The Astronomical Journal, 131:2327–2331, 2006 April

COMET D/1819 W1 (BLANPAIN): NOT DEAD YET

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Received 2005 November 10; accepted 2005 December 9

ABSTRACT

We present a new observation that conclusively reveals the cometary nature of the planet-crossing asteroid 2003 WY_{25} through the detection of a weak optical coma. This observation strongly supports the identification of 2003 WY_{25} with the lost comet D/1819 W1 (Blanpain) made previously on the basis of dynamical similarity. It also shows that 2003 WY_{25} is a continuing but weak source of particles for the Phoenicid meteor stream with a mass injection rate into the stream of $\sim 10^{-2}$ kg s^{-1}. This is too small to supply the estimated 10^{11} kg stream mass on any plausible timescale, suggesting that the mass injection into the stream may be episodic and/or involve additional sources. We estimate a nucleus radius near 160 m and find that, consistent with estimates for other meteor streams, the ratio of the nucleus mass to the stream mass is of order unity. We find that 2003 WY_{25} is the smallest cometary nucleus yet observed.

Key words: comets: general — Kuiper Belt — minor planets, asteroids

1. INTRODUCTION

Comet D/1819 W1 (Blanpain, hereafter D/Blanpain) was proposed as a possible source of the Phoenicid meteor stream nearly 50 years ago (Ridley 1957). The physical association has remained tentative, however, because D/Blanpain was observed for only $\sim$2 months in 1819–1820 and then promptly lost (the "D" stands for "defunct," "deceased," or "disappeared"), leaving its orbital elements with considerable uncertainty. Despite having an unremarkable orbit of the Jupiter-family type, with an orbital period near $\sim$5 yr, the comet has not been reobserved at any more recent perihelion passage, raising the possibility that it might have deactivated or disintegrated. Possibly it was bright in 1819–1820 only because its nucleus had fragmented shortly before.

The planet-crossing asteroid 2003 WY_{25} was discovered on UT 2003 November 22 (Larson et al. 2003) and subsequently found to possess orbital elements resembling those of D/Blanpain (Foglia et al. 2005; Micheli 2005), raising the possibility that it might be either the dead nucleus of D/Blanpain itself or a remnant of the nucleus surviving from an earlier, unseen fragmentation event. The semimajor axis, eccentricity, and inclination of 2003 WY_{25} are 3.086 AU, 0.676, and 5°.94, respectively, corresponding to a Jupiter-family comet-like Tisserand parameter $T_J = 2.81$. The perihelion and aphelion of 2003 WY_{25} lie close to the orbits of the Earth and Jupiter, respectively, leading to the rapid evolution of the orbital elements on timescales of decades and centuries. Backward integrations of the orbit of 2003 WY_{25} show consistency with the orbital elements of D/Blanpain, leading Foglia et al. (2005) to conclude that 2003 WY_{25} must be related to D/Blanpain. Jenniskens & Lyytinen (2005) established a link with the Phoenicid meteor stream. Dynamical models of stream particles ejected from 2003 WY_{25} can match the observed profile of the Phoenicid stream, which peaked strongly at a zenithal hourly rate of 50–100 hr^{-1} on UT 1956 December 5 but has been weak before and since. Assuming that 2003 WY_{25} is the source, Watanabe et al. (2005) predict that the Phoenicid stream could be active again in 2014, to a degree that depends on the current mass-loss rate from the parent. However, the surface brightness profile of 2003 WY_{25} has remained stellar in all reported observations, giving no direct evidence for cometary mass loss.

2. OBSERVATIONS

We observed using the University of Hawaii 2.2 m telescope on Mauna Kea. A Tektronix 2048 × 2048 pixel charge-coupled device (CCD) was employed at the f/10 Cassegrain focus, with an image scale of 0″.219 $pixel^{-1}$ and a field of view of approximately 7′.5 × 7′.5. We obtained three consecutive integrations on 2003 WY_{25}, each of 500 s duration. All data were taken through a Kron-Cousins *R*-band filter, with the telescope autoguided on a fixed star and offset to follow the motion of 2003 WY_{25} at nonsidereal rates (approximately 0″.2 hr^{-1} west and 31″.0 hr^{-1} south during these observations). Images were corrected by subtracting a bias image and dividing by a bias-subtracted flat-field image, the latter constructed from scaled, dithered images of the evening twilight sky. Photometric calibration was obtained from images of the standard star 104−330 from the catalog by Landolt (1992). The full width at half-maximum of untrailed star images in data taken close in time to 2003 WY_{25} was 1″.2 (Table 1).

