5		
Ω	73°.09		
π	260°		
Q	7.6 AU		

The largest uncertainty in these elements, is in the semi-major axis *a* and eccentricity *e*, and hence in the aphelion distance *Q*. These parameters are highly dependant on the accuracy of the velocity determination. This is apparent from the following table, which shows the variation in elements for slightly differing speeds:

Table 4: variation of orbital elements with speed

V_∞	q	a	e	i	ω	Ω	Q
17.5 km/s	1.01	3.8	0.73	15.7	187.3	73.09	6.5
*17.9 km/s**	*1.01*	*4.3*	*0.76*	*16.3*	*187.5*	*73.09*	*7.6*
18.5 km/s	1.01	5.3	0.81	17.1	187.7	73.09	9.5

For speeds > 20.6 km/s the orbit becomes hyperbolic. The influence on the resulting orbit of possible variations of up to a few degrees in the radiant position, is less pronounced. In general, a lower entry angle result in larger aphelion distances and eccentricities and vice versa.

4. A likely cometary origin

Even with the uncertainties in speed and radiant position taken into account, one in my opinion unambiguous conclusion that can be made from the approximate orbit, is that the 3 June bolide was due to a meteoroid of cometary origin. The orbit is Jupiter crossing, which is unlikely for a meteoroid of asteroidal origin. In order to bring the aphelion distance down to values that place it in the asteroid belt between Jupiter and Mars, either the real speed has to be < 17.0 km/s, or the real declination of the radiant has to be several degrees higher. And even then, the resulting orbit has an aphelion at the very distant edge of the asteroid belt. The cometary character of the meteoroid might also reflect in the massive flaring behaviour of this bolide.

A likely cometary origin for the bolide, is of relevance to the issue of surviving meteorites. Cometary meteoroids are not likely to survive as meteorites, and if they by chance do, they can be expected to consist of very fragile carbonaceous material, that does not withstand long exposure to the terrestrial environment well. Chances of recovery of material therefore are very slim.

5. A June Bootid, from comet 7P/Pons-Winnecke?

As mentioned in paragraph 3, the position of the radiant in the northwestern part of Bootes, along with its speed of 18 km/s, makes this an interesting meteor. During the second half of June, a stream of slow 18 km/s meteors known as the *June Bootids* is known from historic observations. The June Bootids are a minor stream with a maximum ZHR < 2, but known to produce erratic meteor outbursts during which rates go up to >50 per hour. Such outbursts of June Bootids have been observed in 1916, 1998, and 2004 (Jenniskens 1995; Asher and Emel'yanenko 2002). The parent comet of the stream, is comet 7P/Pons-Winnecke. This is a Jupiter family comet that moves in a 2:1 mean motion resonance with Jupiter, showing a rapid orbital evolution as a result. The orbit of the comet was earth-crossing before 1916, but has now evolved to a perihelion distance slightly outside earth orbit. The inclination of the orbit has varied by almost 20° over the past two centuries.

The maximum of the June Bootid stream occurs after the end of the third week of June. A meteor on June 3 therefore would be a very early member, occuring 20 days prior to the stream's maximum. A stream like the June Bootids, influenced by severe Jovian perturbations, however spreads quickly. Judging from the historic rate of orbital evolution shown by the parent comet, orbital parameters of meteoroids in the stream could easily have evolved to include an apparition in early June (David Asher, *priv. com.*).

A simple tabular comparison of the computed fireball orbit with those of 7P/Pons-Winnecke and a June Bootid fireball photographed by the EN network in 1998 (Spurny 1999), already shows clear similarities in the orbital elements:

Table 5: comparison of fireball orbit to a 1998 June Bootid fireball and 7P/Pons-Winnecke

Object	q	e	i	ω	Ω	π	Q	D’
EN 270698 June Bootid	1.016	0.690	18.4	183.6	96.0	279.6	5.5	0.101
7P/Pons-Winnecke (1915)	0.971	0.702	18.3	172.4	100.5	272.9	5.5	0.086
2004 June 3 fireball	1.0	0.76	16.3	187.5	73.09	260.6	7.6	

In this comparison, the 1915 orbit of 7P/Pons-Winnecke has been chosen because this was the last year during which the orbit was still earth-crossing. The most notable difference between the fireball orbit and that for 7P/Pons-Winnecke and June Bootid EN 270698, is that the aphelion of the 2004 June 3 fireball is at a larger distance. This is however a very sensitive function of the accuracy of the speed determination (see table 4).

A possible connection of the 2004 June 3 fireball to the June Bootids and comet 7P/Pons-Winnecke can be more formally tested by comparing the orbits by means of the *D’ criterion of Drummond* (Drummond 1981). The D’ criterion weights the similarity of the orbital elements, and expresses them as a criterion value. The value usual taken as a treshold for accepting orbital association, is D’ < 0.105. In table 5, it can be seen that the D’ values for the nominal orbit of the 3 June fireball, satisfy the treshold. The fireball therefore could have been an early member of the *June Bootids* / “Pons-Winneckeids”.
When the real velocity of the meteoroid was slightly less than 17.9 km/s and/or the entry angle slightly larger than 51°, the similarity of the orbit to the orbits of the June Bootids and 7P/Pons-Winnecke will increase.

6. Final remarks and conclusions

The results above are preliminary results. Any future revisions in the trajectory, speed and entry angle, will necessitate revisions in the orbit. The accuracy of the result as it currently stands, is highly dependant on the accuracy of the speed determination. Yet, two conclusions can be made even though the results are preliminary. One is, that the 2004 June 3 bolide was likely of cometary origin. The other is, that a real possibility exists that this was an early member of the June Bootid meteor stream, which means its parent body would be comet 7P/Pons-Winnecke.

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