A&A 407, L37–L40 (2003)
DOI: 10.1051/0004-6361:20031066

Astronomy & Astrophysics

Letter to the Editor

New spin period determination for comet 6P/d'Arrest

P. J. Gutiérrez[1], J. de León[2], L. Jorda[1], J. Licandro[3], L. M. Lara[4], and P. Lamy[1]

[1] Laboratoire d'Astrophysique de Marseille, BP 8, 13376 Marseille Cedex 12, France
[2] Instituto de Astrofísica de Canarias, C/Via Lactea s/n, 38200 La Laguna, Tenerife, Spain
[3] Isaac Newton Group of Telescopes & Instituto de Astrofísica de Canarias, PO Box 321, 38700 Santa Cruz de La Palma, Tenerife, Spain
[4] Instituto de Astrofísica de Andalucía, CSIC, PO Box 3004, 18080 Granada, Spain

Received 22 May 2003 / Accepted 3 July 2003

Abstract. A lightcurve of comet 6P/d'Arrest from *R*-band CCD images taken at La Palma 2.52 m NOT telescope is presented. The lightcurve shows noticeable periodic changes in brightness produced by rotational modulation. The periodogram analysis of the lightcurve shows a peak with a confidence level exceeding 99.9% at 3.336 h. Assuming an elongated nucleus, the most likely spin period is therefore 6.67 ± 0.03 h, but other periodicities are also possible. The peak to peak amplitude is 0.082 ± 0.016 mag. This period, and the other peaks detected in the periodogram, are not commensurable with previous estimates of the spin period of comet 6P/d'Arrest. If all the measurements are correct, the differences between this estimate and the previous ones could be due to a possible change in the spin period of comet 6P/d'Arrest or to this comet being rotating in a complex mode.

Key words. comets: individual: 6P/d'Arrest

1. Introduction

The knowledge of the rotational state of cometary nuclei is necessary for the correct interpretation of many observational data. Moreover, cometary spin parameters can help to understand the internal structure of nuclei and it may seed some light into their formation processes. So far, approximately only 15 cometary spin periods are reliably known (Jorda & Gutiérrez 2002) and only a few spin axis orientations have been estimated. An additional difficulty concerning rotational parameters of comets is that they may evolve or change during the lifetime of the comet due to the outgassing-induced torque. This was first pointed out by Whipple (1950) in his historical paper. More recently, Samarasinha et al. (1986), using an approximate description, obtained the timescale for a change in the angular momentum. They also pointed out that 1P/Halley's spin period could have changed since its 1910 apparition. Recent modeling of the evolution of the rotational parameters simulating the outgassing-induced torque shows that these changes are indeed very likely, at least for relatively small cometary nuclei (e.g. Samarasinha et al. 1996; Neishtadt et al. 2002; Gutiérrez et al. 2003). Another potential effect of the outgassing-induced torque is that it can lead the nucleus to rotate in a complex mode. So far, the only confirmed comet rotating in a complex mode is comet 1P/Halley (e.g., Belton 1991).

Send offprint requests to: P. J. Gutiérrez,
e-mail: pedro.gutierrez@oamp.fr

Given the importance of the rotational parameters, strong observational efforts should be addressed in order to increase the database of cometary rotational parameters and to determine possible variations of these parameters. Under these aims, we have carried out observations of comet 6P/d'Arrest, after its last perihelion passage. 6P/d'Arrest was one of the best observable candidates during the second half of 2002 from the Northern hemisphere. Moreover, at the time of the observational proposal, this comet was one of the targets of NASA's Contour space mission.

As reported in Belton (1991), some early estimates of the spin period of this comet seem to be in conflict. The last published spin period determination was performed by Lowry & Weissman (2003). These authors observed the comet when it was inactive, at 2.83 AU from the Sun in the pre-perihelion branch of its last orbit. From their analysis, they deduced a spin period of 7.20 ± 0.12 h (assuming a double-peaked lightcurve). This spin period seems to be also in conflict with the previous ones.

2. Observations and data reduction

Optical observations were taken on 2002 December 6–7–8 at La Palma 2.52 m Nordic Optical Telescope with the ALFOSC instrument. The CCD detector was a Loral/Lesser 2048 by 2048 pixels chip, with a pixel scale of 0.188 arcsec. Images were obtained through standard Bessell filters. The seeing (FWHM) varied from 1.2 to 1.6 arcsec.