3. OBSERVATIONAL RESULTS

Figure 1 shows 2003 WY_{25} in a composite of three separate images, each of 500 s integration. To construct Figure 1 we removed prominent cosmic-ray strikes from the images by hand, then shifted and aligned the images to the optocenter of 2003 WY_{25}. Next we background-subtracted each image to remove the sky emission and computed the average intensity in each pixel. Finally, we convolved the composite image with a Gaussian function of full width at half-maximum 1″.5 in order to improve the visibility of low surface brightness features. (This last step was used for presentation purposes only. No measurements were taken from the convolved data.) A coma is evident to the southeast of the nucleus and is visible to $\sim$10″ distance ($\sim$5000 km in the plane of the sky). The local sky background appears structured for two reasons. First, numerous faint field stars and galaxies are streaked in the north-south direction by the nonsidereal motion of the telescope during and between the three integrations. Second, there is a large-scale gradient in scattered light from the $V = 8.3$ mag A0 star HD 89085, which is located in the field of view about 3′ east of 2003 WY_{25} in our data. The coma is easily distinguished from the background objects and the scattered light field. It comoves

TABLE 1
Journal of Observations

UT Date	Integration Time (s)	R[a] (AU)	Δ[b] (AU)	α[c] (deg)
2004 Mar 20	3×500	1.637	0.720	20.7

[a] Heliocentric distance.
[b] Geocentric distance.
[c] Phase angle.

with 2003 WY_{25} both relative to the CCD, as the telescope pointing direction is dithered, and relative to the stars, as 2003 WY_{25} tracks across the sky. These properties are inconsistent with scattered light and internal reflections in the optics. In addition, the coma surface brightness profile peaks on 2003 WY_{25} and is morphologically unlike any trailed field object or scattered light pattern.

Figure 2 shows a contour plot of the image in Figure 1 compared with a similar plot from a field star located near the same pixel coordinates on the CCD. The star is taken from a separate integration with the telescope tracking at sidereal rates and so is unaffected by the trailing seen in Figure 1. Figures 1 and 2 show that the image of 2003 WY_{25} is extended relative to a point source, particularly along position angle $159° \pm 5°$. This is significantly different from the projected antisolar direction of 131.°3 and consistent with the action of radiation pressure on grains having $\beta \sim 0.1$, where β is the ratio of the radiation pressure acceleration to solar gravitational attraction. This suggests a particle size of $\sim$10 μm, but we regard this as little more than a guess, given that the Earth was only 7.°7 from the orbital plane of 2003 WY_{25}, and the syndynes are as a result not well separated in the plane of the sky.

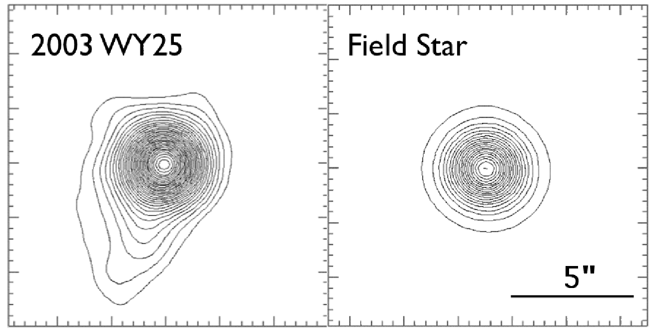

Fig. 2.—Surface brightness contours of 2003 WY_{25} (*left*) and a field star (*right*) shown at the same scale. Both plots have north to the top and east to the left. The lowest contour is 1% of the peak value.

