DRAFT DRAFT Comet 17P Holmes Outburst DRAFT DRAFT

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Introduction

On Oct. 23.7 2007, the then faint (mag 14) and unremarkable Comet Holmes emitted a large quantity of material which expanded as a large generally circular (presumed spherical) coma over the next several months. The coma included a brighter region (usually referred to as the false nucleus) roughly centered within the coma. The coma and comet nucleus moved apart after the event. Within 48 hours, the coma had brightened to about mag 2.5 which then slowly decreased over the next two months.

This paper reports several researches done to explore the characteristics of the event. These include

- Development of a rough model relating the particle density in the coma to its transparency, and comparison to observations
- Coma transparency measurements using stars shining through the coma, and an evaluation of when the nucleus became visible through the coma
- Measurement of coma density distribution using reflected sunlight intensity
- Measurement of the relative movement of the true and false nucleus that implies a two step outburst event

The writer is an amateur astronomer using equipment and methods generally described on the above web site. Note that dates given as decimals (eg Oct 23.5) are UTC dates, while non-decimal dates (eg., Oct 23, 2007) are Eastern Standard Time (US).

Material in the Coma

On Oct 28.1 and 29.1 I conducted spectroscopic study of the coma. This was reported on my website at http://menkescientific.com/Comet17P-Holmes.pdf   The basic conclusion was that most of the brightness was reflected sunlight, with some red shifting. This would indicate that the coma was primarily made up of dust longer than the wavelength of light. Bad weather plus the rapidly decreasing area brightness of the coma prevented followup spectroscopy by the writer.

Coma Density Distribution

CCD observations can be used to estimate the mass, density, and the density distribution within the coma. I pursued several lines of investigation.

One line of investigation was to model the evolution of the coma using reasonable assumptions for emitted mass, particle size, etc. One can estimate the time evolution of the transparency of the coma and compare it to actual.

The second line was to measure the transparency of the coma using background stars shining through the coma. Although limited in amount, I did have and analyzed several days of data early in the outburst, though none earlier than 5 days after the outburst.

Modeling the Density of Comet Holmes Coma

I established a very crude model of the ejection of material from Comet Holmes. Initial conditions assume a given mass ejected (10^11 kg, private communication from Richard Miles), density (3.5, same source), particle size (1u), and an expansion rate of the coma cloud (0.506 km/s, assumed constant with time, derived from the Seiichi Yoshida web site). For purposes of the model, the density of the cloud is assumed to be uniform throughout the cloud. Using these data, I calculate the number of particles present in a 1u cylinder through the center of the cloud. If this value exceeds "1", then the cloud will be opaque at the center. If it is .01, then one would expect a maximum of about 1% obscuration at the center (thickest) portion of the cloud. I assume that 1u particles will simply block light via the particle geometry (no allowance is made for multiple scattering or other forms of light scattering).

Figure 1 shows the resulting graph. Using these assumptions, one sees that by Day1 the center of the cloud is almost down to 1% obscuration. Clearly, data from the very first hours and days of the event are needed to allow matching models to the early evolution of the event. This is consistent with the results of the transparency measurements discussed below.

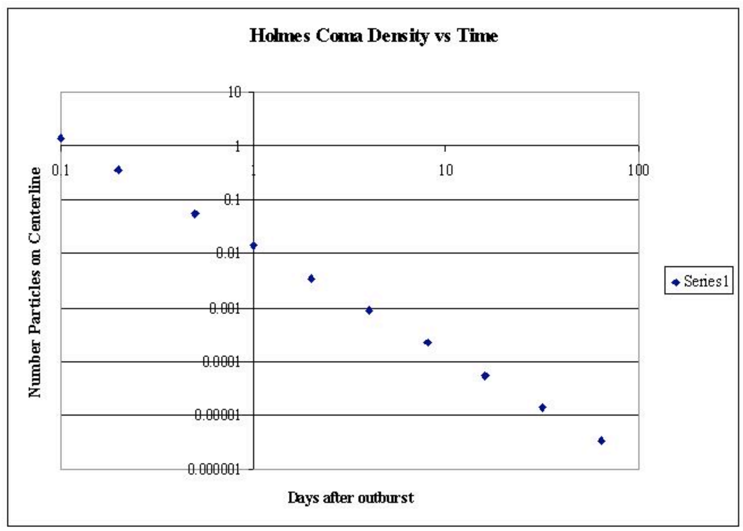

Figure 1. Model of Expanding Coma Density

Assuming that the obscuration of the coma is essentially zero, then the particles in the coma all have equal access to reflecting sunlight and do not shade one another. Therefore, the mass of the coma in a given direction is proportional to the brightness of the coma at that point. This would at least allow one to evaluate whether the assumption of a homogenous sphere is reasonable.

