Ongoing meteor work

Comet 17P/Holmes: originally widely spreading dust particles from the 2007 explosion converge into an observable dust trail near the common nodes of the meteoroids' orbits

Esko Lyytinen[1], *Markku Nissinen*[2], *Harry J. Lehto*[3]

Meteoroids were ejected in the 2007 explosion of comet 17P/Holmes. They experienced a spread into elliptic orbits around the Sun. The cloud widened and apparently vanished altogether. We have now re-discovered this swarm of meteoroids. At exactly the opposite side of the Sun, the meteoroids converge again around the mutual node of the orbits (where the orbital planes cross each other). Later the particles re-converge at the original explosion site, all passing through the "point of explosion". Because of differences in the orbits this passage through the convergence point lasts for quite a while, maybe around two years. In spite of the long duration, the increase in surface brightness around these regions is expected to be enough to be observable in visible light. It could be observed as thermal IR in the mid infrared (15–25μm) corresponding to temperatures 200K–120K expected at distances 2AU–5AU, between the perihelion and the aphelion of the comet. We present here our observations on two nights of February 2013. We observed the meteoroids at the far away node, which is opposite of the explosion site relative to the Sun. The comet itself passed the observed region a little more than two-and-a-half months earlier in late December 2012. This why the February 2013 observations had a better chance of success than observing the same spot on previous years as the meteoroids would had not reached this spot earlier. Another probably more prominent convergence is expected to happen at the 2007 explosion site. As seen from Earth it will appear to be at a different place in the sky than the 2007 outburst. We predict this to be observable starting in the autumn of 2013, probably around November and continuing for about two years. Based on the expected dispersion in the orbits and a purely gravitational solution we expect the effect to last almost two years, but due to solar radiation pressure, it will probably continue longer (Burns & Lamy, 1979). Observing both or either of these future convergences will give further information about the explosion itself and the effects of solar radiation pressure on particles of different sizes. Such information may be useful in the development of meteor outburst prediction models.

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1 Introduction

Comet 17P/Holmes underwent a massive outburst on 2007 October 23. This was the largest recorded cometary outburst releasing large quantities of gas and dust (Sekanina, 2009; Montalto et al., 2008; Ishiguro et al., 2010). The dust particles from this explosion entered into several different orbits that are similar but not identical to the orbit of the comet. The orbital elements of each individual meteoroid orbit may vary in all aspects, but for our research the differences in orbital planes are of special importance. The shape of the orbit is further affected by solar radiation pressure. This pressure is proportional to the inverse of the distance squared from the Sun and it causes a force component pointed away from the Sun. It lengthens the orbital periods, in principle to some degree for all particles and drives the smallest particles into hyperbolic orbits.

Particles smaller than a few microns will go to hyperbolic, although particles much smaller than the solar radiation effective wavelengths may not do this.

The ratio of the radiation force to the gravitational pull is denoted as β. For a given particle (assuming similar properties like density and reflecting properties), the value of β is inversely proportional to the diameter, except when the size is clearly smaller than the radiation wavelength. We consider a mm size particle to have a beta value of $\beta = 0.001$ (Burns & Lamy, 1979).

An important issue here is that β does not affect the orbital planes and also do not divert particles away from passing through the explosion site (if not pushed to very long or hyperbolic orbits). The orbit geometry remains a conic section orbit.

After one revolution of 6.9 years (orbital period of the comet), the particles on elliptic orbits should converge in space at the explosion site. As calculated from a spherical symmetric explosion with maximum ejection velocity of 0.5 km/s, individual particles will have orbital periods from 6.06 to 7.94 years. But solar radiation pressure will lengthen the orbital periods of small size particles to infinity, in theory. We call the solutions that assume a zero radiation pressure, as "purely gravitational solution". For example the above values 6.06 and 7.94 years are from such a solutions. Radiation pressure properties in which the simple regular model

[1]Kehäkukantie 3 B, 00720 Helsinki, Finland. Email: esko.lyytinen@jippii.fi
[2]Kirvesniementie 24 B, 78880 Kuvansi, Finland. Email: markku.nissinen@pp.inet.fi
[3]Tuorla Observatory, University of Turku, 21500 Piikkiö, Finland. Email: hlehto@utu.fi

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are not adequate, were discussed in our earlier papers (Lyytinen & Van Flandern, 2000; Lyytinen et al., 2001).

