METHODS

Photometry. Swift/UVOT observations were obtained with the V-band filter, centred at 547 nm with a full-width at half-maximum (FWHM) of 75 nm. We measured the brightness of the coma using photometry extracted from a circular aperture centred on the nucleus with a 1,600-km (10–11-arcsec) radius at the distance of the comet. The median background flux was determined from an annulus with an inner radius of 50 arcsec and an outer radius of 100 arcsec (beyond the visible extent of the coma). We followed a standard calibration procedure[24] to derive the apparent magnitudes, V. These were then converted into absolute magnitudes, H, at 1 AU to account for changes in the geocentric distance Δ, heliocentric distance r_h and phase angle PA (using a phase function normalized to a phase angle of 90°, PA(90))[25] of the comet during our observation using the relation:

$$H = V - 5\log(\Delta) - 5\log(r_h) - 2.5\log[\mathrm{PA}/\mathrm{PA}(90)] \quad (1)$$

The relation between the activity of the comet and its heliocentric distance, which increased from 1.099 AU to 1.108 AU during the Swift observations, is currently not well constrained. This implies that a range of scale factors A are possible for the activity-corrected brightness H' of the comet:

$$H' = H - A\log(r_h/r_0) \quad (2)$$

where r_0 is the heliocentric distance of the comet at the first Swift observation (1.099 AU). Larger scale factors imply longer rotation periods. We considered scale factors of $A = 0$ (an r_h^2 relation; see equation (1)), $A = 28$ (an early empirical fit to the current brightness trend[26]), and an upper limit of $A = 35$ (derived from an empirical fit to the brightness trend during the apparitions of 1995 and 2001[26]). As is shown in Extended Data Fig. 2, this results in a range of possible periods of repetition between 46 h and 60 h, with a central solution around 53 h ($A = 17$). Independent of the r_h correction, periods shorter than 46 h are not possible with our light curve (under our assumptions of simple rotation and no outburst or other unusual activity).

There are too few measurements with the DCT to construct a meaningful light curve, and the night of 8 March was not photometric (owing to Cirrus clouds); consequently, our observations focus on morphology rather than absolute measurements.

Production rates. We used Swift/UVOT images to determine water production rates following a previously outlined method[24]. The UVW1 filter (central wavelength, 260 nm; FWHM, 70 nm) encompasses the three strong OH A–X transitions. We first created stacks containing all UVW1 images and V-band images acquired on 4–9 May 2017 using a clipped mean routine. We then removed the continuum contribution to the light measured with this filter by subtracting a weighted V-band image. There was no obvious repetitive morphology in the OH images. Fluxes in apertures with radii of 5–300 arcsec (775–46,500 km at the comet) were converted into OH column densities assuming fluorescence rates at the heliocentric velocity and distance of the comet[27]. Production rates were derived using a vectorial model[28].

Active area. We derived the minimum active area corresponding to the measured water production rate using a sublimation model[29]. We assume that every surface element has constant solar elevation—as would be the case if the spin axis were pointed at the Sun (an obliquity of 90 degrees) or if the nucleus were rotating very slowly—and is therefore in local, instantaneous equilibrium with sunlight. This maximizes the sublimation averaged over the entire surface and results in a minimum total active area. We further assumed a Bond albedo of 0.02 and 100% infrared emissivity. The modelled H_2O sublimation rate is 3.35×10^{17} molecules per cm^2 at 1.05 AU. Assuming a peak water production rate of 2×10^{28} molecules per second (Extended Data Fig. 1), we find an active area of at least 6 km^2, equivalent to an active fraction of 50%–97% of a spherical nucleus with a radius of 0.7–1 km.

Modelling the change in rotation period. To extrapolate the rotation period of comet 41P to past and future apparitions we used the relation between the rate of change of the angular velocity dω/dt, the water mass loss rate Q and the radius of the nucleus R (ref. 18):

$$\frac{d\omega}{dt} = C\frac{Q(t)}{R^4} \quad (3)$$

We assumed a nucleus with a radius of 0.7 km and used our measurements of the production rate and the average change of rotation period during the current apparition to determine the constant C empirically. To estimate the orbital gas mass loss, we fitted the empirical relation between the brightness of the comet and its heliocentric distance ($Q \propto r_h^{-4.8}$) to the SOHO measurements of water production rates during the 2006 apparition[15]. We assumed abundances of 10% for both CO and CO_2 relative to water, and that activity beyond 3 AU is negligible. When the nucleus reaches a rotation frequency of 0, the period is infinite, hence the growth off the top of Fig. 4. At this point in the model, the rotation reverses (rotational pole flip) and the period decreases from infinity. However, in reality the rotation will become excited, the illumination on the surface will change and the torques should also change.

Integrating the gas production rates from 3 AU before to 3 AU after perihelion results in a mass loss rate of 6×10^9 kg in volatiles per orbit, or about 1% of the mass of the nucleus for a density of 500 kg m^{-3}.

Rotation evolution models[5] assume a certain initial spin state and evolution is modelled for 10–100 orbits. Comet 41P has orbited the Sun approximately 30 times since its discovery in 1858. After considering several scenarios, hyperbolic evolution after 10–30 orbits was concluded previously, with the spin states of the comets evolving continuously throughout the simulations[5]. However, these models[5] did not explore the full parameter space[4] and we are hesitant to imply a more quantitative interpretation of them.

Data availability. All Swift/UVOT data are available from the Barbara A. Mikulski Archive for Space Telescopes (https://archive.stsci.edu) and from the Swift Archive Portal (http://www.swift.ac.uk/swift_portal/) under programme ID 1316125. The photometric measurements are provided as Source Data for Fig. 2. Other data that support the findings of this study are available from the corresponding author on reasonable request.

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