Feature Story:

The Synodic Rotation Period of Comet 17/P Holmes

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Abstract

Comet 17P/ Holmes was observed in October and November 2007, after the brightness outburst of 24 October. Approximately 11.5 hours of data were collected. A time series analysis reveals a periodicity of 6.29 ± 0.01 hour in the brightness of the inner coma with a single-peak light curve. The object probably has an extremely active area in the nucleus. Therefore, the synodic rotation period is probably equal to the 6.29-hour the periodicity that we found.

Introduction

Comet 17P/Holmes, a comet of the Jupiter family, was chosen as the target of this investigation due to its outburst of October 24, 2007. In this event, the object changed its magnitude from V ~17 to V ~2.5 in approximately two days. This magnitude variation was at least 100 times greater than any of those that have been occasionally observed in other comets of the Jupiter family (Miles, 2007.) A similar tremendous outburst gave opportunity for the initial discovery of this comet by Edwin Holmes in London on November 6, 1892. At that time, the comet had passed perihelion approximately five months earlier (T = June 13). The present event occurred nearly six months after perihelion passage (T = May 4 2007.)

Outbursts of such magnitude, though uncommon, are well documented in the literature and may or may not be associated with nuclear fragmentation (Boehnhardt, 2002). In the case of 17P/Holmes, Montalto, *et al* (2008) estimated the loss of mass from the nucleus at one percent of its total mass and concluded that the outburst may have been associated with an event of disintegration of the nucleus. Miles (2007) suggested that the outburst may be due to heterogeneity on a large scale in the nucleus of the object. In his model, the nucleus possesses a mantle rich in water in which there are isolated agglomerates that are rich in metal, especially iron. Such composition might enable hydrogen peroxide to form slowly, and later undergo explosive catalytic decomposition. He proposed that such rapid decomposition is the origin of the outbursts observed in 17P/Holmes and other short period comets.

Table 1: Observational Geometric Circumstances of Comet 17P/Holmes

UT date	Δ	r	Ecliptic Longitude	Phase Angle
Oct. 27	1.630	2.447	53.1°	16.3°
Oct. 28	1.628	2.451	53.4°	16.0°
Nov. 2	1.622	2.471	54.9°	14.8°
Nov. 4	1.621	2.478	55.4°	14.3°
Nov. 11	1.623	2.506	57.5°	12.8°

Δ is the distance from Earth in AU.
r is the distance from the Sun in AU.
Ecliptic Longitude is in degrees.
Phase Angle is the degrees of separation of the Earth and Sun as seen from the comet

Several phenomena of cometary physics, such as the dynamic evolution of the objects, cannot be correctly explained without considering the rotational state of the nucleus (Neishtadt, *et al*, 2002). However, little information about the rotation of active comets is available. Fewer than 20 of the comets of the known cometary dynamical families have had rotational periods calculated accurately.

In general, when near the Sun, the nucleus of a comet is completely hidden by its coma. In this circumstance, periodic variation in the brightness of the inner coma can be linked to the rotation of the nucleus. Such brightness changes are not associated with the variation in the amount of light reflected directly from the nucleus' surface, but rather with the variation of the level of activity of discrete deposits of volatiles that are exposed to solar radiation by the object's rotation (Schleicher, *et al.*, 1998). This assumption seems to be inappropriate for the nuclei of some short period comets, such as 4P/Faye, due to the observed lack of structure in the coma of these objects (Lamy, *et al*, 1996). However, close-up inspection by spacecraft of the nuclei of the comets 1P/Halley and 19P/Borrely clearly revealed non-homogeneity in the activity of volatiles at the surface of the nucleus.

Snodgrass, *et al* (2006) observed 17P/Holmes on two nights in March, 2005, and concluded that the nucleus was inactive at its distance of 4.66 AU from the Sun. They found the R magnitude (the magnitude of the object obtained by Bessel R filter band and then calibrated in the photometric system Kron-Cousins) to be 22.86 ± 0.02, which yielded a nuclear radius of 1.62 ± 0.01 kilometers. They also considered the shape of the nucleus, as follows. If the nucleus is a triaxial ellipsoid with $a \quad b = c$, then a light curve with an amplitude of 0.3 magnitude implies a ratio $a / b \quad 1.3$. This ratio corresponds to a nucleus with dimensions a and b of 1.9 and 1.4 kilometers, assuming a bare (coma-free) nucleus for this object. This hypothesis was tested by calculating the V-R and R-I colour indices in various rota-