The most immediate convergence will happen in the near-side common node of the meteoroids, which is the explosion site. Differences in the orbital periods of the orbits, will mainly cause a spread in the timing. Differences in other orbital elements, (e.g. in orbital planes) will cause an hour-glass shape.

Minor effects (such as the fact that the explosion was not quite momentary and the influence of differential planetary perturbations, and some expected departures of the radiation pressure from the simple model) affect the exact location of individual particles near common nodes causing some spread to the width of the hour-glass center width. Planetary perturbations will also slightly shift the location.

We expect that the increased number of small meteoroids in the limited volume of space will cause a small and local increase in the sky background. This node crossing is spatially quite narrow. The above mentioned limits of the orbital period in principle determine the duration of the phenomenon. Because of the radiation pressure, the upper limit is not well defined but we expect the observing window to last maybe a lot more than two years, and keep recurring for several successive orbital revolutions. Although it is not at all certain if this is bright enough to be observable during these successive revolutions. We cannot now predict how long the hour-glass of one revolution will be observable and to what degree the successive revolution convergences can be observed. And these are dependent on the observing equipment.

As a first approximation (i.e. without perturbations), every elliptic orbit stays fixed also in the next revolutions. When affected by the solar radiation pressure (to some approximation level) the orbits will be kept as conic sections and consequently, if not pushed into parabolic or hyperbolic orbits, will also be in elliptic orbits. The assumption of a “point-like” explosion in space and in time (which it of course is not actually) implies that every particle remains in an elliptic orbit and it will later pass trough the explosion site according to this level of approximation. This is expected to be sufficient level of accuracy for explaining a general view of the phenomenon, although the orbit is further in reality altered by planetary perturbations for example, and by the fact that the explosion was not quite point-like.

There is a second common node, the far-side node, which is located on the orbit at exactly the opposite side of the Sun. The transit of meteoroids close to this point differ in one important respect: the individual meteoroids have a significantly wider dispersion in the orbital radii. The implication is that this common node can be detected optically only when the Earth is close to the comet’s orbital plane, which is when the dispersive effect of the radial spread is minimized. Such a node crossing occurred on 2013 February 15. The observing window of the far side common node is expected to be a month at the most.

We distinguish two types of nodes. First, the line of common nodes of orbits of the explosion material: we refer to two locations along this line as the near-side node and far-side node. Second, the points at which the Earth crosses the comet’s orbital plane: the Earth reaches these points in February and August.

Because of the changing geometries between the orbit of the comet and Earth, the positions of both nodes vary in the sky and are not located on the ecliptic nor at the same position as the 2007 apparent orbit.

The first time we are aware envisioning the possibility of this kind of a phenomenon, that we know of was in the Finnish language magazine *Tähdet ja Avaruus* in an article of the comet explosion by Mikko Suominen and interview of Esko Lyytinen (Suominen, 2007). An approximate English translation of this is: Esko Lyytinen expects that at the next revolution, a phenomenon “shaped like an hour-glass” may appear at the explosion site. It could be visible for a long time. Probably it cannot be observed with amateur instruments, but space-telescopes may have success. “As the comet appears very interesting now, it could be research wise even more interesting after around one revolution has passed”.

This last sentence mainly reflects the interests of Esko Lyytinen with dust trail models for meteor outbursts predictions. And as to the observability of these phenomena we later had different thoughts of this.

2 Computer visualizations of the convergence in the common nodes

We calculated the orbits of some individual meteoroids, needed for the predictions etc, although no actual multiparticle modeling was made. No planetary perturbations were applied to the tracks. Some additional minor approximations were applied.

We modelled the explosion as spherically symmetric. We adopted the 2007 MPC or MPEC orbital elements for the comet, except that we changed the inclination to the cometary value of the epoch in 2013 (IAU MPC, 2013). The selection of the epoch has an effect of a few arc minutes on the position of the track. The comet itself passed the observed region a little more than two-and-a-half months earlier in late December 2012.

