doi:10.1038/nature09456

P/2010 A2 was observed using the Hubble Space Telescope and its Wide Field Camera 3 (WFC3) on eight occasions between 2010 January 25 and May 29 (Supplement Table 1) under Director's Discretionary Time proposals 12053 and 12077. During this time, the geocentric distance increased by a factor of 2, while the Earth moved from beneath the plane of the orbit to above it. These changes affect the spatial resolution of the data and the perspective from which P/2010 A2 was viewed, providing extra constraints on the orientation of the dust tail relative to the orbit.

Within each HST orbit, we obtained typically five separate images of P/2010 A2. Individual images from WFC3 were bias subtracted and flat-fielded according to standard procedures. The images from each orbit were combined in such a way as to improve the signal-to-noise ratio of the data on this very faint target, and to identify and reject cosmic rays using "drizzle" software. Trailed images of background stars and galaxies were also removed where possible. In a few cases, images of the nucleus region were severely compromised by cosmic rays or other artifacts. These images were rejected from further analysis.

The image scale on WFC3 is 0.0396 arcseconds per pixel. Photometry of the main nucleus, N, was obtained using a synthetic aperture with a projected radius of 5 pixels, while the sky background was estimated from the median of the pixel values in a concentric annulus having inner and outer radii of 5 and 13 pixels. Experiments showed that measurements with smaller photometry apertures under-estimated the flux from the nucleus while larger apertures were more susceptible to sky noise and contamination by background objects (Supplementary Table 2). We scaled the apparent V magnitudes to unit heliocentric and geocentric distances, R and Δ, respectively, and to zero phase angle, α, using

$$V(1,1,0) = V - 5log_{10}(R\Delta) - f(\alpha) \qquad (1)$$

where $f(\alpha)$ is the phase function of S-type asteroids[20]. Calculation of the nucleus radius was made using the inverse square law, expressed as

$$r_e = \frac{1.5 \times 10^{11}}{p_V^{1/2}} 10^{0.2[V_{\odot} - V(1,1,0)]} \qquad (2)$$

in which $V_{\odot}$ = -26.75 is the V magnitude of the Sun. We took $p_V = 0.15$ as the representative V-band geometric albedo of the nucleus, as appropriate for S-type asteroids. The resulting median value of the nucleus radius is r_e = 60 m (Table 2), with scatter around this value consistent with variation caused by rotation of an aspherical body and photometric uncertainties. The unknown albedo is the main source of uncertainty in the radius of the nucleus.

The albedo is unlikely to be lower or higher by a factor of 4 (corresponding to the albedo of a C-type asteroid or an icy body, respectively), showing that the radius is probably accurate to better than a factor of two. The phase function of the nucleus is also unmeasured, but its likely effect on the derived radius is comparatively small.

We measured the optical flux from the tail within boxes of fixed angular size, as a function of distance from the nucleus. The vertical size of the boxes was larger than the visible width of the tail. We translated the nucleus distance to the radiation pressure coefficient β through the linear relationship obtained from the synchrone belonging to emission on 2 March 2009. For particles with $\beta > 3{\times}10^{-5}$, the resulting surface brightness profile corresponds to a particle differential size distribution index α =-3.3±0.2 (see also ref. 11), with no apparent change in α with time.

We took photometric measurements of the tail using a rectangular aperture having fixed dimensions 28,710×7,180 km at the comet (Supplementary Table 3) and scaled them for the changing geometry as we did for the nucleus. The sum of the cross-sections of the tail dust particles is equal to the area of a circle of radius r_e = 2100 m, assuming albedo 0.15, and r_e may decline slowly with time (Table 3). The mass of this dust, if composed of material having density $\rho = 3000$ kg m^{-3}, is $M = 4/3\pi\rho\overline{a}r_e^2$, where $\overline{a}$ is the average effective radius of the particles in the tail. We take $\overline{a}$ = (1 to 10) mm to find M = (6 to 60) $\times 10^7$ kg, equivalent to a sphere of the same density and having a radius r_p = 17 to 36 m. [Additional mass may have been carried away in the form of small, fast particles that are now outside the field of view. However, the derived size distribution index is relatively flat and indicates that the total mass of the small particles was probably not significant.]. The principal sources of uncertainty lie in the albedo, which may differ from the assumed $p_V = 0.15$ value and in the possible existence of a small number of large particles which could dominate the mass and yet escape optical detection. In this sense, the optically-derived mass gives a lower limit to the tail mass.

1. Supplementary References

20. Bowell, E., Hapke, B., Domingue, D., Lumme, K., Peltoniemi, J., & Harris, A. W. 1989, Asteroids II, 524

Table 1. Geometry of the Hubble Space Telescope Observations

UT Date	R^{a}	Δ [b]	α^{c}	Scale[d]	Plane[e]
2010-Jan-25	2.018	1.078	11.5	30.96	-1.28
2010-Jan-29	2.019	1.099	13.5	31.56	-0.94
2010-Feb-22	2.034	1.286	23.1	36.93	0.90
2010-Mar-12	2.047	1.473	27.0	42.30	1.82
2010-Apr-02	2.066	1.717	28.8	49.31	2.40
2010-Apr-19	2.083	1.922	28.7	55.20	2.55
2010-May-08	2.105	2.150	27.4	62.15	2.46
2010-May-29	2.130	2.393	25.0	69.18	2.13

[a]Heliocentric distance in AU at the mid-time of the observations.

[b]Geocentric distance in AU at the mid-time of the observations.

[c]Phase angle [degrees] at the mid-time of the observations.

[d]Image scale, kilometers per 0.0396 arcsecond pixel.