I therefore built a simple model in which I can set the radius and relative density for either one or two cocentered spheres, and then compute the intensity of reflected light. The result is shown in Figure 2. The dark curve is the two sphere model empirically fitted to the light curve of the actual normalized intensity data from Oct. 30.1. As one can see, the actual fit is fairly reasonable. In actuality, the brighter central peak that the smaller sphere is representing is the light from the "false nucleus" region of the coma (easily visible as a bright patch in Figure 3, and as a broad streak in Figure 4).

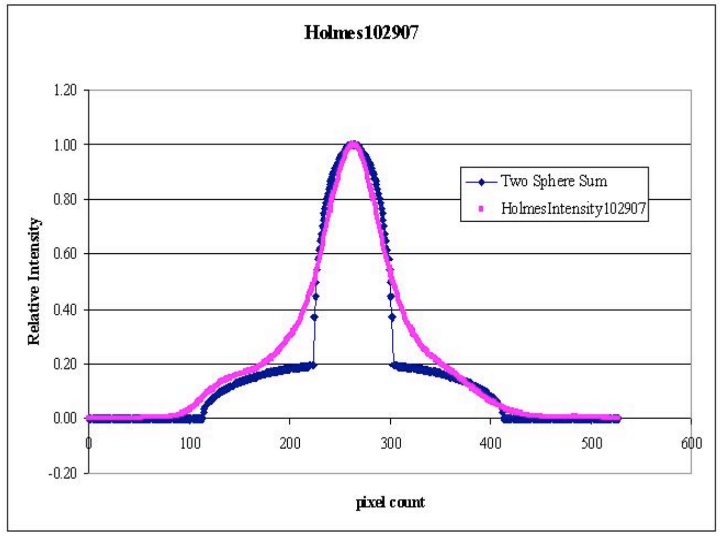

Figure 2. Two Sphere Model Compared to Actual Intensity Profile

This rough analysis (supported by the transparency measurements) indicates that both the coma and the false nucleus are each generally homogeneous. The analysis clearly rules out the possibility that the coma is a shell or that it has an extended large diameter dense tail (which would be in line with the coma), though one cannot rule out that the central "false nucleus" region is a tail-like object extending in the line of sight.

Method of Transparency Measurements

The coma imposes a very substantial gradient on the image. Thus, in measuring the star brightness through the coma, when one measures the background brightness near the star, the gradient may cause errors in the measurement. This error will be rduced if the star is bright, or if one can reduce the gradients.
I conducted the measurements in two ways:

- using direct measures of the star brightness relative the star local background in the presence of the coma
- subtracting a smoothed version of the comet image to remove most of the coma and the associated gradients

In the case of the Oct. 30.1 data I also had available images of the same field using the same telescope/camera combination. I could then compare the star brightness from the comet-free field with the brightness in the subtracted field to determine any obscuration of the stars due to the coma. I then plotted the difference of the two measures vs. the relative brightness of the coma at the point of measurement. This method allows the use of more stars in the field to help determine whether variations are due to the coma or other factors.

There remain additional problems related to the presence of large gradients, not all of which were removed by the subtraction process. This is the major source of the large values of apparent obscuration, and of the negative values (indicating unrealistically that the star is brighter through the coma than without the coma). However, the method does seem to be reasonably robust, and can produce good results with additional image sequence data so that more (and brighter) stars can be used to sample the coma.

I applied both methods on the Oct 29.1 data. However, the Oct. 28.1 and 30.1 data contained only relatively faint stars in the coma, so I used the subtraction method only.

Measurement of Transparency of Comet Holmes Coma on UTC Oct. 28.1 2007

On this date, I had a series of images 20 images taken using the C11/ST7E in clear, red, V, and blue filters. Unfortunately, only relatively faint stars are visible through the coma. The scale was approximately 1.40a-s/pixel, with a FOV of approximately 11.7x17.7 a-m. A preliminary evaluation showed that little information could be taken from these images so these images were not evaluated in detail.

