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LETTER

Origin of the 2006 Orionid Outburst

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Abstract

The Orionid outburst observed in 2006 resulted in strong activity, continuing for about four days. We have found that this activity was caused by the dust trails formed by meteoroids ejected from 1P/Halley in −1265, −1197, and −910. These meteoroids had six times the Jovian orbital period, and their orbit was able to intersect the Earth's orbit at the present day because of this mean motion resonance with Jupiter.

Key words: interplanetary medium — meteoroids — comets: individual (1P/Halley) — meteors — meteor showers: individual (Orionids) — solar system

1. Introduction

Strong, unexpected activity of the Orionid meteor shower was observed in 2006. Its zenithal hourly rate (ZHR) was over 50 (Green 2006; IMO[1]), the same as the usual Perseids, and the hourly rate (HR) recorded by two observers in Japan was over 100 on October 21 (Iiyama 2007). The period when the ZHR was more than 30, which corresponds to the usual maximum value of the Orionids, lasted for about four days, from October 20.4 to 24.2, or solar longitude 206.8 to 210.6 (IMO 2006). This long period of high level activity was remarkable.

The parent body of the Orionids is Comet 1P/Halley. However, the ascending node of 1P/Halley is located 0.8 AU outside the Earth's orbit. We may therefore suppose that very old dust from 1P/Halley forms the Orionid meteor shower, although the time of ejection of the meteoroids has not been studied in detail. In this paper, we try to determine the cause of the strong activity of the 2006 Orionids by using the dust trail theory.

2. Calculation of the Dust Trails

We applied the most simple approach of the dust trail theory (e.g., Asher 2000), which was described by Sato (2003) in detail. Each trail was assumed to be formed by meteoroids ejected during the perihelion passage of the parent comet. The trail was calculated by test meteoroids ejected parallel to the comet motion, both ahead of and behind the comet. At first the ejection velocity was set to be within the range between $\pm$ 30 m s^{-1}, where "+" is in the direction of the comet's motion and "−" in the opposite direction. Integration was carried out by using the Runge–Kutta–Fehlberg method together with Encke's method. To calculate the perturbations, we included the three largest main-belt asteroids in addition to the eight planets, Pluto and the moon, using the JPL ephemeris DE406. We did not take the effect of radiation pressure on the meteoroids into account in our calculation. The comet orbital elements were those calculated by Yeomans and Kiang (1981). The calculated trails in this study were those generated from −1403 (1404 BC) onwards because this is the oldest orbit in that paper; a close approach to the Earth at that time means that any attempt to calculate 1P/Halley's orbit further back in time is somewhat unreliable.

3. Results

Figure 1 shows the distribution, at the present epoch, of ejected meteoroids relative to the orbit of Earth. R is the heliocentric distance of meteoroids at their ascending node. The upper graph shows the distribution of newer meteoroids which were ejected between 66 AD and 1910 AD. The meteoroids are seen to be concentrated around the parent comet. Many parts of that graph show coherent trails of meteoroids, where over a substantial range R is a well defined function of the nodal passage time, i.e., the dust trail structure remains until the present day. However, the heliocentric distance at the ascending node of meteoroids is above 1.2 AU, so that meteoroids do not reach the Earth's orbit. Therefore, Orionid meteors observed at the present time should not be due to meteoroids ejected in the past 2000 yr.

The lower graph in figure 1 shows the distribution of older meteoroids which were ejected between −1403 (1404 BC) and −11 (12 BC). Most meteoroids have been scattered and the dust trail structure is hardly maintained. On the other hand, meteoroids whose heliocentric distance at their ascending node is lower than 1.2 AU exist, and some of them even reach the Earth's orbit. Specifically, they approached in 2006 or will approach within a few years after that. It is clear that the dust trail structure has been preserved in these particular regions.

Table 1 gives the situation of the dust trails in 2006. The date is the time when the Earth passed the ascending node of the given trail particles. Δr is the difference in heliocentric distance between Earth and each trail in the ecliptic plane. Note that Δr is not the closest distance between the orbit of the meteoroid and the orbit of the Earth in the case of the Orionids, whose motion has a significant component perpendicular to the Earth's orbit at $r = 1$ AU. Therefore, the actual closest distance between the two orbits is a bit less than the Δr in the

[1] ⟨http://www.imo.net/news/orionids2006⟩.