The normalized surface brightness profile of 2003 WY_{25} is compared with the profile of a field star in Figure 3. As a result of the nonsidereal guiding used on 2003 WY_{25} we are unable to use field stars from the same images to define the image point-spread function. Instead, we used sidereally guided images taken at a similar air mass immediately following the 2003 WY_{25} data. The lack of simultaneity introduces a potential systematic error in the determination of the coma surface brightness profile (because the seeing might have changed between the two images, and the tracking performance of the telescope might not be the same) and is an unavoidable limitation of our data. The central surface brightness of 2003 WY_{25} is $\Sigma = 21.43$ mag arcsec^{-2}, while at $\theta = 4''$ from the optocenter the surface brightness has fallen to about

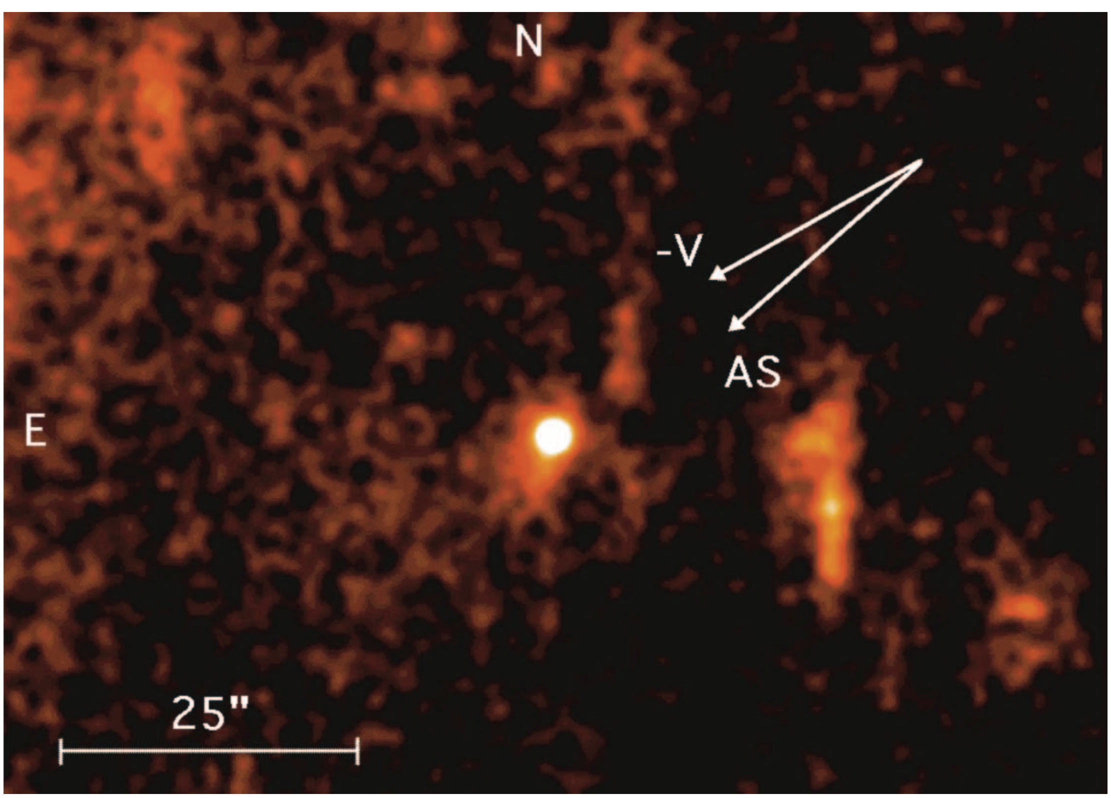

Fig. 1.—*R*-band image of 2003 WY_{25} taken at the University of Hawaii 2.2 m telescope on UT 2004 March 20. The image is a composite of three 500 s integrations taken with the telescope tracking the nonsidereal motion of the object. A faint coma is apparent, extending to the southeast. Vertical streaks are caused by field stars and galaxies unrelated to 2003 WY_{25}. Arrows show the directions of the negative heliocentric velocity vector (marked "$-$V") and the antisolar direction ("AS").