Measurement of Transparency of Comet Holmes Coma on UTC Oct. 29.1 2007

I had a very limited data set from UTC Oct 29.1 (Day 5.4), specifically, images taken through the C11/DSS7/SBIG402 spectrometer setup taken during the spectrometry session. Because they were taken through the spectrometer, the images suffer from reduced sensitivity and other image quality issues. The scale was approximately 1.40a-s/pixel.

Making up for the problems, at that time the comet was passing directly before a mag9 star and a nearby mag11 star, thus providing excellent probes of the coma (see Figure 3) and allowing a reasonable measurement of the extent to which the coma obscured the star image. Because the data span two hours, the mag9 star moved from the brightest part of the coma to the region in which the brightness was <50% maximum. Thus, a simple time series of the stellar and comet nucleus provided a reasonable measure of obscuration. These are the only images that had sufficiently bright stars in the center of the coma to allow measurement in that dense (bright) part of the coma.

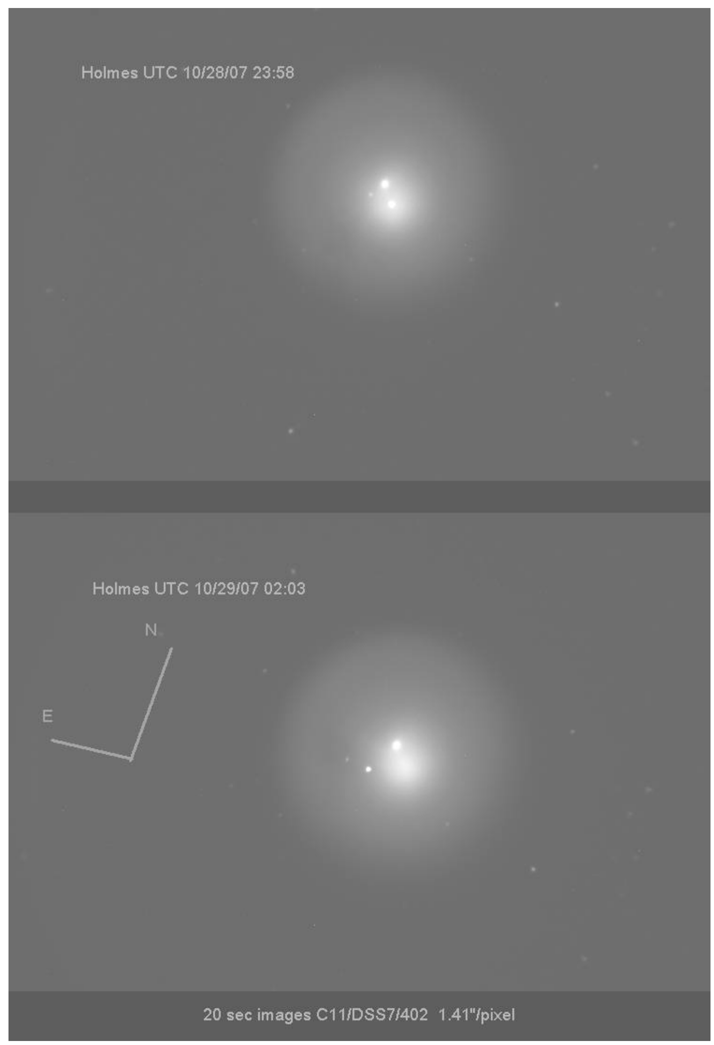

Figure 3. Holmes Oct. 29.1 Sample Images

Using the comet nucleus as the reference, and employing both the direct measurement and subtraction methods. While the results were consistent with an obscuration of zero, due to the limited and poor data I was only able to set a limit on the obscuration of about 10%.

Measurement of Transparency of Comet Holmes Coma on UTC Oct. 30.1 2007

The Oct. 30.1 sequence was taken using the C11/ST7E setup. At that time, the diameter of the coma was approximately 6a-m.

The sequence was taken using 60 sec images. The comet was moving at less than 10 a-m /hour, so seventeen images were averaged to provide for reasonably deep images while the comet did not move more than 10% of its coma diameter.

Figure 4 shows a mosaic of the original combined (average of 17x60sec images) comet image, the subtracted image, and the comet-free field. Figure 5 shows the averaged comet image along with an intensity plot across its middle.

