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A rapid decrease in the rotation rate of comet 41P/Tuttle–Giacobini–Kresák

Dennis Bodewits[1], Tony L. Farnham[1], Michael S. P. Kelley[1] & Matthew M. Knight[1]

Cometary outgassing can produce torques that change the spin state of the cometary nucleus, which in turn influences the evolution and lifetime of the comet[1,2]. If these torques increase the rate of rotation to the extent that centripetal forces exceed the material strength of the nucleus, the comet can fragment[3]. Torques that slow down the rotation can cause the spin state to become unstable, but if the torques persist the nucleus can eventually reorient itself and the rotation rate can increase again[4]. Simulations predict that most comets go through a short phase of rapid changes in spin state, after which changes occur gradually over longer times[5]. Here we report observations of comet 41P/Tuttle–Giacobini–Kresák during its close approach to Earth (0.142 astronomical units, approximately 21 million kilometres, on 1 April 2017) that reveal a rapid decrease in rotation rate. Between March and May 2017, the apparent rotation period of the nucleus increased from 20 hours to more than 46 hours—a rate of change of more than an order of magnitude larger than has hitherto been measured. This phenomenon must have been caused by the gas emission from the comet aligning in such a way that it produced an anomalously strong torque that slowed the spin rate of the nucleus. The behaviour of comet 41P/Tuttle–Giacobini–Kresák suggests that it is in a distinct evolutionary state and that its rotation may be approaching the point of instability.

The combination of close approach, brightness and large solar elongation of comet 41P/Tuttle–Giacobini–Kresák (hereafter 41P) made it the target of observations worldwide for several months. We report results from our observations of comet 41P obtained in March 2017 using the Large Monolithic Imager on Lowell Observatory's 4.3-m Discovery Channel Telescope (DCT) and in May 2017 using the UltraViolet–Optical Telescope (UVOT) on board the Earth-orbiting Swift Gamma Ray Burst Mission[6] (Extended Data Table 1).

We used comet-specific narrowband filters[7] on the DCT to capture the emission of cyanogen gas. Cyanogen coma structures have been used to infer rotational properties of otherwise unobservable comet nuclei since their discovery in comet 1P/Halley[8]. Volatile ices at or near the surface of a comet sublimate when exposed to sunlight during the diurnal cycle of the comet. As the gas moves outwards, it and daughter species produced by photodissociation trace spirals or arcs that can be used to infer the rotation of the comet. Cyanogen is one of the most effective gases in this respect, owing to its large fluorescence efficiency in sunlight. Its use is widespread[9] and its connection to the rotation of comet nuclei has been verified by *in situ* missions such as EPOXI[10]. During our first epoch of observations (Extended Data Table 2), we identified rotating spiral arms, of which one is persistent whereas a second is visible for only part of the rotation (Fig. 1). The repetition of these features indicates a rotation period of 19.75–20.05 h during 6–9 March[11].

For our second epoch, we adopted a photometric technique, using variations in the brightness of the comet to measure periodicity. Although these two techniques measure different characteristics, they both identify repetitions in their respective phenomena and we assume that the associated periodicity reflects the rotation of the nucleus. We used Swift/UVOT to observe comet 41P on 7–9 May 2017 and measured all of the light within 1,600 km of the nucleus, including molecular emissions and sunlight reflected by dust grains. The light contributed by the small nucleus was negligible during this time, indicating that variations in brightness in our aperture were dominated by the material that had recently been released from the nucleus. The photometric variations are small and slowly varying (Fig. 2, Extended Data Table 2). Although the light curve is incomplete, the unobserved parts can reasonably be inferred, resulting in a single-peaked sinusoid (the hallmark of activity being modulated by changes in illumination induced by rotation) with a period of 46–60 h. The 14-h range arises because the alignment of the overlapping segment of the phased sine curve is affected by changes in the activity of the comet with its increasing distance to the Sun. We therefore conclude that during the two months of our observations, there was a substantial change in the rotation period, with an average increase of 0.40–0.67 h per day. For the discussion presented here, we adopt 53 h, the middle of our range, as our representative period.

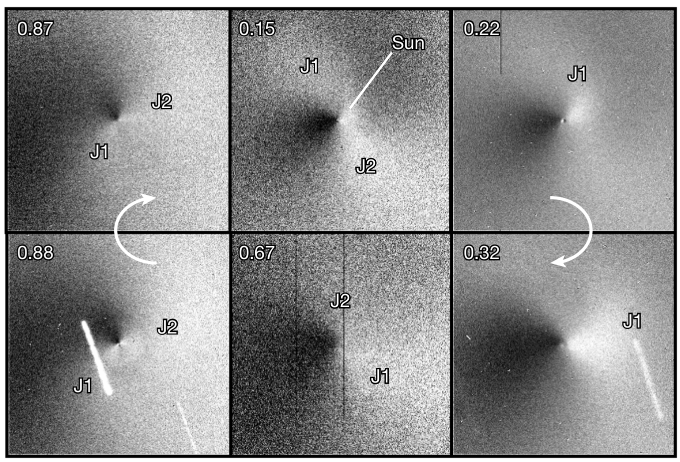

Figure 1 | Repeating cyanogen jets in the coma of comet 41P/Tuttle–Giacobini–Kresák. Sequence of DCT images showing the cyanogen coma of comet 41P, enhanced to reveal two rotating jets (labelled J1 and J2). The images, obtained on 7 and 8 March 2017, progress in a clockwise direction, as indicated by the curved arrows. Nearly identical morphologies are seen in the left two panels, which were obtained 20.1 h apart, and the sequence suggests that these two images are slightly more than one full rotation apart, leading to the derived 19.9-h period. The other panels, labelled in the upper left corner with the fraction of the period (phase) when the image was obtained, show a continuously changing morphology that precludes any periods that are sub-multiples of the 19.9-h derived value. Each panel spans approximately 20,000 km at the distance of the comet, is centred on the position of the nucleus (too small to be resolved), and is oriented with north up and east to the left. The direction to the Sun is indicated in the middle-top panel. Images were enhanced by dividing out the averaged azimuthal profile. Regions that are brighter than average at that distance from the nucleus are white and regions that are fainter are black. The white streaks are background stars.

[1]Department of Astronomy, University of Maryland, College Park, Maryland 20742, USA.