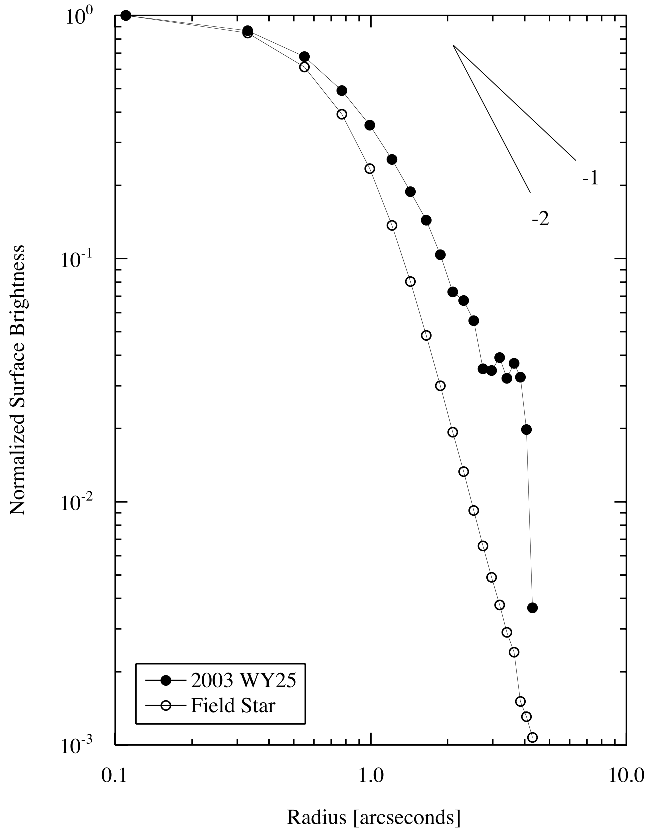

FIG. 3.—Normalized surface brightness profiles of 2003 WY_{25} (*filled circles*) and a field star (*open circles*). The 2003 WY_{25} profile was determined from an image tracked to follow the motion of the comet. Therefore, simultaneous measurements of background stars were not possible, and the profile shown here was determined from a separate image taken shortly afterward. The straight lines have slopes of -1 and -2, as marked.

$\Sigma = 25.1$ mag arcsec^{-2} and the effects of sky level uncertainty are dominant. The surface brightness gradient appears steeper than the canonical $d\log(\Sigma)/d\log(\theta) = -1$, but, given the limited radial distance range over which the gradient is measured and the significant effects of sky background uncertainty and seeing on the profile, we are reluctant to interpret this fact in detail. Moreover, with only single-epoch data we are unable to prove that the coma profile is in steady state, and this is a necessary condition for a meaningful interpretation of the profile.

Photometry obtained within apertures of radii 5, 10, and 20 pixels is summarized in Table 2. The sky background was determined with a concentric annulus having inner and outer radii of 20 and 45 pixels, respectively. Comparison of the magnitudes from the three images provides an estimate of the measurement uncertainty. Aperture photometry beyond 20 pixels (4.″4) is seen to be heavily influenced by the uneven structure of the sky background and is not considered further. The coma can be traced by eye in Figure 1 to distances larger and surface brightnesses lower than can be reliably measured.

Neither the quantity nor the quality of the new data justify a detailed model of the surface profile and the mass loss from 2003 WY_{25}. Instead, we proceed with a simple analysis that captures the key results and that is relatively model-independent. First, what is the apparent magnitude of the nucleus? The value $m_R(5) = 21.86 \pm 0.02$ in Table 2 probably overestimates the brightness of the nucleus because of the effects of the near-nucleus coma. By examination of the surface brightness profiles in Figure 3, we estimate that the nucleus contributes about 62% of the light

TABLE 2
RED FILTER PHOTOMETRY

N	Mid-UT 2004	$m_R(5)$[a]	$m_R(10)$[a]	$m_R(20)$[a]
1................	Mar 20.3818	21.88	21.26	20.94
2................	Mar 20.3923	21.86	21.36	21.03
3................	Mar 20.4000	21.83	21.25	20.85