Table 2 shows the star data resulting from the measurements. For each star in or near the coma, the first column gives a catalogue brightness (where available), the second gives the apparent magnitude in the comet free field, the third column shows the magnitude obscuration (positive means obscured), and the fourth column shows the coma brightness (relative to the brightest portion of the coma) at each point where a star was measured. The data are sorted by the last column.

Figure 5 shows the results of the analysis process. The data indicate that the measured amount of obscuration is

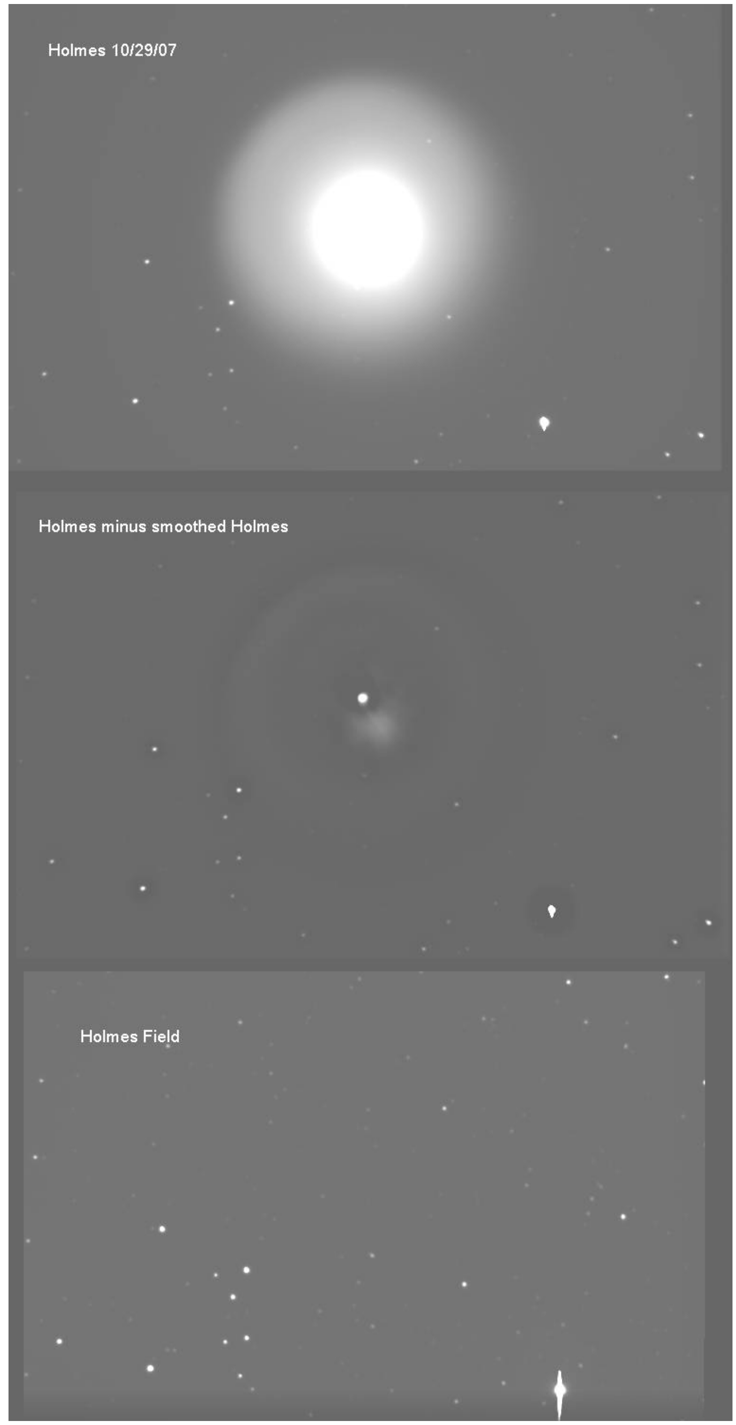

Figure 4 Holmes Image Mosaic Oct. 30.1

less than 2-5% for coma regions as dense as 30% of the peak brightness. The measurement quality is limited by the small number of stars (many of which are relatively faint) in the coma region,. There were no stars bright enough in the more dense regions of the coma to allow measurement.