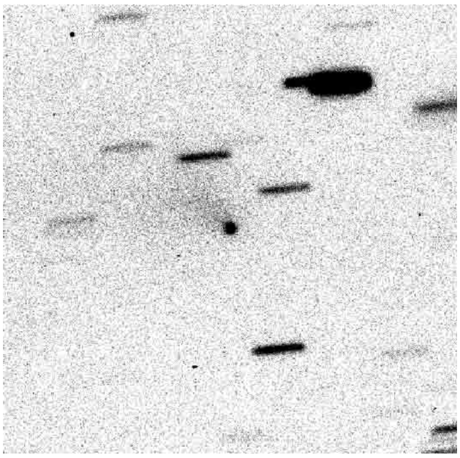

Fig. 1. Individual CCD image of comet 6P/d'Arrest observed at the 2.52 m NOT telescope (Canary Islands) on Dec. 7th, 2002 at 23:17 UT through a broadband R filter. The exposure time is 900 s.

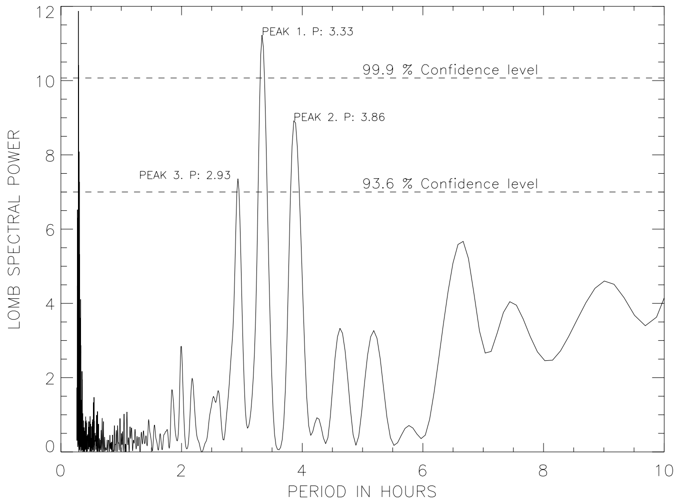

Fig. 2. Lomb spectral power of the lightcurve data in Table 1. The periodogram shows two very high confident peaks at 3.33 h and 3.86 h.

The exposures times were 15 min and comet tracking was used. The airmass of the observations ranges from 1.15 to 2. The reduction of the data was carried out following standard procedures of average bias subtraction and flatfield correction. The CCD bias level was determined from an overclocked region of the frame. Flatfield calibration was performed by median averaging a large number of high signal-to-noise images of the twilight sky. Two techniques (PSF fit and partial derivatives) were used to find the optocenter and several synthetic apertures, ranging from 4 to 20 pixels in radius, were used to extract the flux of the comet. Images of the comet photometrically affected by bad columns or field stars were rejected from the analysis. The sky level was calculated from a statistical analysis of a 200 by 200 pixels window centered at the comet in order to avoid possible coma contamination. The effective airmass for each comet image was calculated from an integration of instantaneous airmasses during the exposure. Absolute calibration of the data was obtained by using observations of several Landolt's (1992) fields. Two linear fit methods (least absolute deviation and least squares) were used to extract the atmospheric extinction and zero point parameters. Both methods gave similar sets of coefficients.

At the time of the observations, comet 6P/d'Arrest was at 3.15 AU from the Sun (post-perihelion) and at 2.24 AU from the Earth. The phase angle was 7.6 deg. A quick image analysis shows that a small coma was present. We have estimated the $Af\rho$ parameter of comet 6P/d'Arrest from the analysis of brightness profiles of images obtained during the three nights of observation. We considered only pixel values at $\rho > 12$ pixels to avoid the nucleus contribution. We find a value of $Af\rho = 2.2 \pm 0.1$ cm compatible with previous estimates (Sanzovo et al. 2001; Lowry & Fitzsimmoms 2001).

3. Results and discussion

The magnitude of the nuclear region was obtained using different apertures, in order to study the possible effect of seeing variations on the aperture photometry. Table 1 contains the data corresponding to the 15–pixels (2.8 arcsec) aperture lightcurve of 6P/d'Arrest. The effect of seeing variations on the integrated magnitudes was evaluated following Licandro et al.'s (2000) procedure for the range of seeing values measured on the images. For a 15–pixels diaphragm, the effect of the seeing variation is lower than 0.005 mag, which is smaller than the error of the magnitude determination. We have also checked for a possible correlation between the seeing and the comet magnitude. Six field stars were used to estimate the mean FWHM in each cometary image. The Pearson coefficient of the pairs (FWHM, comet magnitude) was −0.17 indicating that there is no such correlation.

