The Lightcurve and Colors of Unusual Minor Planet 1998 WU_{24}

John K. Davies

Joint Astronomy Centre, 660 N A'ohoku Pl., Hilo, Hawaii, 96720, USA

E-mail: JKD@jach.hawaii.edu

David J. Tholen & Robert J. Whiteley

Institute for Astronomy, 2680 Woodlawn Dr, Honolulu, Hawaii, 96822 USA

Simon F. Green [*], Jon K. Hillier, Michael J. Foster [†], & Neil McBride[‡]

Unit for Space Sciences & Astrophysics, School of Physical Sciences

University of Kent, Canterbury, CT2 7NR, UK

Tom.H Kerr & Erica Muzzerall [§]

Joint Astronomy Centre, 660 N A'ohoku Pl., Hilo, Hawaii, 96720, USA

September 13, 2000

Number of pages (inc Figs. and Tables): 23

Text: 18 pages

Tables (including footnotes): 4

Figures: 6

Keywords: Asteroids, comets, Rotation, Photometry, Infrared.

[*]Present Address: Planetary and Space Science Research Institute, The Open University. Walton Hall, Milton Keynes, MK7 6AA. UK.

[†]Present Address: Hovemere Ltd, 56 Hays Street, Bromley,BR2 7LD, UK.

[‡]Present Address: Planetary and Space Science Research Institute, The Open University. Walton Hall, Milton Keynes, MK7 6AA. UK.

[§]Present address: Dept of Physics and Astronomy,University of Victoria, Box 3055, Victoria, B.C., V8W 3P6, Canada.

Suggested running head: Lightcurve and colors of 1998 WU_{24}

Correspondence and proofs to:

Dr J.K. Davies

Joint Astronomy Centre

660 N A'ohoku Pl.

Hilo

Hawaii 96720, USA

tel: 808-969-6524

e-mail j.davies@JACH.Hawaii.edu

Abstract

Minor Planet 1998 WU_{24} is unusual in having the orbital characteristics of a Halley family comet but showing no sign of cometary activity. We present optical data that reveal a double peaked lightcurve with a period of 7.283±0.003 hr and a peak to peak amplitude ∼0.54 mag. Infrared spectroscopy and quasi-simultaneous BVRIJHK photometry reveal a featureless K band spectrum and colors typical of D type asteroids and suspected 'bare' comet nuclei (B−V=0.78±0.034, V−R=0.53±0.037, V−I=0.99±0.035, V−J=1.67±0.043, V−H=2.10±0.076 and V−K=2.34±0.102). Image profiles from co-added frames in the R band indicate no apparent cometary activity with an implied upper limit to the dust production rate of 150 g s^{-1}. Assuming a D-type albedo of 0.04 we derive a spherical equivalent diameter of 5.28±0.07 km although the lightcurve amplitude implies an irregular body with an axial ratio of 1.29:1. We conclude that 1998 WU_{24} is probably an inactive comet nucleus.

1 INTRODUCTION

Minor Planet 1998 WU_{24} was discovered by the LINEAR sky survey programme on 1998 Nov 25 (MPEC 1999-X11). With a semimajor axis of 15.2 AU, an eccentricity of 0.9 and an inclination of 45° its orbit resembles that of a Halley-type comet. This family is defined by Bailey & Emelýanenko (1996) as comets with periods between 20 and 200 years, perihelion distances less than 1.5 AU and inclinations not restricted to the general region of the ecliptic plane. However, no coma or other cometary features associated with 1998 WU_{24} were reported at the time of the discovery. Observationally similar objects include minor planet (5335) Damocles, which is also in a Halley-type orbit, and the far more eccentric object 1996 PW. Weissman and Levison (1996) have suggested that 1996 PW could be a main belt asteroid ejected to the Oort cloud during the formation of the solar system that subsequently evolved into an orbit indistinguishable from that of an Oort Cloud comet.

We observed 1998 WU_{24} in the optical and near infrared regions to compare its physical properties with those of other low activity comets and possibly related objects such as Centaurs and trans-Neptunian objects.. Optical observations were carried out from both the University of Hawaii 2.24m telescope on Mauna Kea, Hawaii, and the 1m Jacobus Kapteyn Telescope on La Palma. Near infrared observations were made from the United Kingdom Infrared Telescope (UKIRT) on Mauna Kea. The observational circumstances are given in Table I. The observations from La Palma were used primarily to derive rotational parameters. The synchronised observations from Hawaii were intended to determine optical-infrared colors and covered a range of optical (BVRI) and near infrared (JHK) filters.