Table 2. Holmes Oct. 30.1 Coma Star Data

max coma	15000.00			
bkgd	280.00			
USNO/GSC	raw	dif	Coma&bk	% peak
13.60	13.17	0.11	338.00	0.004
13.20	10.81	0.10	343.00	0.004
	14.45	0.05	349.00	0.005
11.00	13.53	0.04	353.00	0.005
	11.62	0.16	385.00	0.007
11.90	12.95	0.04	412.00	0.009
10.90	10.62	-0.01	591.00	0.021
14.40	14.40	0.09	602.00	0.021
14.30	14.32	0.07	859.00	0.039
	14.66	0.07	1010.00	0.049
14.20	14.15	-0.01	1315.00	0.069
14.30	14.55	0.03	1557.00	0.085
	15.38	-0.16	1570.00	0.086
	15.34	-0.17	1573.00	0.086
12.30	12.04	0.04	1750.00	0.098
	15.46	-0.07	1780.00	0.100
	14.86	0.04	2100.00	0.121
	15.18	0.00	2334.00	0.137
	15.52	-0.03	2583.00	0.154
13.00	12.78	0.02	2595.00	0.154
	14.71	-0.09	2795.00	0.168
	14.93	-0.02	3357.00	0.205
	15.36	-0.03	4220.00	0.263
12.90	13.37	0.04	4955.00	0.312

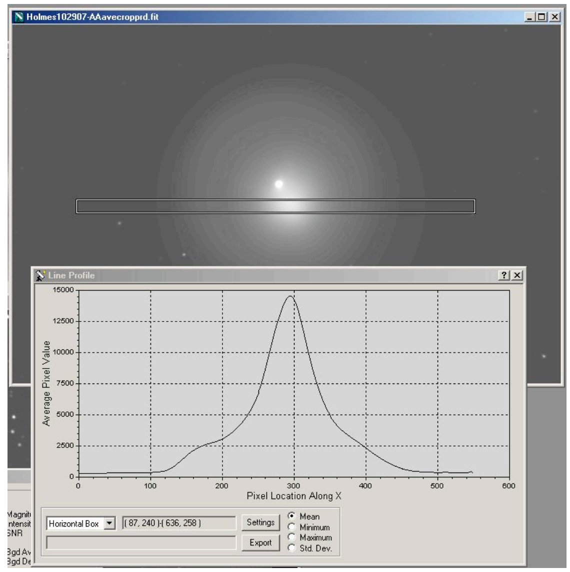

Figure 5. Holmes Oct. 31.1 Intensity

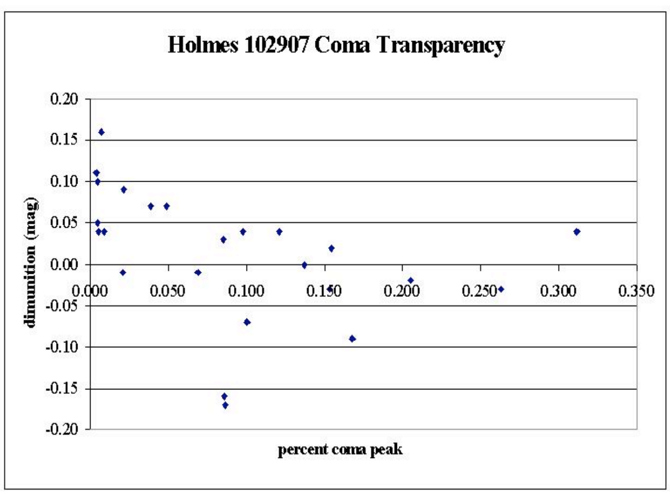

Figure 6. Holmes Oct. 30.1 Coma Star Obscuration

Changes of Coma Brightness with Time

Seiichi Yoshida on his web site http://www.aerith.net/comet/catalog/0017P/2007.html has compiled data concerning Comet Holmes, including the two graphs shown in Figures 6 & 7.

One of his graphs shows the brightness rise in the first 48 hours. This shows that the brightness began increasing from about mag14 at approximately Oct. 23.7 and reached maximum at about Oct. 25.0, about 1.3 days (31 hours) after the event. This is consistent with the evidence discussed above which indicates that the coma had become transparent by the end of day 1.3; that is, at day 1.3 all particles are exposed to sunlight, and the maximum coma brightness is obtained. Measurements of Holmes images before Oct. 25.0 would be very desirable to evaluate.