We modeled the individual meteoroid orbits as having orbital planes that differ from each other by up to 3 degrees. This is the most important factor in forming of the apparent hourglass shape.

The crossing of the planes causes a definite contraction and increase of apparent brightness at the mutual nodes. This brightening is quite noticeable, even though the time span, when the meteoroids pass by these regions is relatively long. We also estimated the surface brightness of the trail.

Figure 1 shows how the orbits seem to cross in the sky, as seen from inside the orbit close to the Sun, and close to the plane itself. The orbits form a narrow “hourglass” pattern in the sky. The opening angle shown here has been exaggerated a bit. In reality, it is expected to be around three degrees. The surface

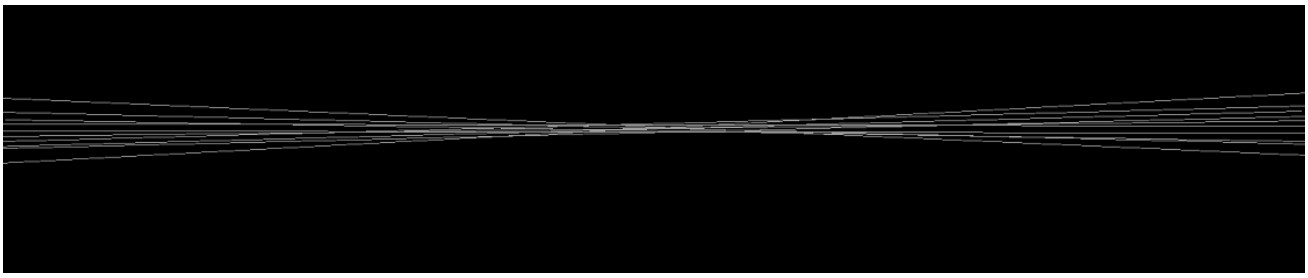

Figure 1 – Schematic diagram of how the orbits cross in the sky.

brightness increase near the crossing is the center of the common node. Of course, we cannot see the actual orbital planes but a similar figure is formed by a vast number of individual meteoroids.

As to the near side node of the explosion site, we expect the radial dispersion to be roughly equal to the normal dispersion, possibly slightly more. Since also the radial dispersion is fairly small, the observing of the convergence is not restricted to when the Earth is near the orbital plane. However, we expect the brightness distribution to have this same hourglass shape. The center is expected to be narrower and with a higher surface brightness than in the far side common node.

3 Our observations in February 2013

We carried out observations to detect the far side common node. The predicted optimum date was on 2013 February 15 but due to circumstances our observations were carried out on 2013 February 17 and 19.

We used the 32 cm T9 [1] and 51 cm T30 [2] Australia remote-controlled iTelescopes in the Siding Spring Observatory and pointed at the expected position of the trail and the hourglass figure at $16^h07^m07^s$, $-40°17'$ (J2000.0). The T30 is a Planewave $20''$ (0.51 m) CDK Corrected Dall-Kirkham Astrograph on a Planewave Ascension 200HR mount equipped with a FLI-PL6303E CCD. The images were unbinned and taken in white light with a Luminance filter. A $0.66\times$ focal reducer was used providing an effective focal length is 2280 mm. The total field of view was 27.8×41.6 arc minutes. We could barely see it in the images taken with the T9 telescope. The T30 turned out to be superior because of its larger size and automatic guiding, which helped tremendously in applying the image subtraction method in a very dense Milky Way star field. The observing conditions were very good on both nights and the Moon was not present. Our first set of seven 300-second exposures were taken on 2013 February 17, 16^h31^m UT. The second set of frames consisting of six 300-second exposures was obtained on 2013 February 19, 17^h21^m UT. Each night standard reductions were applied and the reduced image were averaged into one master image per night, so we had two masters with a time separation of 48^h50^m.

Next we subtracted the February 17 master image from the February 19 master image. It was immediately obvious that the stars had been mostly removed and that the trail showed in the difference image as a positive band at the February 19.7 location and as a negative one at the February 17.7 location.