2 OBSERVATIONS AND DATA REDUCTION

2.1 The La Palma lightcurve

Optical photometry was carried out on 1999 Jan 22–24 from the Observatorio del Roque de Los Muchachos, La Palma, using the 1m Jacobus Kapteyn Telescope (JKT) and a CCD camera. The camera had a usable area of 1024×1024 pixels with an image scale of 0.33 arcsec per pixel, resulting in a field of view of 5.6 arcmin on a side. Since autoguiding was only possible for fixed sources the telescope was tracked at the sidereal rate, but the exposures were kept short enough (typically 40 s) that the object did not move more than 2 pixels (0.66 arcsec) during each exposure. Typical seeing over the three nights was of the order of 1 arcsec.

The weather was photometric on 1999 January 23 and 1999 January 24. On those nights observations of standards (PG0231, SA 95, SA 98, PG0918, PG1047 and PG1323 (Landolt 1992)) were made through VRI broadband filters (equivalent to the Johnson V and Kron-Cousins RI photometric system) to derive zeropoints and color corrections. However, as data from the larger UH 2.24m telescope were better suited to the determination of colors, the majority of the La Palma data was taken in a single filter (R).

The images were bias corrected and then flat fielded using twilight flats. Intensity was extracted using the STARLINK package GAIA. On each night aperture profiles were determined for a number of frames and it was found that the apertures giving optimum signal to noise ratios were 3–5 pixels in radius. Since the JKT data amount to several hundred data points, the raw data are not given here but are available from author JKD on request.

The object and two reference stars were measured using a 5 pixel (1.65 arcsec) radius aperture to derive a relative magnitude for 1998 WU_{24} in each frame. The two comparison stars for each night were chosen such that the target moved approximately along a line joining them during each night's observation. This allowed any change of focus across the frame to be accounted for in the aperture correction, although the JKT camera focus is very flat in this regard. An aperture correction was then derived by determining the magnitudes of the two reference stars in every frame using both 5 and 20 pixel radius apertures. These multiple values were then averaged to give the true magnitudes of the stars in both apertures. From these values a high precision aperture correction from 5 to 20 pixels could be deduced for each frame. The resulting aperture corrections ranged between $\leq$0.1 mags to $\sim$ 0.3 mag depending on the image quality of individual frames. Applying this correction to the relative magnitudes of the target effectively gave a lightcurve in a 20 pixel (6.6 arcsec) radius aperture. The relative magnitudes were then calibrated using the standard fields.

2.2 UH 2.24m Optical photometry

Optical photometry was carried out on 1999 January 17 and 18 with the University of Hawaii 2.24m telescope. The telescope was equipped with a Tektronix 2048$\times$2048 CCD camera mounted at the telescope's f/10 focus and having a pixel scale of 0.219 arcsec per pixel. Repeated images in the BVRI filters were taken in 2×2 rebinning mode. Standard aperture photometry was performed using the DAOPHOT package in IRAF. The aperture size used was 6 pixels in radius, which in 2×2 binning mode is 2.6 arcsec on the sky. We employed standard star measurements on multiple fields taken from Landolt (1992). Full solutions for extinction coefficients, color terms and magnitude zero points were performed. The data are given in Table II.

2.3 UKIRT infrared photometry

Infrared imaging was obtained on 1999 January 17, 18 and 19 with the infrared camera IRCAM on the UK Infrared Telescope, UKIRT. The camera, which was equipped with a 256×256 InSb array, had a plate scale of 0.286 arcsec per pixel and a field of view of 73.2 arcsec. The observations were made and reduced using standard techniques described in Davies et al. (1998a, 1998b). The quoted errors include statistical uncertainties in the images plus the uncertainties in photometric calibration. These data are given in Table III.

2.4 UKIRT infrared spectroscopy

The infrared spectroscopy was obtained with the UKIRT Cooled Grating Spectrometer (CGS4) on 1998 Dec 19 and 1999 Jan 19. The instrument was configured with its 40 lines mm^{-1} grating and its short focal length camera. This configuraton provides a spectral grasp of approximately 0.64 μm per grating setting at a resolution of the order of 700.

The December 1998 observations were made as a single observation between 14.198 and 15.029 UT at an airmass of 1.03. The G0V comparison star BS4027 was observed immediately prior to this observation, also at an airmass of 1.03. The January 19th observations spanned the period from 8.832 UT to 10.860 UT. Three individual observations were made during which the object ranged in airmass from 1.43 - 1.15. Total time on target was 168 minutes. A comparison star, the solar analogue Hyades 64, was observed at airmasses of 1.1 and 1.45.