Assuming that the coma is made of relatively large particles (perhaps 1u) and is transparent, as the coma expands the overall brightness should not change unless there are other processes occurring that affect the light scattering processes of the particles.

During the following two months, the coma expanded more than tenfold in diameter, and a thousandfold in volume. The overall brightness decreased during that time by about 1.5 magnitudes as the comet has receded from the earth and actually approached slightly closer to the sun. These geometric effects account for 1.25 magnitudes of brightness reduction. It is difficult to know whether the large area brightness measurements are sufficiently accurate to conclude that the apparent discrepancy in brightness reduction of 0.25 mag represents real changes occurring in the coma.

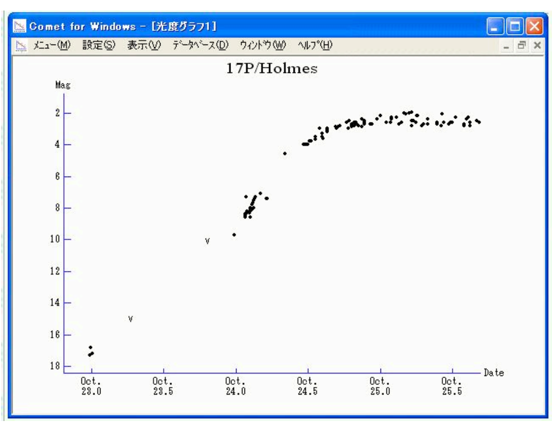

Figure 6. Comet Holmes Early Light Curve

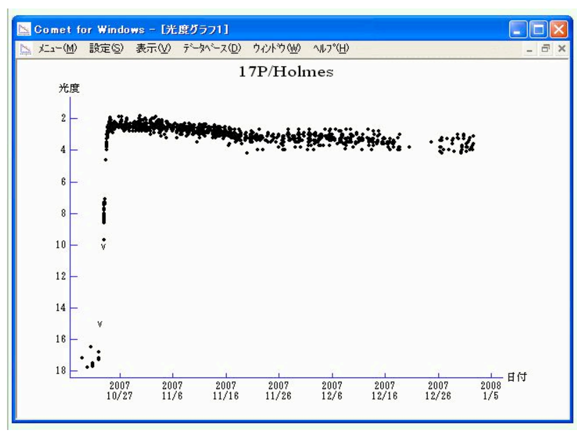

Figure 7. Comet Holmes Long Light Curve

Holmes Nucleus and False Nucleus

During the first week after this outburst, 17p appeared to many observers to have two nuclei. The "true" nucleus was starlike. The second, dubbed the "false" nucleus, started out almost starlike, but evolved into a brighter, more dense, region within the coma (as discussed above).

Rolando Ligustri provided images of Holmes that were taken from a remotely operated observatory in New Mexico on Oct 25.215, 26.157, and 27.299. These were taken with a Mewlon 300mm reflector with an ST8 camera. The images were 1, 10, 10 sec. respectively in Red, V, and Blu filters. Plate solving the images using Pinpoint within MaximDL indicated a scale of 1.15 a-s/pixel and allowed alignment of these images to others I had taken.

Appearance of Nucleus

Consistent with the evolution of the coma, the model discussed above indicates that the nucleus would have been heavily obscured during the first hours of the event, and it, too, should have reached maximum brightness at about Day 1. That is, the nucleus itself can be used as a probe of the density of the coma during the early hours of the event.

The Ligustri images (Red Filter) are shown in Figure 8 where they have been enlarged and processed to bring out the details in the inner coma. Examination of these images shows that the nucleus is essentially undetectable in the Oct. 25.215 image (Day 1.5 since outburst), that is, while the coma has a central peak, there is no sign of a separate peak or visible concentration. However, by Oct. 26.157 (Day 2.5) a separate nucleus is clearly visible, but is faint and fuzzy. By Oct. 27.299 (Day 3.6) the nucleus is a clear, starlike object, and is clearly not at the center of the coma.

With only a few images from this period, one cannot accurately determine the exact rate at which the nucleus became visible. However, this is additional evidence that the central portion of the coma became transparent between Day1 & Day 2, generally corroborating the conclusions from the model and the transparency measurements.