[1] http://www.itelescope.net/telescope-t9
[2] http://www.itelescope.net/telescope-t30

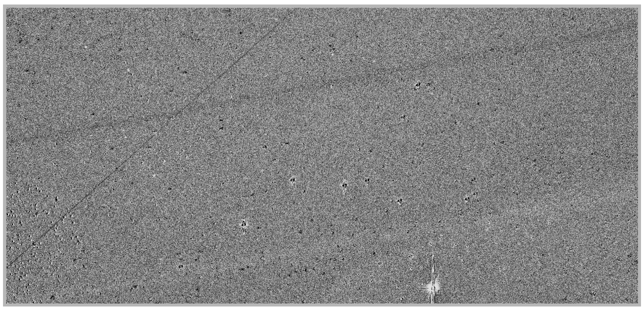

Figure 2 – The subtracted image of 2013 February 17.

The difference image is shown in Figure 2. It has been cropped to some degree so the center of the image is not exactly the original one. The center of the original image is horizontally in the center but close to the February 17.7 trail, about $40''$ to the south of the trail. North is up, but the position angle of the vertical axis (around the image center) is about 2.0 degrees off.

The horizontal width of Figure 2 is about 42 arc minutes. The meteoroid trails are seen as two broad bands in the position angle of 100 degrees. Also visible in the image are a couple of narrow satellite trails and an unknown artifact in the lower right corner. The difference image was made with ISIS2.2 program (Alard, 2000). The subtraction technique proved a much more effective method than looking at master images or using other subtraction programs for detecting the trails. The critical factor was the good field star removal capability of the ISIS2.2 program.

We tried to observe the trail again on the night between March 7 and 8 with a reference image taken later. We did not detect the trail. It is likely that this is due to too much time passing after the most favorable conditions of February 15 when the Earth crossed the orbital plane of the comet. Furthermore, the galactic background was even more challenging than earlier.

Our observing time was restricted on other nights by the high overall demand of the telescopes, the Moon, sky cloudiness and humidity in the morning hours. With more observing time, it would have been useful to image additional fields along the trail.

We have planned new observations for the next possibility of observing the far side node, around 2013 August 19.

4 Analysis of the February 2013 images

The location of the phenomenon in the sky was calculated in advance. The position of the trail was within one arc minute of the calculated location. The mutual separation of the two trails is consistent with what the calculated change of the trail track is over $48^{\mathrm{h}}50^{\mathrm{m}}$ to within about 10 arc seconds, which is roughly the accuracy of this comparison measurements and expected calculated ephemeris accuracy. The position angle of the tracks in the sky is within a few tenths of a degree of the calculated one, which is practically as accurate as one could measure. Considering that the position of the trail, the change in the position with time and the position angle all match calculated values, we are confident that we really have detected and imaged the trail, i.e. the cloud of meteoroids produced by 17P/Holmes at their common node.

To search for the hourglass pattern we rotated the difference image by 10.4 degrees to make the trails appear horizontal. We further smoothed and compressed the image along the trail and finally separated the two tracks into Figures 3 and 4. The hourglass shape is readily visible. The center of the hour glass in the February 17.7 image is at a distance of about 1/3 of the Figure 3 from the left-hand side. On the February 19.7 image (Figure 4) it is even closer to the left-hand edge of the image which is consistent with our calculations.

The profile across the February 17.7 trail shown in Figure 5 is the median along a 1400 pixel stretch of the trail. The stretch was centered on about the hourglass center and calculated from the original subtracted image. Optimally we would have preferred to measure the profile at the hourglass center, but to improve the signal-to-noise ratio we carried out the averaging along the trail. The horizontal direction one unit equals 0.81 arc seconds. The vertical unit is equal to that of the original subtracted image. The sky background corresponded to 785 units. We further note that the during the total covered exposure time of about 40 minutes, the trail track itself shifted about 20 arc seconds, affecting also to this profile width and shape.