The CGS4 spectra were reduced in the standard manner for this instrument. Each image was divided by a flat field taken using the CGS4 internal black body followed by construction of object-sky pairs from consecutive observations nodded along the slit. The object-sky pairs were added to make a final 2D spectral image. This was corrected for the curvature of the image resulting from the CGS4 optics by using the signal from the standard star to map the distortion across the array and resampling the data to remove the distortion. The rows containing the asteroid and standard star spectra were extracted from the rectified images and wavelength calibrated using arc lines from the internal calibration argon lamp. The asteroid spectra were divided by the spectra of the comparison stars at near matching airmasses to remove the effects of telluric absorptions and to allow the production of a reflectance spectrum directly.

3 RESULTS

3.1 Lightcurve of 1998 WU_{24}

The lightcurve was initially defined using the largest contiguous data set (1999 Jan 22–24; JKT R Band). The JKT magnitudes were corrected to $R(1, \alpha)$ since the change in phase angle during the entire period of the observations reported here was small (0.47° from 1999 Jan 17–24). The data were then binned with five data points in each bin to improve the signal to noise ratio of each lightcurve element.

A Fourier fitting procedure (Harris et al. 1989) was used to fit a 7^{th} order curve to the data by treating data from separate nights as independent datasets and applying a magnitude shift between the individual groups until the residuals of the fit were minimised. This same process was subsequently used for all the lightcurve fitting calculations.

Data from the three nights of JKT R band observations gave a double peaked lightcurve characteristic of a non-spherical rotating body (Fig. 1) The period obtained was 7.283 ± 0.003hr with a maximum peak to peak amplitude of $\sim$0.54 mag.

To check the consistency of the JKT and UH data before combining them, a lightcurve was also derived from the V band data available from 1999 Jan 17 and Jan 18. (Fig. 2). These data gave a period of 7.287 ± 0.005 hours. The close agreement of these totally independent lightcurves leads to a high level of confidence that all the data are consistent. This consistency enabled the entire optical and infrared dataset to be combined to derive a more accurate lightcurve. The resulting composite BVRIJHK lightcurve (Fig. 3), at a mean phase angle of 11.83°, has a period of 7.283 $\pm$0.003 hr and an amplitude of $\sim$0.54 mag (peak to peak).