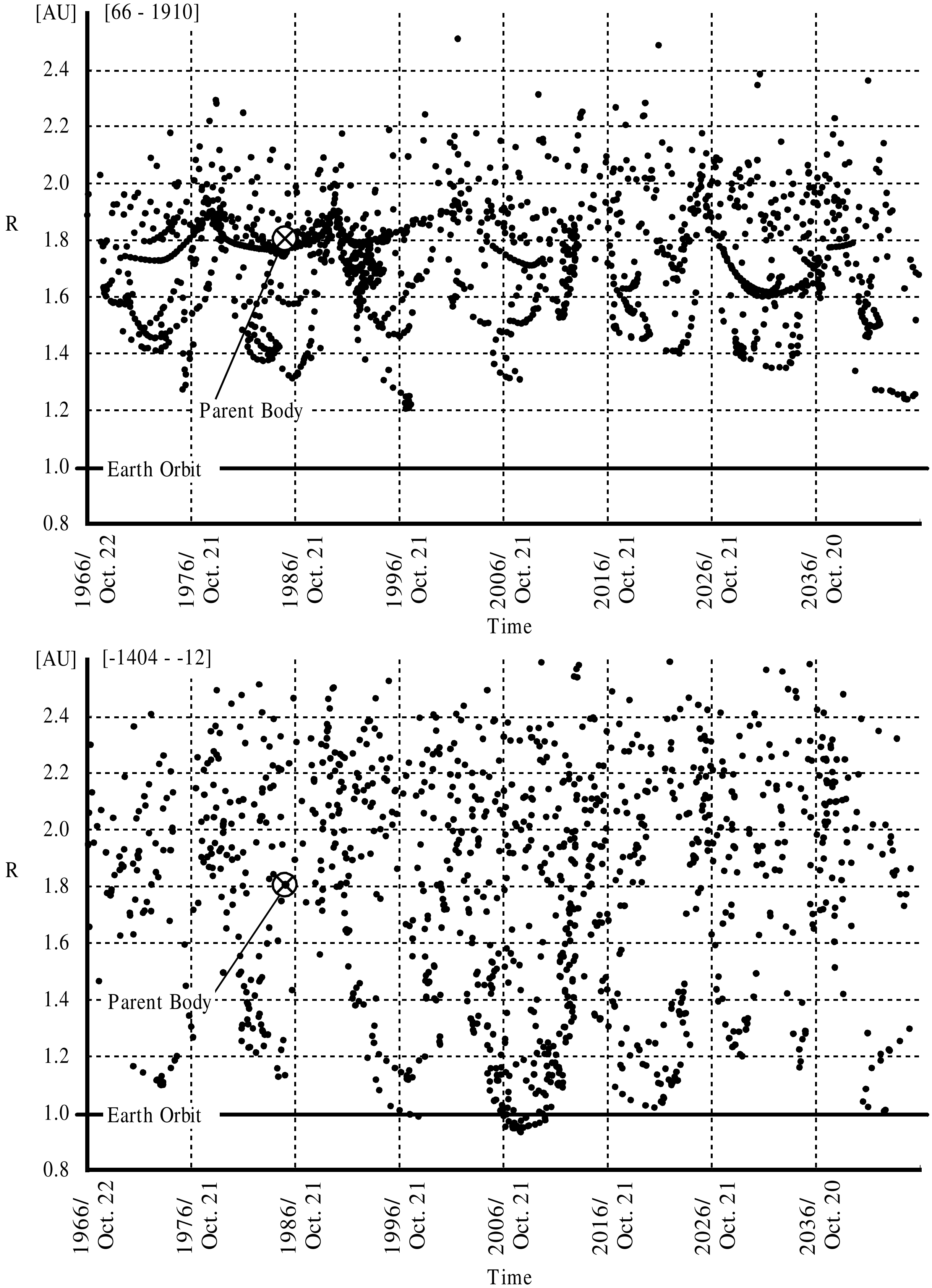

Fig. 1. Distribution of meteoroids. R is heliocentric distance at ascending node of meteoroids and Time is date when meteoroids reach ascending node. Upper graph shows distribution of newer meteoroids ejected between 66 and 1910. Lower graph shows distribution of older ones ejected between −1403 and −11.

Table 1. Data of trails related to the 2006 Orionids.