The noise (standard deviation of individual pixel values in the background) in the master images is about 10 units, while the signal is only about 3 or 4 units. It appears from these numbers that the brightness (increase over the background) near the center is measured at 0.5% of the sky background. We expected this to be a challenging observation but this is even dimmer than what we thought it would be. Maybe it was fortunate that we did not accurately know its actual brightness (dimness) as we might not have even tried these observations.

5 Estimating the observed trail brightness from the observed explosion cloud brightness

The comet's apparent maximum brightness after the explosion was about magnitude 2. We start from the assumption of magnitude 2.0 and derive what the expected surface brightness in February 2013 should be if only geometry is considered, i.e. no loss of brightness from vanishing particle numbers, or change in size or surface color of the particles. Transforming the magnitude 2 brightness of the explosion to what it would be at the far node, taking into account the distance from both Earth and the Sun, and assuming the inverse square dependency on both distances, we get an expected total magnitude of 4.8. However, this has become dispersed along the trail rather than concentrated in a cloud. Starting from a supposed maximum ejection velocity of 0.5 km/s we derive from our orbit simulations that the phenomenon will last for roughly 600 days. We did not know prior to our observations what to expect of the width of the trail in the center of the hour glass. We measure this to be about 25″. During one day, a particle would move on these orbits about $0\overset{\circ}{.}148$ (532″), in true anomaly and about a similar length as seen from the Earth, if it were stationary.

Let us assume the phenomenon to have a constant brightness, provided that we could observe it from the same fixed location in the Solar system. Now we can calculate the factor of reduction in surface brightness. We get the expected surface area by multiplying $600 \times 532 \times 25$ which equals about 8.0 million square arc seconds. We can now divide the assumed brightness by 8.0 million square arc seconds. This factor is equals to 17.3 magnitudes, giving a value of $4.8 + 17.3 = 22.1$

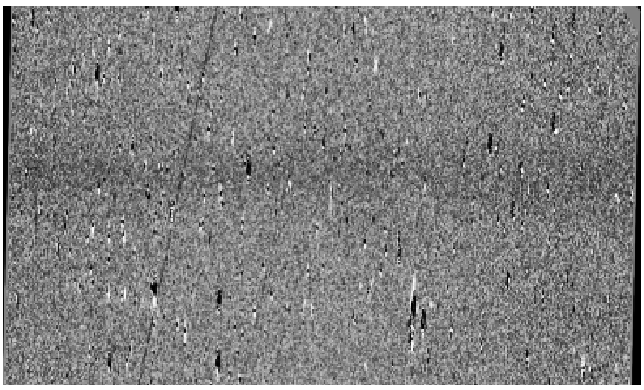

Figure 3 – The trail observed on 2013 February 17, rotated and reduced in length.

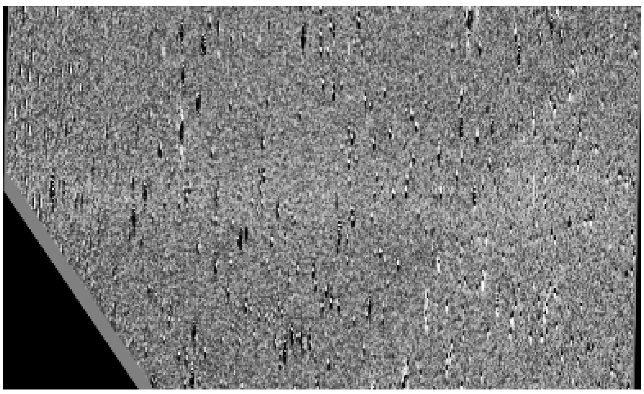

Figure 4 – The trail observed on 2013 February 19, rotated and reduced in length.