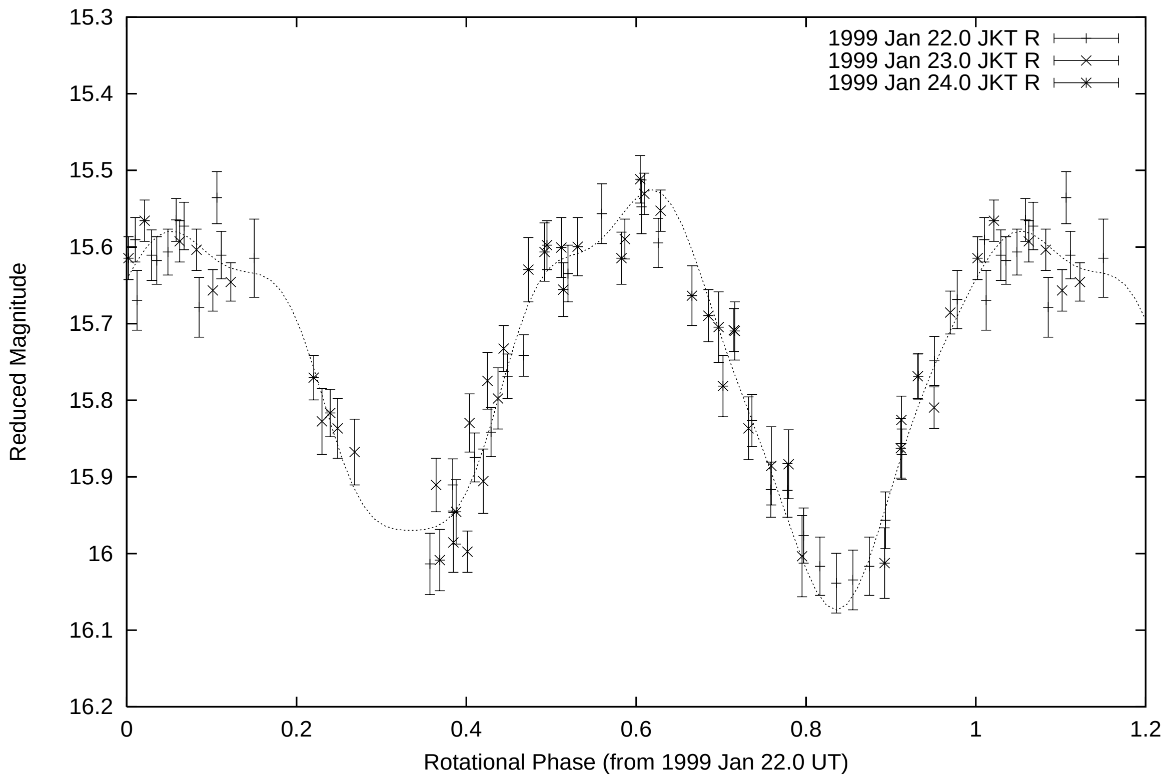

Figure 1: The R band data from the JKT. The final lightcurve deduced from the entire dataset plotted as a line.

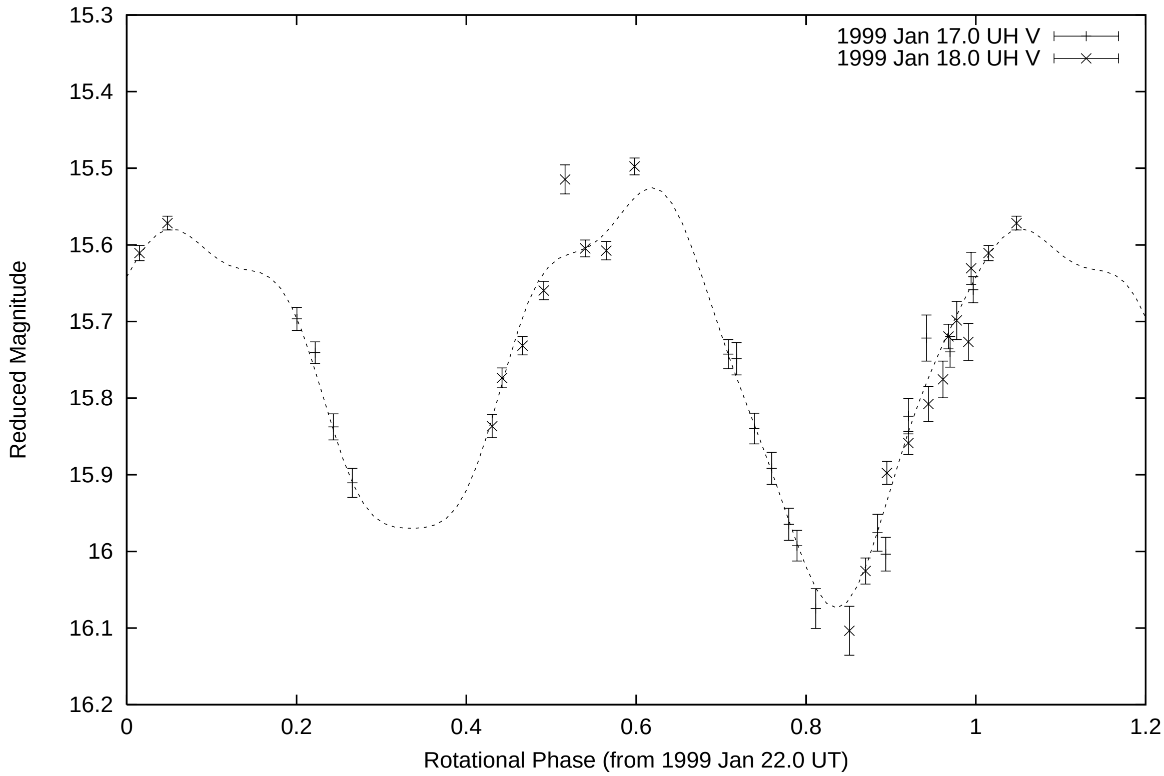

Figure 2: V Band data from the UH 2.24 m telescope compared with the final lightcurve.