The data of Table 1 and the data obtained with the other apertures were carefully analyzed using several spectral analysis techniques: Lomb (1976), PDM (Stellingwerf 1978), and

Table 1. Photometry of 6P/d'Arrest. *R* magnitude measured for an aperture of 15 pixels.

JD	*R* mag	1–σ	JD	*R* mag	1–σ
0.5357	20.25	0.03	1.6574	20.28	0.04
0.6035	20.18	0.03	1.6688	20.27	0.04
0.6150	20.18	0.03	1.6803	20.26	0.04
0.6264	20.18	0.04	1.6930	20.23	0.04
0.6501	20.21	0.04	2.4419	20.24	0.04
0.6833	20.28	0.04	2.4657	20.23	0.04
1.4337	20.14	0.04	2.4771	20.25	0.04
1.4469	20.15	0.08	2.4885	20.22	0.04
1.4583	20.15	0.04	2.5012	20.26	0.04
1.4701	20.18	0.04	2.5126	20.25	0.04
1.4816	20.20	0.04	2.5240	20.24	0.03
1.4941	20.25	0.04	2.5355	20.22	0.03
1.5055	20.24	0.04	2.5469	20.20	0.03
1.5169	20.23	0.04	2.5913	20.25	0.03
1.5284	20.24	0.03	2.6027	20.24	0.03
1.5652	20.22	0.03	2.6370	20.30	0.04
1.5766	20.22	0.03	2.6497	20.27	0.04
1.6206	20.24	0.03	2.6611	20.24	0.04
1.6321	20.25	0.04	2.6749	20.27	0.04
1.6460	20.31	0.04			

JD = Julian date – 2452615.0.

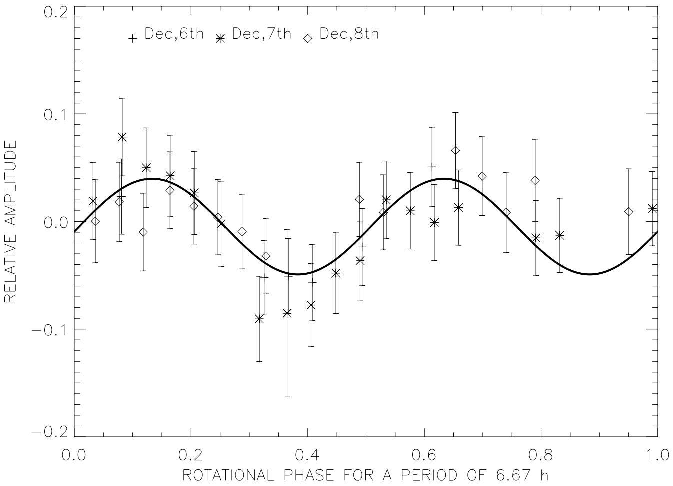

Fig. 3. Observed relative magnitudes phased to a period of 6.67 h. Different symbols correspond to different nights of observation. The continuous line is a sinusoidal fit of the data. The observed magnitude corresponds to the signal integrated in a circular diaphragm of 2.8 arcsec radius centered at the optocenter.

a Fourier analysis. The results obtained with all these techniques were fully consistent. In Fig. 2, the Lomb periodogram for the data of Table 1 is shown. The periodogram shows one peak with a confidence level larger than 99.9% (which was estimated with the procedure described in Press et al. 1992) located at 3.336 h (7.19 cycles/day). This peak is flanked by two another peaks located at 3.86 h (6.21 cycles/day) and at 2.93 h (8.19 cycles/day) which are probably daily aliases of the first frequency. In the periodogram we also detect a relatively strong peak at 6.67 h, which is twice the period corresponding to the most significant peak. The remaining peaks are aliases of the most significant frequency or of its half.