Ejection year	Expected peak time (UT) in 2006	Solar longitude (2000.0)	Δr (AU)	Ejection Velocity (km s^{-1})	fM	Expected position of radiant α(°) δ (°)	V_g^* (km s^{-1})	Orbital period† (yr)
−1265	Oct 21.10 02:28	207.464	+0.00055	+10.77	0.14	95.14 +15.45	66.88	70.5
−1197	Oct 21.58 13:59	207.942	+0.0076	+11.98	0.019	95.41 +15.47	66.67	71.8
−910	Oct 23.05 01:14	209.404	−0.0089	−10.26	0.023	96.56 +15.47	66.94	71.4
−910	Oct 23.13 03:03	209.480	−0.0086	−10.76	0.036	96.66 +15.47	66.94	71.1
−910	Oct 23.19 04:31	209.540	−0.0075	−10.75	0.015	96.71 +15.47	66.91	71.0
−910	Oct 23.31 07:20	209.657	−0.0039	−9.87	0.33	96.76 +15.48	66.81	71.3
−910	Oct 23.36 08:32	209.707	−0.0034	−9.73	0.039	96.79 +15.49	66.79	71.4
−910	Oct 23.47 11:21	209.824	−0.00070	−9.62	0.14	96.88 +15.49	66.72	71.3
−910	Oct 23.66 15:51	210.011	−0.00046	−11.12	0.089	97.03 +15.50	66.71	70.9

* V_g is the expected geocentric velocity before the gravitational focusing of the Earth.

† The orbital period is the value in 2006.