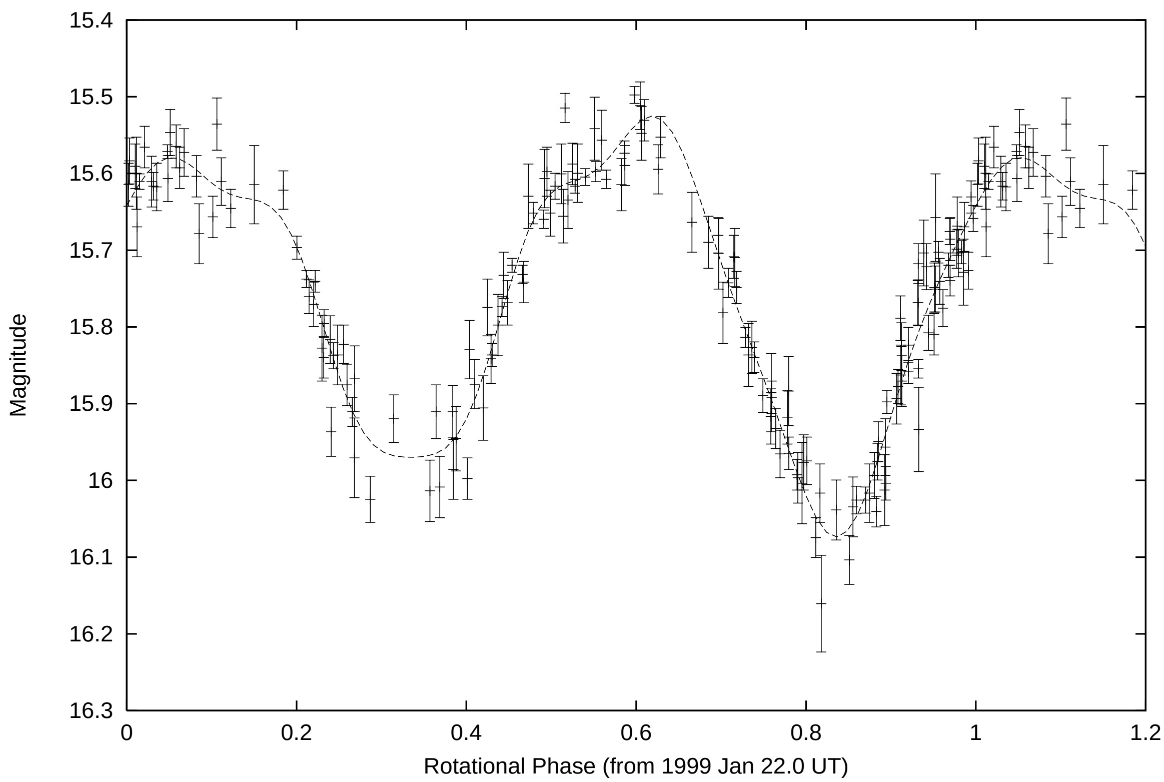

Figure 3: The composite lightcurve comprising data from all three telescopes in all filters.

3.2 Search for activity

The search for a cometary coma was carried out in an identical fashion to previous searches on 1996 PW (Davies et al. 1998b) and the Centaur (10199) Chariklo (McBride et al. 1999).

A total of 51 of the 40 s exposure JKT R Band frames taken on 1999 Jan 23 between 21:23 and 06:30 UT were used, giving a total exposure time of 2040 seconds. These frames were co-added in the object's reference frame and an azimuthally averaged radial profile was determined.

Similar profiles were also obtained from two field stars (co-added in their reference frames). One was of a similar brightness to 1998 WU_{24}, the other was approximately 30% brighter. The profiles, after conversion to sky-subtracted surface brightness versus sector radius and normalisation, were compared with that of 1998 WU_{24}. Although the profile of 1998 WU_{24} shown in Fig. 4 diverges slightly from that of the fainter comparison star (Star 2) in the wings, this is well within the errors and as such there appears to be no coma.

An upper limit to the mass production rate can be calculated by comparison of the stellar and object profiles (eg. Davies et al. 1998b). Using

$$\dot{M} = \frac{16\pi}{3}\frac{\Delta^2}{a^2}\frac{r^2}{S_0}\frac{BR\rho V r_o}{A}$$

with the geocentric distance Δ = 1.59 AU, the heliocentric distance r = 2.49 AU, the projected pixel width a = 3.81×10^5 m, the solar constant S_0 = 1430 $Wm^{-2}\mu m^{-1}$ in the R band and B = c $\times$ 3.66×10^{-21} W $m^{-2}\mu m^{-1}$ (where c is the difference between the object profile and the stellar profile, i.e. the counts per pixel due to the coma at the projected distance $r_\circ$). The assumed values for dust grain terminal velocity V_t, geometric albedo A, dust grain bulk density ρ and dust grain radius R are 400 km s^{-1}, 0.04, 1000 kg m^{-3} and $0.5\mu m^{-1}$ respectively.

These values result in a 3 σ upper limit to the dust production rate of 1998WU_{24} of 150 g s^{-1}.