We have estimated the coma contribution in a diaphragm of 15 pix using the value of the $Af\rho$ parameter determined from radial profiles. The value amounts to only 20%, allowing us to assume that the observed brightness variation corresponds to rotational variations of the nucleus photometric cross-section[1]. This leads to double-peaked rotational lightcurves if the nucleus is elongated. Thus, according to the periodogram, and assuming a double peaked lightcurve, the most likely periodicity is 6.67 ± 0.03 h. In Fig. 3, we see that this period produces an acceptable double-peaked lightcurve. The peak-to-peak amplitude is 0.082 ± 0.016 mag (1–σ error). The 1–σ errors have been calculated with a Monte Carlo method. Nevertheless, 5.86 h and 7.72 h (twice the other significant periodicities found in the periodogram) also produce acceptable double-peaked curves and therefore they cannot be totally discarded as possible periodicities associated with the rotation of 6P/d'Arrest.

3.1. Previous spin period estimates

Fay & Wisniewski (1978) (henceforth F&W) performed time-resolved photometry of comet 6P/d'Arrest during its perihelion of 1975. Their periodogram showed that the most confident peak was at 5.17 ± 0.01 h but other peaks were present. Nevertheless, Leibowitz & Brosch (1986), reanalyzing the data published by F&W with a different period analysis technique, found two groups of peaks. The most significant peak in the first group was located at 1.3 h. This group is presumably produced by the sampling of the lightcurve. In the second group, the highest peak was at 4.17 h. This peak was also present in the periodogram by F&W but with a confidence level lower than that of 5.17 h. We have also reanalyzed the data published by F&W with different techniques. The Lomb technique gives a periodogram similar to that of Leibowitz & Brosch (1986). There are two groups of peaks, one around the peak at 1.3 h and another one with its most significant peak located at 4.18 h, both with a confidence level larger than 99.99%. In the second group, other peaks with a similar confidence level are located at 5.11 h (99.98%), which is close to the periodicity reported by F&W, and at 3.53 h (99.98%), which is also very close to a significant peak in the periodogram showed by F&W. All the curves phased to these periods appear to be very noisy and none of them exhibits a double-peak pattern. Therefore, we cannot conclude which peak is the best candidate for the nucleus spin period.

As mentioned above, Lowry & Weissman (2003) (henceforth L&W) also performed time resolved photometry of P/d'Arrest before its last perihelion passage. They found a series of peaks with very similar significance levels located at 3.60 h, 4.20 h, and 5.10 h (ordered by significance level) using the PDM technique. They concluded that the nucleus spin period could possibly be 7.20 h. We have reanalyzed the data of L&W with other techniques. With the Lomb technique, the relative spectral power of the peaks is slightly different. The highest peak is at 4.16 h, with a confidence level of 96.1%. The second peak is located at 5.11 h (93.1%) and the third peak is at 3.61 h (91.8%). Interestingly, the two first peaks are nearly coincident with the two main peaks obtained in our analysis of the data published by F&W. The three periods give reasonable single-peaked curves but the number of data is insufficient to cover a double-peaked rotational curve. Thus, our analysis is again inconclusive regarding the most likely spin period of comet P/d'Arrest from L&W's data.

The most significant peaks obtained from our lightcurve, i.e. 3.33 h, 3.86 h, and 2.93 h are different and non-commensurable with the most significant periodicities found from the data published by F&W and L&W, i.e. 4.16 h, 5.11 h and 3.53–3.61 h. Synodic effects can not explain the large differences. At present, we have no final explanation for the differences in the main frequencies detected in the three periodograms. A first explanation could be that the modulus of the angular momentum has changed, at least, during the last apparition. Such a change can be triggered by the outgassing induced torque or by a partial fragmentation of the nucleus.

If the spin period of comet d'Arrest is actually associated to the periodicities reported by F&W and L&W, i.e. 5.17 h in

[1] We have also checked that the size of the nucleus estimated from the 80% of the total flux measured is in agreement with previous size estimates (Tancredi et al. 2000, and references in Lamy et al. 2004).

1975, 3.60 h in 2001 and to our highest peak after its last perihelion passage, i.e. 3.33 h, the outgassing induced torque could indeed be a very satisfactory explanation. These variabilities could imply that the spin velocity has changed nearly by the same quantity during the last 5 perihelion passages. This behavior is expected to be typical for a nucleus with a small active fraction like P/d'Arrest, regardless if it is rotating in a complex or principal axis mode (Gutiérrez et al. 2003). Numerical simulations indicate that, given the size and water production of comet P/d'Arrest, the outgassing-induced torque could indeed produce such an evolution of the spin period for typical values of the nucleus density. On the contrary, if the actual spin period is associated to the most significant peaks we find after reanalyzing the data published by F&W and L&W, i.e. ~4.17 h both in 1975 and in 2001, the outgassing is not a very likely explanation for the variation. A small fragmentation of the nucleus could have modified the angular momentum during the last perihelion passage.