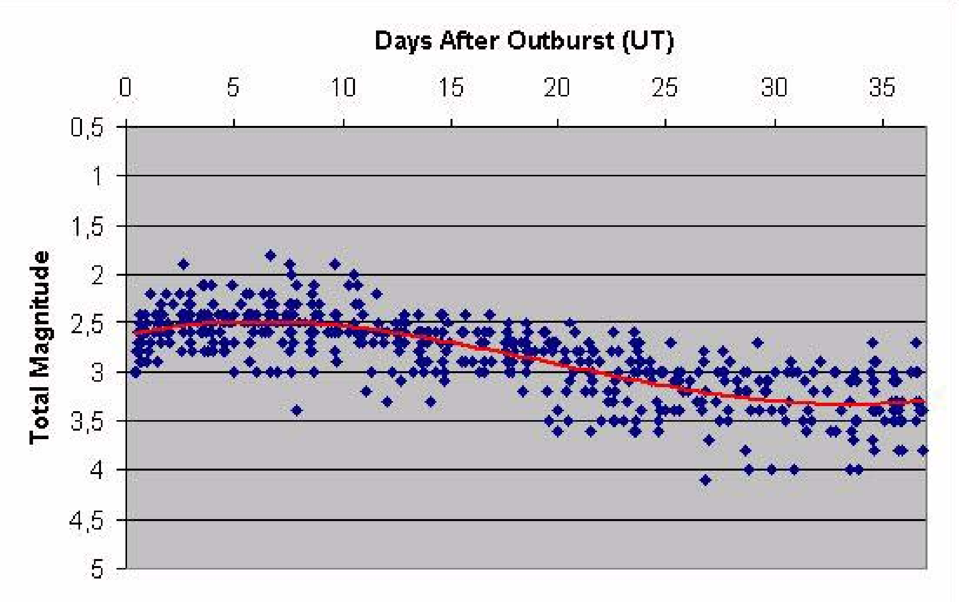

Figure 1. The light curve of 17P/Holmes after the October 24 outburst, as determined by 547 estimates of the total magnitude taken from the International Comet Quarterly database (*http://www.cfa.harvard.edu/icq/CometMags.html*). (Our observations did not contribute to these data.) On the abscissa, the zero point is the fractional date October 24.21 UT, which is the time of the first mention by Kugel in the database of the occurrence of the outburst. The observational period of our study was days 03 through 18. The solid wavy (red) line is a nearest-fit curve of a third degree polynomial. The brightness variations are due to the combination of variation in the intensity of the outburst and the effect of changing distance.

tional phases. The phase-specific color indices revealed evidence of homogeneity in the chemical composition and topography of the surface, implying that the variation in the object's brightness may be caused by variation in the size of the surface the object presented to the observer, that is, rotation. A double-peaked light curve is expected for such an object. An analysis of the photometric data indicated possible periodicities of 3.6, 4.3, 5.2 and 6.4 hours, corresponding to possible rotation periods of 7.2, 8.6, 10.4 and 12.8 hours.

In our observing campaign, photometric observations of the inner coma of 17P/Holmes were carried out. In this study, we assumed that the variations in the flow of the inner coma materials were associated with rotation of the nucleus rather than irregularities in the intensity of the outburst. This assumption appears to be true in view of the slowness of the change in the comet's brightness during the observational period (*Figure 1*.)

Equipment, methods, and observations

The Holmes comet was observed in Salvador, State of Bahia, Brazil, using a 0.3m (12 in.) *f*/3.3 Schmidt-Cassegrain telescope manufactured by Meade, and an ST-7XME CCD camera made by the Santa Barbara Instrument Group (SBIG). The angular scale was 1.8 arc seconds per pixel. The CCD's field of view was 23.5 arc minutes by 15.7 arc minutes. The 523 images obtained in this project were taken with 10-second exposure times through a Bessell V filter. Images were taken continuously at one-minute intervals during the whole of each of the observing sessions. The observations were carried out from UT October 27 to November 11, 2007, during five nights with an interval of 15 days between the first and the last observation.

The Bessell V filter was chosen because it not only transmits most of the wavelengths reflected and emitted by the coma, but also absorbs certain undesirable wavelengths of the background, such as those associated with light pollution (Mikuz and Dintinjana, 1994). The combination of these two factors increased the signal-to-noise ratio (SNR) of the object.

The images were calibrated with median images of bias, dark and dome flat exposures. For the measurement of the instrumental magnitudes of the inner coma and the comparison stars and for the search for periodicities by time series analysis, we used the CANOPUS program by Brian Warner, version 9.3.1.0. The instrumental magnitudes were obtained using aperture photometry.