3.3 BVRIJHK Colors

For an irregular object that is rotating rapidly a reliable way of determining colors is to use the output from the lightcurve fitting program described above. If the data in each filter are input to the program as separate datasets, then the adjustments in magnitude required to bring the data in each filter into agreement correspond to the various colors. Provided the data are

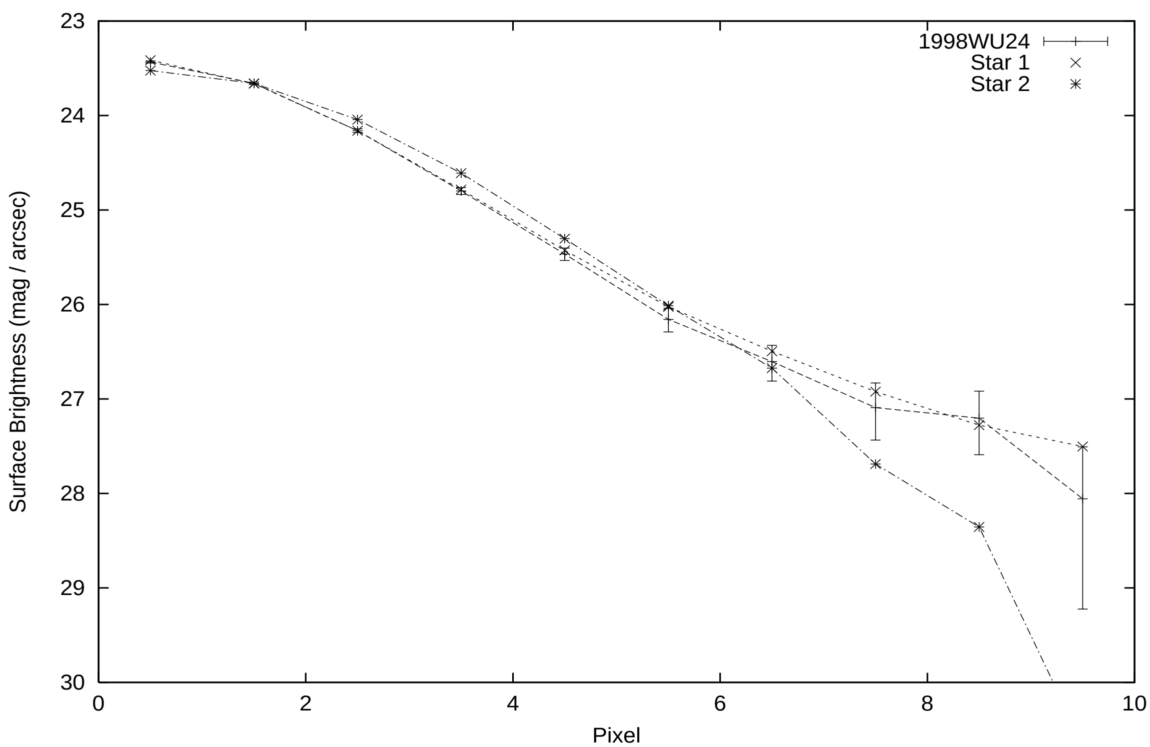

Figure 4: Surface brightness profile of 1998 WU_{24} compared with field stars. Error bars are plotted only for 1998 WU_{24} but are similar for each profile. The faint test star (Star 2) was of similar brightness to 1998 WU_{24}

taken quasi-simultaneously, so that phase effects do not become significant, this method has the advantage that all the data are used in the determination of the colors. Using this approach removes any need to interpolate across pairs of observations taken in sequences such as RVR and JHJ which may cover an inflexion or peak in the lightcurve. This procedure was followed for all the optical and infrared data and the resulting average values are $B-V=0.78\pm0.034$, $V-R=0.53\pm0.037$, $V-I=0.99\pm0.035$, $V-J=1.67\pm0.043$, $V-H=2.10\pm0.076$, $V-K=2.34\pm0.102$.

3.4 The spectrum

The near infrared spectra from the two different nights covered slightly different spectral ranges, namely 1.87–2.51 μm and 1.72–2.41 μm. The ratios obtained by dividing each asteroid spectrum by its standard star were combined by adding them. The result was then rebinned to increase the signal to noise ratio, resulting in a final spectrum with a resolving power of about 90. This spectrum was then normalised to have a value equal to 1 over the range 2.15–2.25 μm. The result is presented as Fig 5. Note that the large scatter at each end of the spectrum is noise, a consequence of the poor atmospheric transmission at these wavelengths. Furthermore, although the standard stars used on the two nights are of marginally different spectral types, taking a ratio of the spectra of the two standard stars suggests that any difference in the resulting spectral slopes is negligible.