[a] Apparent red magnitude within a circle of projected radius 5, 10, or 20 pixels, as indicated; 1 pixel = 0.″219.

in the central aperture, so that its effective red magnitude in the absence of a coma would be $m_{R,n} \sim 22.4 \pm 0.1$. The magnitude is related to the effective nucleus radius, r_e, by

$$p_R \Phi(\alpha) r_e^2 = 2.25 \times 10^{22} R^2 \Delta^2 10^{-0.4(m_{R,n} - m_\odot)}, \quad (1)$$

where p_R is the red geometric albedo, $\Phi(\alpha)$ is the phase function applicable at phase angle α, R and Δ are the heliocentric and geocentric distances in AU, and $m_\odot = -27.1$ is the apparent red magnitude of the Sun. The phase function is also unmeasured for 2003 WY_{25}. We write $\Phi(\alpha) = 10^{-0.4 k_\alpha \alpha}$, where k_α is the linear phase function, and note that measurements of comets give values of k_α in the range 0.02–0.06 mag deg^{-1} (Lamy et al. 2004). The nucleus magnitude, corrected to unit heliocentric and geocentric distances and to zero phase angle, is $m_{R,n}(1, 1, 0) = 21.2 \pm 0.4$ (where the quoted uncertainty is the range calculated by allowing k_α to vary from 0.02 to 0.06 mag deg^{-1}). We possess no information about the rotational light curve of this object, but, based on other small bodies in the solar system, it is likely to be highly aspherical and have a pronounced light curve.

The albedo of 2003 WY_{25} is not known. We assume $p_R = 0.04$, as is typical of the nuclei of short-period comets and low-Tisserand asteroids (Fernández et al. 2005). Substitution into equation (1), with the nominal value $k_\alpha = 0.04$ mag deg^{-1}, then gives $r_e = 160$ m. Uncertainty in the phase function renders r_e uncertain by about 20%, while a 50% error in p_R would translate into a 25% error in r_e. The uncertainty in the correction for coma contamination is probably on the order of 20%. From all these effects we see that the radius of the nucleus is uncertain at the level of several tens of percent, but the nucleus is undeniably small relative to other nuclei, most of which have radii in the 1–10 km range (Lamy et al. 2004). In fact, 2003 WY_{25} is the smallest active cometary nucleus yet to have been observationally characterized. Assuming $\rho = 10^3$ kg m^{-3} and a spherical shape, the mass of the nucleus of 2003 WY_{25} is $M_n = 2 \times 10^{10}$ kg (uncertain by factors of several).

Subtracting the nucleus magnitude from the aperture photometry in Table 2 provides an estimate of C_d, the scattering cross section of the dust in 2003 WY_{25}. With nuclear magnitude $m_{R,n} = 22.4$, we find that the effective magnitude of the coma alone, measured with a 20 pixel radius circle, is $m_{R,c} \sim 21.5$. Substitution into equation (1), again assuming $p_R = 0.04$ and a phase-darkening coefficient $k_\alpha = 0.04$, gives an effective scattering cross section $C_d = \pi r_e^2 = 1.9 \times 10^5$ m^2, with an uncertainty on the order of several tens of percent. For spherical particles, the dust mass m_d is related to the cross section by $m_d = 4/3 \rho a C_d$, where ρ is the grain mass density and a is the effective grain radius. We assume $\rho = 10^3$ kg m^{-3}. The time of residence within the photometry aperture is $\tau = l/V$, where V is the ejection velocity and l (in meters) is the radius of the aperture projected to the distance of the comet. For our 20 pixel (4.″4) radius aperture and a geocentric distance of 0.720 AU, we find $l = 2.3 \times 10^6$ m. Hence, the dust mass-loss rate is on the order of

$$\frac{dm}{dt} \sim \frac{m_d}{\tau} = \frac{4\rho a C_d V}{3l}. \qquad (2)$$

The effective particle properties in our data are not well known, and so we consider two cases to examine their effect on the derived mass-loss rates. Suppose that the particle radius is $a \sim 0.5$ μm, consistent with the high scattering efficiency of particles whose size is near the wavelength of observation. Such small particles dominate the scattering from most active comets at optical wavelengths. They will be well coupled to the outflowing gas and should attain terminal velocities equal to a large fraction of the outflow speed in the gas. At $R = 1.6$ AU, this speed is $V \sim 450$ m s^{-1}, meaning that their residence time in the 20 pixel radius photometry beam is about 5×10^3 s (1.5 hr) and the mass-loss rate $dm/dt = 0.02$ kg s^{-1}.