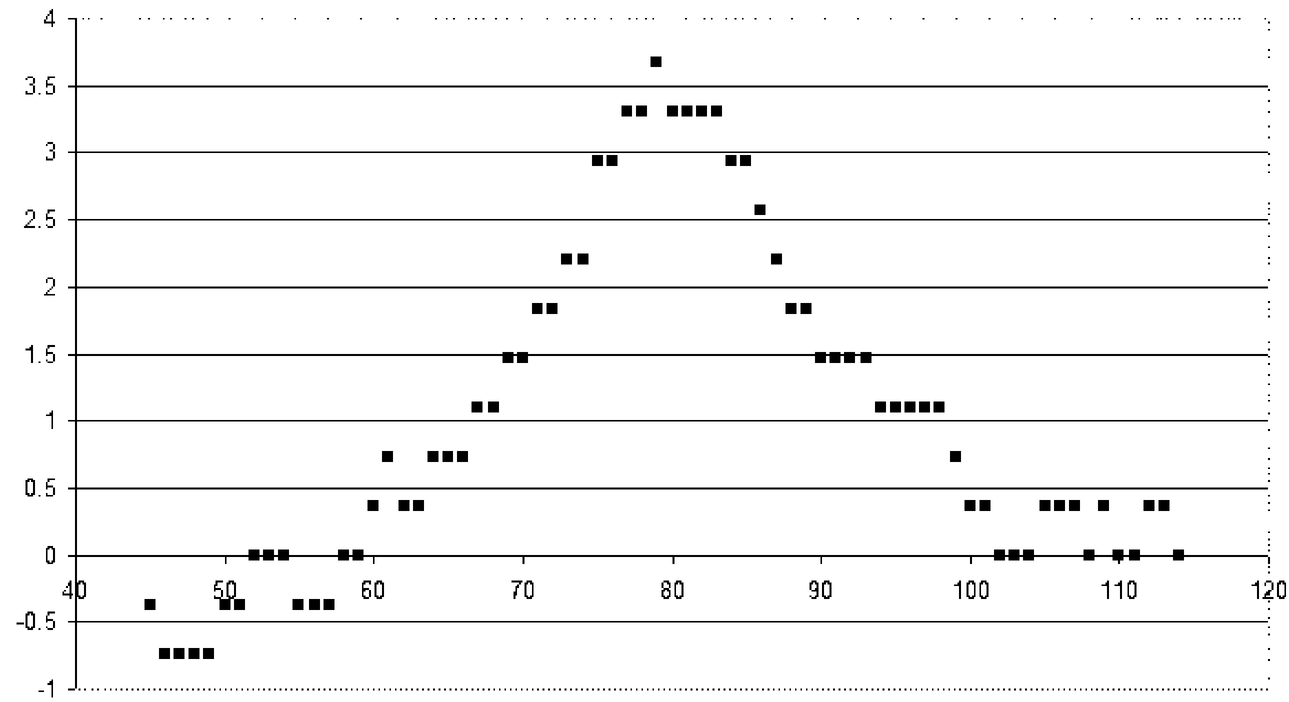

Figure 5 – Profile of the trail on February 17. Horizontal axis is in units of 0.″81 (plate scale of the image) and the zero point is arbitrary. The vertical axis has the same units as the original image (ADU), with the background value of 785 removed. Each point is a median along a 1400 pixel long stretch of the trail. The profile was further smoothed by a 5 pixel running average along the profile. The width of the trail is consistent with to the expected width of 25″ (30 pixels).

magnitudes per square arc second. This is to be added to the sky background. The brightness in our observations is obtained by assuming the sky background of 21.0 mag/square arc second, in this Milky Way region. This value is our assumption. The measured brightness of 0.5% relative to the background is equal to 26.8 mag/square arc second. It appears that there is a 4.7 mag, or about 70 fold, reduction in the brightness as compared to the calculation with no loss assumed. The total brightness of the comet is partially due to water vapor and other volatile gases that escape quickly. Small ice particles evaporate in the coma at a short distance from the comet nucleus (Stevenson & Jewitt, 2012). Dust or meteoroid particles of ice mixed with organics and minerals tend to become darker, lowering the albedo (Stevenson & Jewitt, 2012). Furthermore, larger particles are likely to fragment. Alternatively, it is conceivable that the brightness of the coma is determined by the larger particles and meteoroids (1 cm to meters) but they are much fewer in number than the smaller particles (Fulle, 2004). This would reduce the estimated number of particles entering the calculated orbits right from the beginning.