The resulting spectrum is basically featureless across the entire wavelength range. In particular there is no obvious evidence for the 2.03μm feature of water ice seen in Centaurs and some trans-Neptunian objects (Luu et al. (2000), Foster et al. (1999), Brown et al. (1999), McBride et al. (1999), Cruikshank et al. (1998)). However the water ice band seen in these objects (which is plotted on Fig. 5 as a solid line) is typically only 5–10% deep and can be diluted into near invisibility by a relatively small fraction of darker impurities. Examination of Fig. 5 shows that an ice feature of this depth could be masked by the relatively low signal to noise ratio and so the existence of water ice on the surface is not excluded by our data.

4 DISCUSSION

We were not able to observe 1998 WU_{24} in the thermal infrared and so cannot determine its albedo directly. Furthermore 1998 WU_{24} was observed over a small range of phase angles and

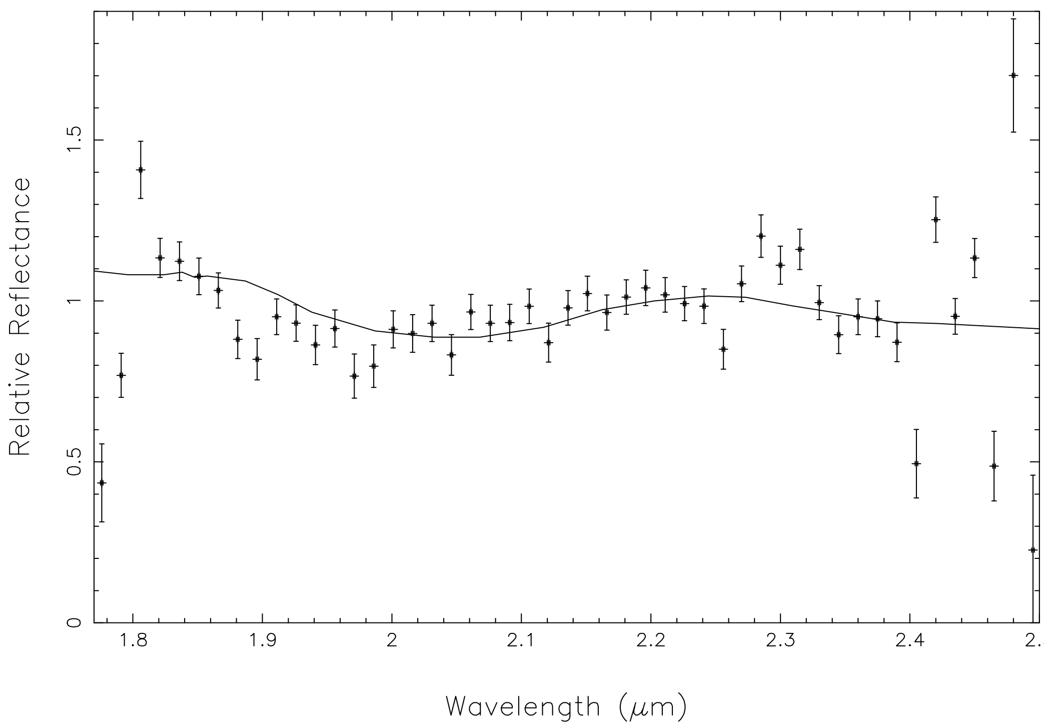

Figure 5: The combined K band spectrum of 1998 WU_{24}. A model water ice spectrum kindly supplied to us By D. C. Jewitt is plotted as a solid line.

consequently a direct determination of the slope parameter G is not possible. To calculate a value of H_V (using the method described in Bowell et al. 1989) a G parameter of 0.15 was used. However it should be noted that varying the G value by as much as 0.1 has very little effect on the result. A G of 0.15 gives H_V = 15.558 $\pm$0.03 mag which, assuming an albedo of 0.04 and an uncertainty in G of $\pm$0.05, implies a diameter of 5.21$\pm$0.07 km. However the significant lightcurve clearly shows that the object is not spherical. If the object is in fact a tri-axial ellipsoid seen equator on, the lighturve amplitude detected implies an axial ratio of 1.29:1.