Alternatively, suppose that the particles have $a = 10^{-3}$ m, similar to the sizes of the optical meteors. Then, gas drag will be barely able to launch the grains against the gravity of the nucleus. The escaping grains will travel at only a few times the nucleus escape speed, which for a 160 m radius body of density $\rho = 10^3$ kg m^{-3} is only $V \sim 0.1$ m s^{-1}. Substitution into equation (2) then gives $dm/dt = 0.01$ kg s^{-1} for the mass-loss rate in this case, which is not very different from the value obtained from much smaller, dynamically better coupled, and faster particles.

In the real case, the ejected particles occupy a distribution of sizes and terminal velocities and the particles may not be structurally well-represented as spheres, complicating the relation between the scattering cross section derived from the data and the underlying dust mass (eq. [2]). Rare, very large particles (like those responsible for the Phoenicid meteors) could dominate the ejected mass while escaping detection in ground-based observations. Still, lacking any further information about the particles, we conclude that the weak coma around 2003 WY$_{25}$ is consistent with mass-loss rates of a few times 10^{-2} kg s^{-1}.

The mass of the Phoenicid stream has been estimated as $\sim 10^{11}$ kg (Jenniskens & Lyytinen 2005). With a steady mass injection rate of 10^{-2} kg s^{-1}, this stream would require an implausibly long 10^{13} s (3×10^5 yr) to reach its present mass. Strong interactions with the Earth at perihelion and, especially, with Jupiter at aphelion force changes in the orbit on timescales of $\sim$100 yr or less. For this reason, the Phoenicid stream particles are likely to have been released from the nucleus within the past few centuries (Watanabe et al. 2005). Our data show that the Phoenicid stream mass is not accumulated in steady state but must be injected episodically and/or result from unseen sources in addition to 2003 WY$_{25}$. The present low mass injection rate is consistent with Jenniskens & Lyytinen's suggestion that stream mass primarily reflects sporadic breakup events in parent bodies rather than steady mass loss through cometary sublimation.

4. FUTURE OBSERVATIONS

Future physical observations of 2003 WY$_{25}$ = D/Blanpain must contend with persistently unfavorable viewing geometries. In Figure 4 we show the apparent magnitude of the nucleus computed from

$$m_R = m_R(1, 1, 0) + 5 \log_{10}(R\Delta) + k_\alpha \alpha, \qquad (3)$$

in which $m_R(1, 1, 0)$ is the magnitude at unit heliocentric and geocentric distances and zero phase angle, k_α is the linear phase coefficient, and α is the phase angle. Three curves in Figure 4