For each observing session, the diameter of the aperture that we used for aperture photometry was chosen based on our measurement of the size of the seeing disc. We used four times the average value of the FWHM ("Full-Width Half-Maximum") of an unsaturated comparison star that was present in every image of an observing session. For instance, in the observations on UT November 11, 2007, the aperture used was 45 arc seconds. In none of the sessions did the use of this photometric aperture result in contamination by the light of background stars.

[FWHM is used to describe a measurement of the width of an object in a picture when that object does not have sharp edges. The image of a star in an astronomical picture has a profile which is closer to a Gaussian curve. The FWHM can be calculated from this curve that is adjusted to the stellar profile.]

The aperture used to measure the background was placed at a distance from the central condensation of the comet in a way that the flux contamination due to light from the outer coma was equal to zero (i.e., it was unmeasurable.)

During the entire observation period, the seeing varied from 6 to 8 on the ALPO scale (with 0 = worst and 10 = best). The comet's geometric circumstances during the observation period are shown in *Table 1*.

Data and Reductions

Based on the instrumental magnitudes of the inner coma of 17P/Holmes and at least three comparison stars in each observing session, the differential magni-

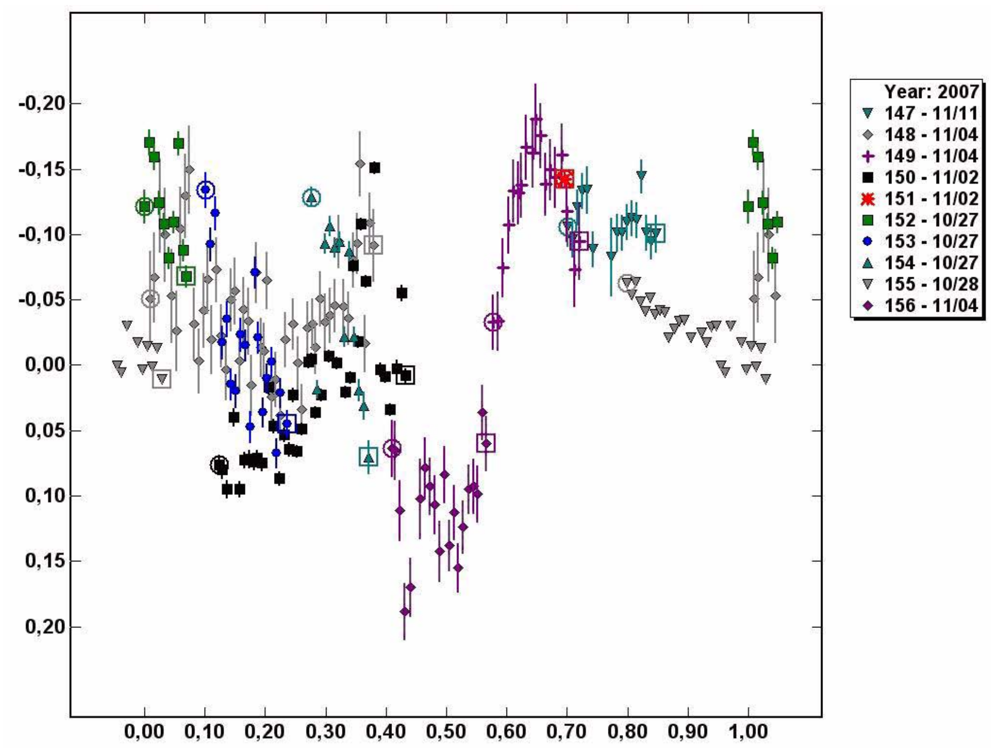

Figure 2. Light curve of Comet 17P/Holmes adjusted based on the periodicity of 6.29h. The phase 0% of the curve corresponds to HJD 2454400.647475 corrected to the light time. This curve has 208 points obtained from the average of three consecutive measurements in the sample. This procedure was applied to reduce the noise level in the lightcurve. In this case, as the number of points in the sample is not divisible by three, the remaining points are still averaged to form a single data point. The box in the figure represents the session of reduction of data in order of entry into the programme Canopus (147, 148, etc...) and the corresponding date of observation.

tude was calculated. Due to discrepancies in the differential magnitudes from one session to another, the session of November 11 was used as a reference. From this session, a factor was added or subtracted from all differential magnitudes of the others nights, this factor being constant for each night but differing from night to night, thus offsetting the differences in scale in order to connect the parts of the light curve of the object. (These differences of differential magnitudes among the sessions are probably due to the slow variation in the intensity of the outburst, rather than due to the nucleus' rotation.) After this correction, the search for periodicity in the 523 differential instrumental magnitudes was done using the Fourier analysis algorithm FALC, developed by Harris, *et al* (1989,) and included in the CANOPUS program.