The assumed duration of 600 days of the spread of the trail is close to the purely gravitational solution. If an especially big proportion of the ejected particle mass is in the form of very small particles, say around 0.01 mm and smaller, then the duration may be considerably longer than that 600 days. Micron-size particles will get into hyperbolic orbits after the ejection and are essentially lost. We expect the larger meteoroids to head the trail and the smaller particles to make an ever thinner, dimmer and long lasting trail. Thermal infrared and radar observations could yield insight into the length and size distribution of the particles in the trail.

6 Future observable phenomena

The next time the Earth is in the orbital plane of 17P/Holmes is on 2013 August 19 or 20. The trail is located at about $13^{h}55^{m}$, $-31°$. It is observable from southern locations in the evening sky right after twilight. We expect the hourglass to be observable for about a week on both sides of this, possibly longer. The apparent location changes daily. The detailed predictions are shown in Table 1. Because we are anticipating to repeat our observations at Siding Spring, we have given the coordinates for 12 UT of the given dates. Rough interpolations of the coordinates are good

Table 1 – Predictions of the "hourglass center" coordinates in August 2013.

Day	Right Ascension	Declination
05.50	$13^{h}49.11^{m}$	$-31.°77$
10.50	$13^{h}50.64^{m}$	$-31.°50$
13.50	$13^{h}51.71^{m}$	$-31.°35$
15.50	$13^{h}52.48^{m}$	$-31.°26$
17.50	$13^{h}53.32^{m}$	$-31.°19$
19.50	$13^{h}54.20^{m}$	$-31.°11$
21.50	$13^{h}55.12^{m}$	$-31.°05$
23.50	$13^{h}56.10^{m}$	$-31.°00$
25.50	$13^{h}57.10^{m}$	$-30.°95$
30.50	$13^{h}59.82^{m}$	$-30.°86$

enough for imaging. We used true anomaly of 241.25 degrees to generate Table 1. This value corresponds to the comet 2007 orbit but the actually used values for meteoroid orbits differ from this, because of differences in the argument of perihelion. We expect that the uncertainty of the center along the trail may be as much as a few tenths of a degree. The stellar background will be much more favorable in August than what it was in February. Unfortunately, the full moon will be a problem. After this the next time Earth will cross the comet's orbital plane will be in February 2014. The hourglass phenomenon in this mutual node would have ended before this, based on a purely gravitational solution. But because of solar radiation pressure, we expect it to still continue on that date. We are going to inform separately about the refined predictions for February 2014.

The convergence to the actual explosion site is also starting soon. Based on the maximum ejection velocity value of 0.5 km/s opposite to the comet's velocity vector, we predict that this will take place on about 2013 November 12. If the velocity were 0.45 km/s it would begin almost a month later. Radiation pressure may slightly delay the start date. It would be optimal if the start of the convergence could be observed. It will be observable in the northern hemisphere. The start is expected to be quite sudden, but will probably not be at full brightness. A pure gravitational solution would give the duration of the convergence through this site close to 700 days, but because of radiation pressure, we expect this to last a lot longer, possibly with an undetermined end and perhaps lasting for a number of years.

The predicted coordinates for the explosion site convergence are given in Table 2. The same coordinates can be used for the year 2015, using the same solar longitude. Then these same coordinates will be valid at about 06^{h} UT on the same dates.

After two or three revolutions one could, in principle, observe the two tracks simultaneously and somewhat separated by planetary perturbations. But it is uncertain if the brightness will be sufficient enough for any actual observations.

In all these future scenarios, we have assumed that practically all the loss of the meteoroids has already happened and there will not be much further loss. If further break up and consequent vanishing of particles takes place, then the brightness of the phenomena will decrease. This would provide important information on the break-up of small particles and meteoroids in interplanetary space.

7 Conclusion

We documented the swarm of meteoroids in the orbit of comet 17P/Holmes. A low surface brightness trail was detected at the calculated position at the correct position angle and the expected motion and shape.

We recommend additional observations of these meteoroids from Southern hemisphere locations in August 2013 and from Northern hemisphere locations from October 2013 onwards.

Table 2 – Predictions for the explosion location. Because of missing planetary perturbations, these can be in error by a few hundredths of a degree.