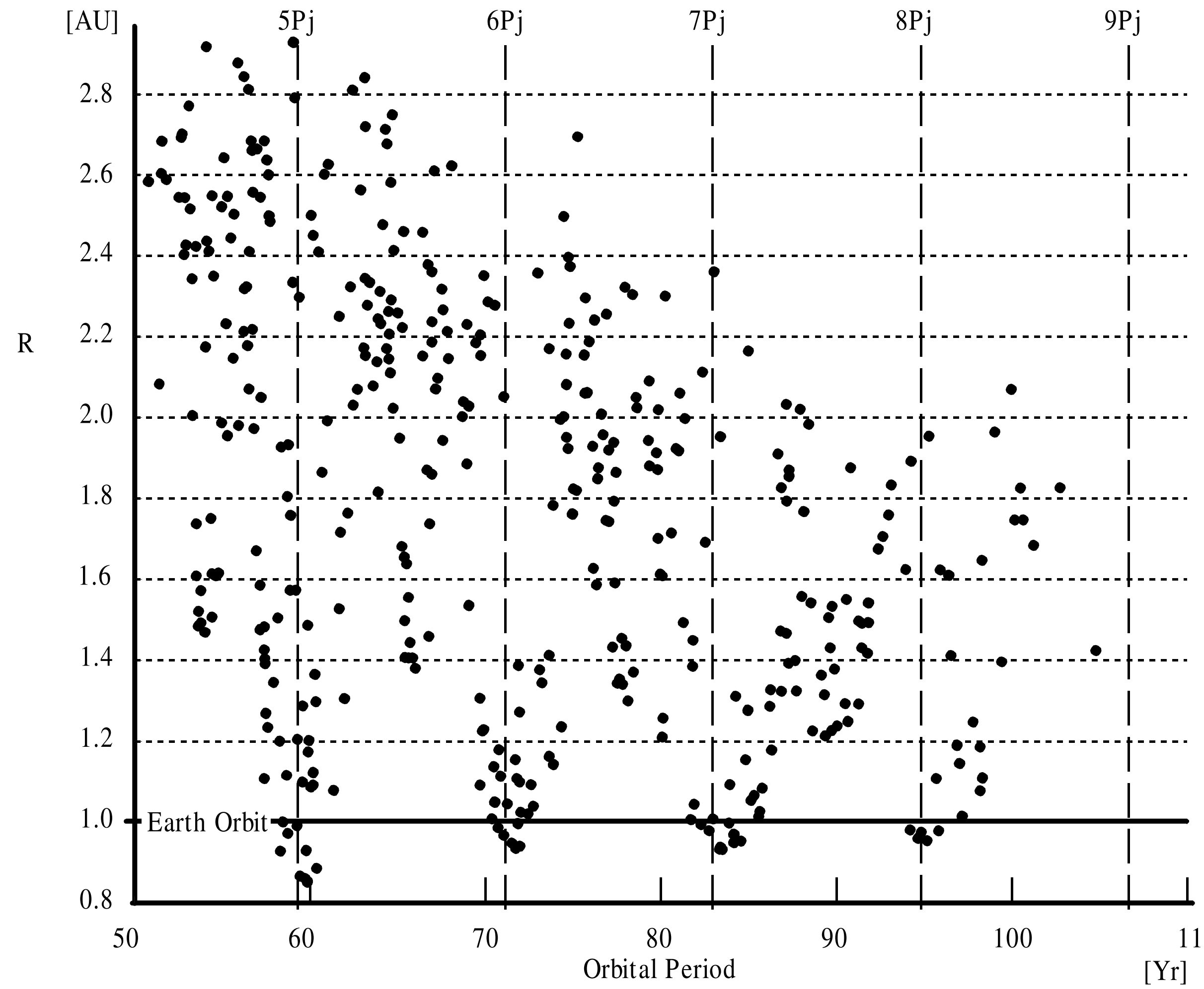

Fig. 2. The relation between R (heliocentric distance at ascending node) and the orbital period, for old meteoroids. Pj is the Jovian period. The ejection velocity was set to range between ± 100 m s^{-1} and the ejection year was set between −1403 and −1197.

table. However, it is still a suitable quantity to consider because smaller Δr means smaller approach distance. The parameter fM is the degree of extension of the trail, and was derived by fM $= \Delta t_0/\Delta t$, where Δt is the time needed for a given part of the trail to pass through the ecliptic plane, and Δt_0 is the same, but at the first return. In the absence of perturbations, the fM value is basically proportional to n^{-1}, where n is the number of returns. In reality, we calculate the effect of perturbations, and hence fM is a measure of the density of meteoroids within the trails. The results show that some parts of trails which were ejected in −1265, −1197, and −910 approached the Earth in 2006. They approached between October 21.10 and 23.66 (solar longitude between 207.464 and 210.011), and so it was expected that the peak lasted for a few days. This calculated period of the activity does indeed match the actual observed period of high level Orionid activity from October 20.4 through 24.2 (solar longitude 206.8 to 210.6).

4. Discussion

According to our calculations, the trails which caused the unexpected strong Orionid shower in 2006 were identified clearly. On the other hand, it is interesting to look for the reason why parts of old trails were able to maintain their trail structure for a very long time such as 3000 yr or so. Figure 2 shows, for older meteoroids, the relation between R (heliocentric distance at ascending node of meteoroids) and the orbital period. The vertical lines in this figure indicate the periods corresponding to multiples of the Jovian orbital period Pj. The ejection velocity was set to be in the range between $\pm$ 100 m s^{-1} and the ejection year was set between −1403 and −1197. This graph shows that the orbital period of meteoroids which have small R is an integral multiple of the Jovian one. For example, these periods are around 59.3 yr (5Pj), 71.1 yr (6Pj), 83.0 yr (7Pj), and 94.9 yr (8Pj). From this fact, it appears that the orbits of many meteoroids whose period is an integral multiple of the Jovian one are able to have their ascending node near the Earth's orbit at the present day because of a mean motion resonance with Jupiter. In contrast, the ascending node of non-resonant orbits has in general precessed away from the Earth's orbit. It appears moreover that the dust trail structure is preserved by the action of these resonances. The meteoroids which approached the Earth in 2006 had an orbital period of between 70 and 72 yr, equivalent to six times the Jovian period (6Pj). This leads to the possibility that an outburst of the Orionids occurred about 71 yr ago. In fact, 70 yr ago, an active appearance of the shower was reported. M. Eppe Loreta reported that the Orionid shower was particularly rich in 1936 (Millman 1936), and Wright et al. observed a remarkable shower on the night of 1936 October 19 (Wright 1936). This outburst would have been caused by the same dust trails as in 2006.

In this research, we targeted meteoroids which were ejected from −1403 onwards since orbital elements of the parent comet are not available before then. However, older meteoroids than this might also approach the Earth in 2006. In addition, meteoroids are expected to approach from 2007 to 2009. Moreover, research into the η-Aquarids, which have the same parent body as the Orionids, is required. Future work should consist of a more detailed investigation, including the η-Aquarids.

5. Conclusion

We confirmed that the dust trails formed by meteoroids ejected in −1265, −1197, and −910 caused the strong activity of the Orionids in 2006. These meteoroids had six times the Jovian orbital period. The 1:6 mean motion resonance with Jupiter affects the precession of the orbits so that these meteoroids intersect the Earth's orbit at the present day, allowing the Earth to encounter these meteoroids from 1P/Halley dust trails in 2006.

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