Another possible explanation for the differences could be that the nucleus is rotating in a non-principal axis mode. The presence of two peaks at 5.11 h (with a very low confidence level in our periodogram) and around 6.60 h in the three Lomb periodograms supports this possibility. In most cases, the periodogram of the lightcurve of a body rotating in complex mode shows preferably the peaks corresponding to a combination of the precession and rotation frequencies and the peaks associated to the precession frequency. However, several peaks corresponding to the rotation frequency can also appear.

In any case, all of these possible explanations are highly speculative and a detailed study, beyond the scope of this paper, should be carried out in order to possibly reconcile all the observations. We will perform numerical simulations in the future in order to explore all the possibilities.

4. Summary and conclusions

A lightcurve of comet 6P/d'Arrest has been deduced from CCD images. The lightcurve shows noticeable periodic changes in brightness, presumably produced by rotational modulation. The periodogram analysis of the lightcurve shows a peak at 3.33 h with a confidence level >99.9%, flanked by two possible aliases located at 2.93 h and 3.86 h. Assuming a double-peaked lightcurve, the most likely spin period of P/d'Arrest is 6.67 ± 0.03 h, but other possibilities cannot be totally ruled out. The main detected periodicities are different and non commensurable with the previous spin period estimates by Lowry & Weissman (2003) and by Fay & Wisniewski (1978). If our present determination is correct, the difference could be due to a change in the angular momentum of the comet, at least during its last perihelion passage, or to an excited rotational state. Further observations are needed to constrain the rotational parameters of this comet and its possible temporal evolution.

Acknowledgements. Based on observations made with the Nordic Optical Telescope, operated on the island of La Palma jointly by Denmark, Finland, Iceland, Norway, and Sweden, in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofísica de Canarias. PJG is currently supported by an ESA External Research Fellowship. We wish to thank the referee for very valuable comments.

References

Belton, M. J. S. 1991, in Comets in the Post-Halley Era, ed. R. L. Newburn, M. Newgebauer, & J. Rahe (Dordrecht: Kluwer), 691
Fay, T. D., & Wisniewski, W. 1978, Icarus, 34, 1
Gutiérrez, P. J., Jorda, L., Ortiz, J. L., & Rodrigo, R. 2003, A&A, 406, 1123
Jorda, L., & Gutiérrez, P. J. 2002, EM&P, 90, 135
Landolt, A. U. 1992, AJ, 104, 340
Lamy, P., Tóth, I., Weaver, H., & Fernández, Y. 2004, in Comets II, ed. M. Festou et al. (Tucson: Univ. of Arizona), in press
Leibowitz, E. M., & Brosch, N. 1986, Icarus, 68, 430
Licandro, J., Serra-Ricart, M., Oscoz, A., et al. 2000, AJ, 119, 3133
Lomb, N. R. 1976, Astroph. Space Sci., 39, 447
Lowry, S. C., & Fitzsmmons, A. 2001, A&A, 365, 204
Lowry, S. C., & Weissman, P. R. 2003, Icarus, in press
Neishtadt, A. I., Scheeres, D. J., Sidorenko, V. V., & Vasiliev, A. A. 2002, Icarus, 157, 205
Press, W. H., Teukolsky, S. A., Vetterling, W. T., & Flannery, B. P. 1992, in Numerical Recipes in Fortran, 2nd ed. (London: Cambridge Univ. Press), 569
Samarasinha, N., A'Hearn, M. F., Hoban, S., & Klingesmith, D. A. 1986, in 20th ESLAB Symposium on the Exploration of Halley's comet. Heidelber, Germany, ESA–SP, 250, 1, 487
Samarasinha, N., Mueller, B. E. A., & Belton, M. J. S. 1996, Planet. Space Sci., 44, 275
Sanzovo, G. C., de Almeida, A. A., Misra, A., et al. 2001, MNRAS, 326, 852
Stellingwerf, R. F. 1978, ApJ, 224, 953
Tancredi, G., Fernández, J. A., Rickman, H., & Licandro, J. 2000, A&AS, 146, 73
Whipple, F. 1950, ApJ, 111, 375