Date (0^{h}UT) yyyy mm dd	Right Ascension	Declination
2013 10 05	$4^{h}38.12^{m}$	$+47\overset{\circ}{.}78$
2013 10 10	$4^{h}28.86^{m}$	$+48\overset{\circ}{.}57$
2013 10 15	$4^{h}17.43^{m}$	$+49\overset{\circ}{.}25$
2013 10 20	$4^{h}03.83^{m}$	$+49\overset{\circ}{.}78$
2013 10 25	$3^{h}48.17^{m}$	$+50\overset{\circ}{.}09$
2013 10 30	$3^{h}30.80^{m}$	$+50\overset{\circ}{.}12$
2013 11 04	$3^{h}12.26^{m}$	$+49\overset{\circ}{.}82$
2013 11 09	$2^{h}53.30^{m}$	$+49\overset{\circ}{.}17$
2013 11 14	$2^{h}34.71^{m}$	$+48\overset{\circ}{.}16$
2013 11 19	$2^{h}17.23^{m}$	$+46\overset{\circ}{.}84$
2013 11 24	$2^{h}01.41^{m}$	$+45\overset{\circ}{.}27$
2013 11 29	$1^{h}47.59^{m}$	$+43\overset{\circ}{.}53$
2013 12 04	$1^{h}35.90^{m}$	$+41\overset{\circ}{.}72$
2013 12 09	$1^{h}26.33^{m}$	$+39\overset{\circ}{.}89$
2013 12 14	$1^{h}18.76^{m}$	$+38\overset{\circ}{.}13$
2013 12 19	$1^{h}12.99^{m}$	$+36\overset{\circ}{.}46$
2013 12 24	$1^{h}08.82^{m}$	$+34\overset{\circ}{.}93$
2013 12 29	$1^{h}06.06^{m}$	$+33\overset{\circ}{.}55$
2014 01 08	$1^{h}04.03^{m}$	$+31\overset{\circ}{.}25$
2014 01 18	$1^{h}05.68^{m}$	$+29\overset{\circ}{.}54$
2014 01 28	$1^{h}10.08^{m}$	$+28\overset{\circ}{.}36$
2014 02 07	$1^{h}16.55^{m}$	$+27\overset{\circ}{.}62$
2014 03 01	$1^{h}35.80^{m}$	$+27\overset{\circ}{.}17$
2014 04 01	$2^{h}10.01^{m}$	$+28\overset{\circ}{.}27$
2014 05 01	$2^{h}47.14^{m}$	$+30\overset{\circ}{.}32$
2014 06 01	$3^{h}26.92^{m}$	$+32\overset{\circ}{.}85$
2014 07 01	$4^{h}04.25^{m}$	$+35\overset{\circ}{.}48$
2014 08 01	$4^{h}37.57^{m}$	$+38\overset{\circ}{.}50$
2014 09 01	$4^{h}57.19^{m}$	$+42\overset{\circ}{.}29$
2014 10 01	$4^{h}44.41^{m}$	$+47\overset{\circ}{.}10$
2014 11 01	$3^{h}24.42^{m}$	$+50\overset{\circ}{.}05$
2014 12 01	$1^{h}43.26^{m}$	$+42\overset{\circ}{.}90$
2015 01 01	$1^{h}05.07^{m}$	$+32\overset{\circ}{.}85$

Extended observations are needed for studying these phenomena and the dust particles involved. These will have a direct impact in the understanding of meteor producing meteoroids.

Some of the issues we have identified are:

a) Measuring the extent of the phenomena in time will provide information on solar radiation pressure on the particles and the particle size distribution.

b) Measuring the width of the hourglass center and inhomogeneity in the trail will quantify the expected non-regular radiation pressure effects, among these the seasonal type radiation effects.

c) Characterizing the brightness evolution of the trail(s). We expect this to provide information about the size-dependent evolution of the particles in the trail.

d) The observation of the hourglass center in February with similar observation in August may tell if the explosion was not symmetric in the radial direction.

e) To ascertain through study if a similar effect from the 1892/1893 eruptions (Sekanina, 2009) could still be observable.

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