The solution is unambiguous, with a periodicity of 6.29 ± 0.01 hour in the brightness of the inner coma. In order to arrive at this value, four harmonics in the Fourier series were required, generating a root mean square error of 0.05 magnitudes. A single peak light curve with amplitude of 0.38 ± 0.06 magnitude was obtained from the adjusted data (*Figure 2*.)

Conclusion

Our result of a 6.29 ± 0.01 hour periodicity may be considered in the light of the results of Snodgrass, *et al* (2006), that suggested that the nucleus is elongated when it is inactive, so that a double-peak light curve is expected; as well as the four possible periodicities that Snodgrass's group detected in their data. Thus, we could convert our 6.29 ± 0.01 hour, single-peak periodicity to a synodic rotation period of 12.58 ± 0.02 hours, with two peaks in the light curve. This value would agree with the largest of Snodgrass's periodicities with a measurement error of 1.7%. This difference cannot be attributed to a period modification due to the recent outburst or to a complex rotational state of the nucleus. It is due to an error in the previous estimate of the rotation period, supposedly in the order of 0.1 hour, due to the insufficient sampling of the previous light curve. Our measurement has a smaller theoretical error, and if one accepts the idea that the light curve should have two peaks, it should be used as the best measure to date of the rotation period of Comet 17P/Holmes.

However, it does not appear that a double-peak light curve is appropriate. Furthermore, our data do not adjust well to a period of 12.58 hours. The results obtained by Trigo-Rodríguez, *et al* (2008), and the single peak light curve of this study suggest a single active area of great proportion in the nucleus after the outburst. This active region can account for our light curve's features each 6.29 hours. For a comet with a bright coma, periodicity found in the brightness of the inner coma can be equal to the rotational synodic period of the comet. We conclude that the rotation period of Comet 17P/Holmes is 6.29 ± 0.01 hours.

To the extent that the synodic rotation period is ambiguous, we recommend more observations of this object. Such observations should concentrate on the visualization of coma structures, like shells, fans and jets. The variation of position angle of these structures can be connected with rotation of nucleus. This procedure was used by Pittichová (1997) in the study of the comet IRAS-Araki-Alcock.

Discussion

Insofar as the parameters presented in *Table 1* varied only a small amount during the observation period, the comet was observed in relatively stable geometric circumstances.

The same seeing-related variable aperture scale that we used was previously used by Kidger, *et al* (1998), in the observation of C/1995 O1 (Hale-Bopp). This choice may have been motivated by the observation of time variations in the instrumental magnitudes of objects having extended angular diameters, such as comets, associated with fluctuations in the seeing. The possibility that this phenomenon generates spurious brightness periodicities in comets was suggested later by Licandro, *et al* (2000). Though Licandro's group suggested a corrective method for this effect, this correction was not applied in the present study. Our analysis of the instrumental magnitudes that we obtained suggests that the seeing effect was not observed with our use of these apertures. However, a slight reduction of the signal-to-noise ratio was detected, which implies an increase in the errors of the instrumental magnitudes.

Our careful separation of the background measurement aperture from the light of the coma may have been unnecessary. A comparison of the instrumental magnitudes obtained on UT October 27, 2007 (a few days after the beginning of the outburst,) using one aperture that could have led to contamination by the extended coma and another that could not have done so, revealed a difference of 0.03 magnitude. This error is smaller than the error in the instrumental magnitudes of the comparison stars.

Thus, the error in the instrumental magnitudes caused by possible inclusion in the background of light from the outer coma is insignificant. Furthermore, with the eventual expansion of the outer coma beyond the limits of the CCD field so that the outer coma's brightness was necessarily included in the background, we verified that this contamination decreased to less than 0.03 magnitude, undoubtedly due to the reduction of the coma's surface brightness.

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Comet Holmes as imaged by M. Jäger on 2007 October 31.8 and presented online at ALPO Comet Section Coordinator Gary Kronk's "Cometography" website at *http://cometography.com/pcomets/017p.html*. This image is a combination of three 180-second exposures obtained using a 30-cm Deltagraph, a Sigma 6303 CCD camera, and a blue filter. Although a few overly-processed images from October 29 and 30 hinted at this type of tail, which led to excessive discussion on the internet, this is the first image to conclusively prove its existence. The tail appears extremely short, because the tail is heading almost directly away from our line of sight. Image copyright © 2007 by Michael Jäger (Austria).