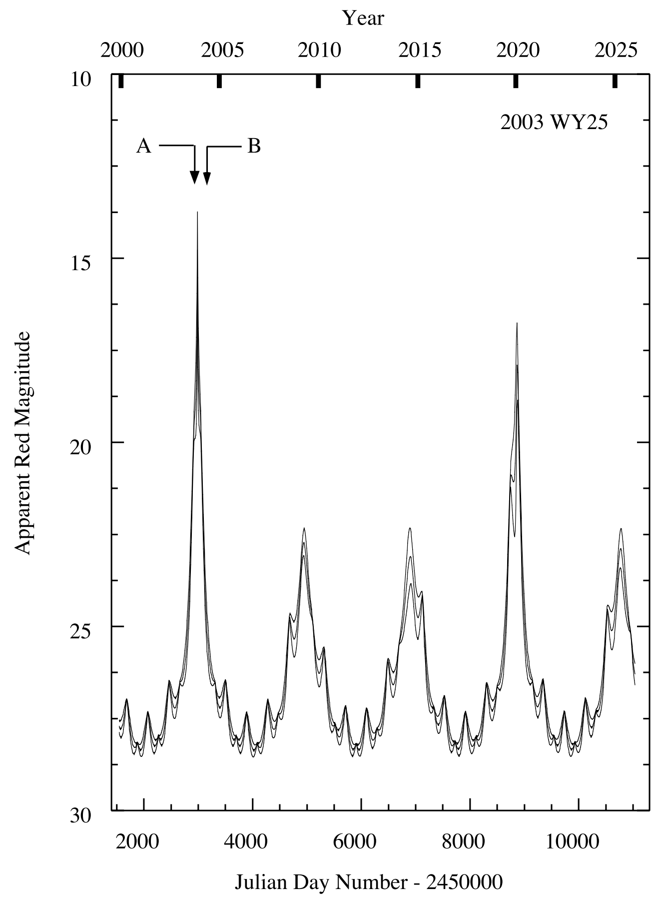

Fig. 4.—Calculated apparent red magnitude of the nucleus of 2003 WY$_{25}$ as a function of time in the 2000–2025 interval. From top to bottom, the three curves show the brightness computed assuming phase functions of 0.02, 0.04, and 0.06 mag deg^{-1}. Arrows marked "A" and "B" show the times of discovery (2003 November 22) and the observations reported here (2004 March 20), respectively.

were computed corresponding to $k_\alpha = 0.02$, 0.04, and 0.06 mag deg^{-1}. The main feature of the figure is that 2003 WY$_{25}$ will not soon recover the brightness it had when discovered (point A in Fig. 4) or when observed by us (point B). Useful physical observations may be possible using moderate- to large-aperture telescopes in 2009 and 2014, when the magnitude will briefly fall below $m_R = 23$ (however, the solar elongation of the comet will then be small, limiting the useful observing windows). The best observational opportunity will occur in 2019 December–2020 January, when the comet will pass the Earth within 0.1 AU, briefly becoming brighter than 18 mag, while the solar elongation will not be prohibitively small. In addition to studies of the dust production and its heliocentric variation, we may learn something about the process of nucleus breakup. For example, sudden asymmetric shedding of mass from a rotating nucleus should induce it to precess, and we predict that time-resolved photometry will reveal evidence for multiple periodicities in 2003 WY$_{25}$. Such a small nucleus is also highly susceptible to spin-up through outgassing torques, and evidence of this may be found in the rapid rotation of the body.

5. SUMMARY

New optical observations of 2003 WY$_{25}$ lead to the following conclusions:

1. Our most important result is that 2003 WY$_{25}$ shows a coma when at 1.6 AU heliocentric distance and is thus a comet. This

observation fully supports the inference, made on dynamical grounds by Jenniskens & Lyytinen (2005), that 2003 WY_{25} is related both to comet D/1819 W1 (Blanpain) (of which it may be a fragment) and to the Phoenicid meteor stream.

2. Optical photometry shows that the nucleus has a red magnitude, reduced to unit heliocentric and geocentric distances and to zero phase angle, of $m_{R,n}(1, 1, 0) = 21.2 \pm 0.4$. Assuming a red geometric albedo $p_R = 0.04$, we calculate that the effective radius of 2003 WY_{25} is $r_e = 160$ m, making it the smallest nucleus yet studied.

3. The mass-loss rate through the coma is on the order of 10^{-2} kg s^{-1}. This is too small to supply the estimated 10^{11} kg mass of the Phoenicid meteor stream on the $\sim$100 yr dynamical time of the comet. More likely, mass injection into the stream is stochastic, perhaps corresponding to breakups of parent bodies embedded within the stream.

I thank John Dvorak for operating the telescope, Pedro Lacerda, Jing Li, Scott Sheppard, Bin Yang, and the anonymous referee for comments, and Masateru Ishiguro for a quick syndyne computation. I am grateful for financial support from NASA's Planetary Astronomy Program.

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