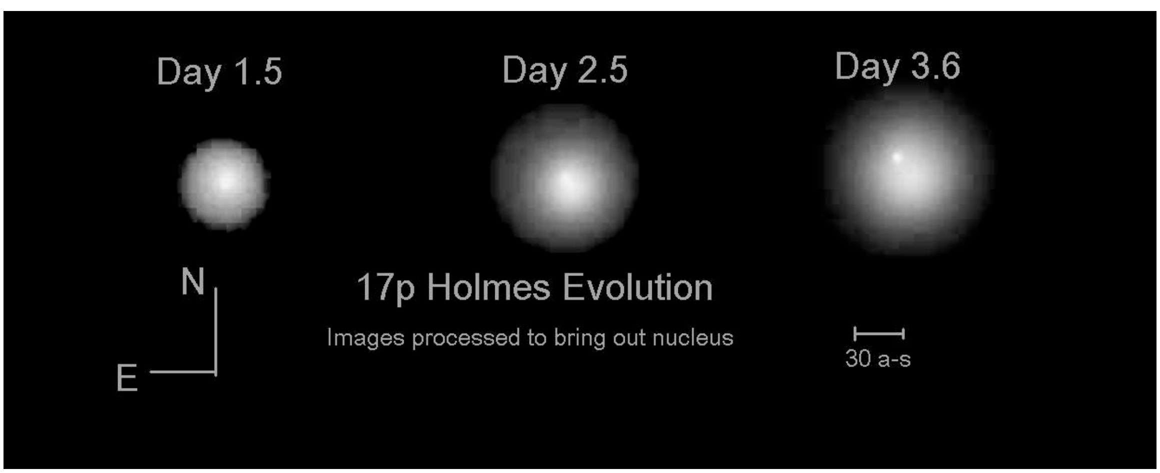

Figure 8. Very Early Evolution of 17P Nucleus

Movement of False Nucleus

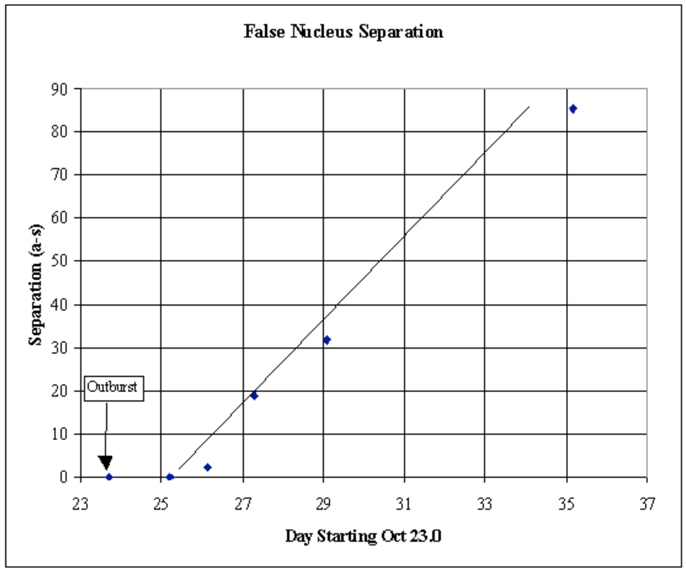

Figure 9. False Nucleus Separation

I measured the relative positions of the nucleus and the "false" nucleus during the first 11 days (during this time as well as later, the false nucleus remained relatively centered on the coma). The relative positions are shown in Figure 9. During this period, the separation increased by 8.75 a-s/day or at a rate of approximately 0.078 km/s, both measurements of course only are in the plane of the sky (remember that the coma expands at a radial rate of 0.506 km/s).

Even more interesting, the separation appears to begin on Oct. 25.2, or on Day 1.5 after the outburst began. This implies that the outburst was really a two stage process. Perhaps a large piece was initially ejected or broken from the comet which piece then broke up energetically 1.5 days later, or the dust cloud was ejected and that non-gravitational forces during the next 1.5 days accelerated the cloud to the uniform velocity seen in Figure 8.

Acknowledgements

I would like to acknowledge the assistance of the following individuals:

- Seiichi Yoshida who maintains an excellent web site as a source on a wide variety of comet information http://www.aerith.net/comet/catalog/0017P/2007.html
- Richard Miles of the BAA who shared ideas, comments, and a draft of his Comet Holmes paper
- Rolando Ligustri who kindly provided excellent quality images from the early days of the outburst.