[e]Elevation of the Earth above the orbital plane of P/2010 A2, in degrees.

Table 2. Photometry of the Primary Nucleus

UT Date	V [a]	$V(1,1,0)$[b]	r_n[c]
2010-Jan-25	24.70	22.39	58
2010-Jan-29	24.60	22.18	64
2010-Feb-22	24.81	21.76	77
2010-Mar-12	25.77	22.30	60
2010-Apr-02	26.24	22.37	59
2010-Apr-19	26.39	22.25	62
2010-May-08	26.53	22.17	63
2010-May-29	26.71	22.16	64

[a]Apparent V-band magnitude of the nucleus measured within a projected aperture of angular radius 0.2 arcseconds.

[b]Magnitude corrected to unit heliocentric and geocentric distances assuming $R^{-2}\Delta^{-2}$ scaling and to zero phase angle using the phase function of S-type (bright) asteroids. The V magnitude of the Sun was taken to be -26.75.

[c]Nucleus radius in meters computed assuming S-like albedo $p_v = 0.15$

Table 3. Tail Measurements

UT Date	V [a]	$V(1,1,0)$ [b]	r_e [c]	θ [d]
2010-Jan-25	16.72	14.31	2370	277.9
2010-Jan-29	16.80	14.49	2170	277.6
2010-Feb-22	17.42	14.37	2300	279.3
2010-Mar-12	17.88	14.41	2250	281.8
2010-Apr-02	18.45	14.58	2090	285.0
2010-Apr-19	19.77	15.64	1280	287.7
2010-May-08	19.19	14.83	1860	290.5
2010-May-29	19.52	14.97	1750	292.9

[a] Apparent V-band magnitude of the tail measured within a rectangular aperture fixed in size at 28,710×7180 km.

[b] Magnitude corrected to unit heliocentric and geocentric distances assuming $R^{-2}\Delta^{-2}$ scaling and to zero phase angle using the phase function of S-type (bright) asteroids.

[c] Radius of the circle, in meters, having area equal to the sum of the cross-sections of the dust particles in the tail photometry box.

[d] Position angle of the tail, measured from North through East [degrees]

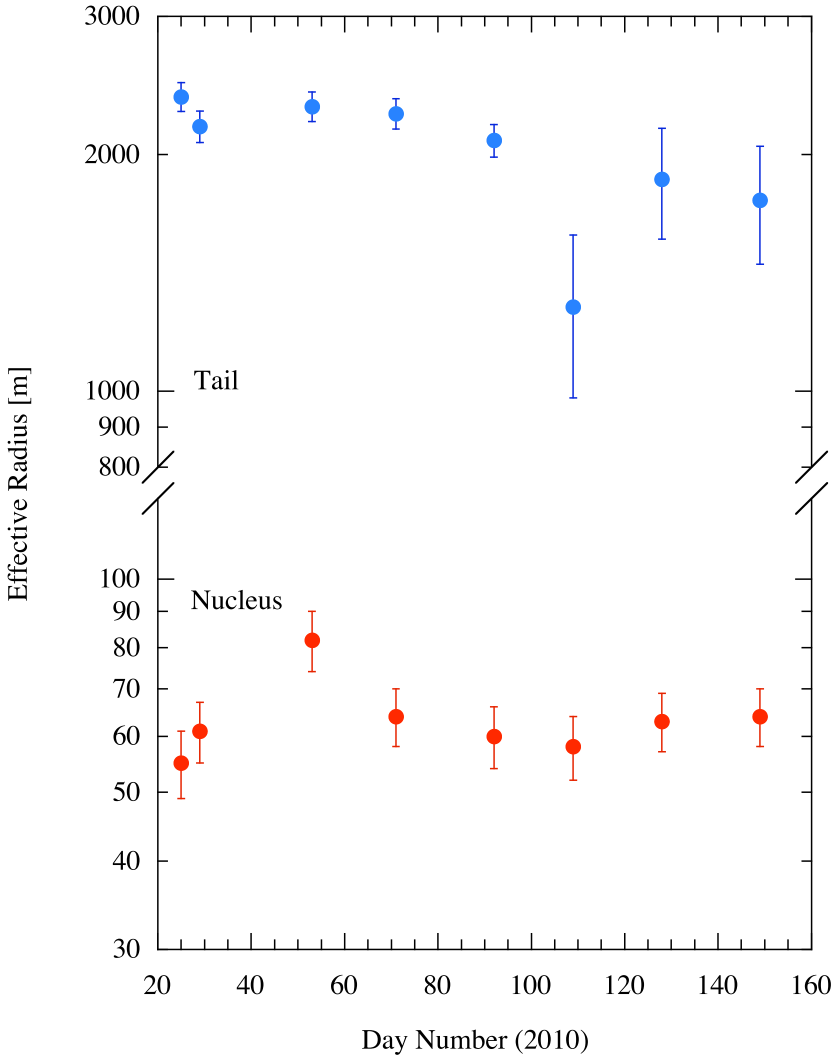

Fig. 1.— Effective radius (the radius of a circle having area equal to the cross-sectional area) of the nucleus and of the tail as functions of time. The nucleus (red circles) shows evidence for variability consistent with a rotating, aspherical body shape. The sampling is too sparse to determine the rotation period, however. The tail (blue circles) was measured within a co-moving box of fixed absolute dimensions in order to minimize problems with the changing geometry of observation. Error bars on both measurements show the standard deviation resulting from uncertainties in the photometry but do not include the systematic uncertainty due to the unknown albedo. The tail measurements suggest (but only at the $\sim 2.5\sigma$ level of confidence) a slowly declining cross-section (and implied mass) of dust.