There are several dynamical pathways which might lead an object into an orbit such as that of 1998 WU_{24}. Main belt asteroids can evolve into Earth crossing orbits and may then suffer a planetary encounter that ejects them from the inner solar system. A small fraction of the ejected objects may remain bound to the Sun rather than escaping into interstellar space. Subsequently these objects might re-appear on trajectories similar to those of Oort cloud comets and then be captured into a Halley-type orbit by further planetary encounters. Although not yet quantified the probability of such a chain of events must be low and accordingly the steady state population of such obects is probably very small (D. Asher and M Bailey *Private Communication*). Thus at first sight it would appear that the object is probably an Oort cloud comet which entered the inner solar system and was subsequently captured by one or more planetary encounters into its present Halley-type orbit

However, an alternative is that 1998 WU_{24} may have evolved inward from the trans-Neptunian region in a manner similar to that of the Centaurs and Scattered Disk Objects. Although given the generally low inclinations of Centaurs and Scattered Disk Objects, the fairly high inclination (43°) of 1998 WU_{24} might be perceived as an argument against this possibility, it should be noted that the descending node of 1998 WU_{24}'s orbit is currently located very close to the orbit of Jupiter, and so it is quite likely that its current high inclination is the result of a close encounter with Jupiter. Its orbital inclination prior to such an encounter could well be significantly lower, and comparable to those of the Centaurs and Scattered Disk Objects.

Having established the small size and likely absence of a coma around 1998 WU_{24} and noting that its orbit is suggestive of a Halley family comet, it is natural to compare its properties with those of inactive comet nuclei and distant minor planets. Sample VRIJHK colours for three comet nuclei, four Centaurs and 1996 PW are given in Table IV and plotted in Figure

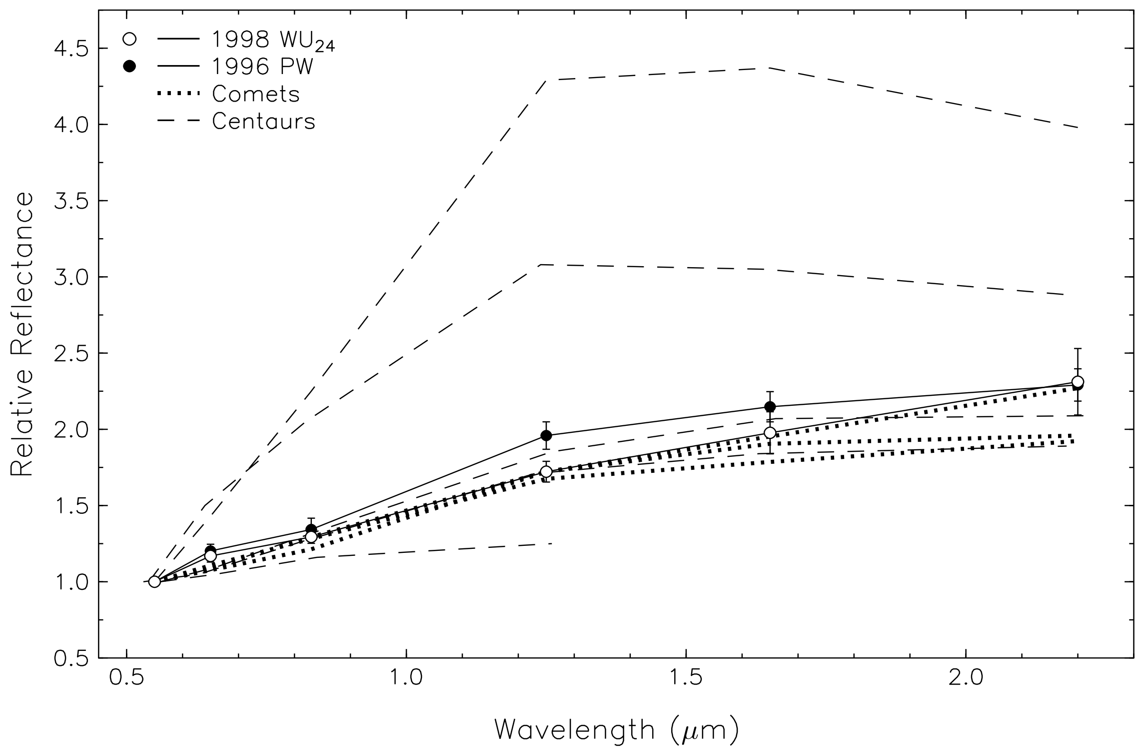

Figure 6: Relative reflectances of objects listed in Table IV.

6. From this it is clear that 1998 WU_{24} has colors very similar to those of low activity comet nuclei. While this color similarity is by no means conclusive (the range of D-type asteroid colors embraces those of 1998 WU_{24} and the highly eccentric object 1996 PW) it is not inconsistent with the hypothesis that 1998 WU_{24} could be a dormant or deactivated comet nucleus. The object's present perihelion distance of 1.41 AU certainly brings it close enough to the Sun to activate the sublimation of water ice should there be any on the surface and yet we show that no coma was observed during this apparation (our observations were made post perihelion when the object was 2.4 AU from the Sun) This argues for an object for which activity has been cut-off, rather than simply one that has never been activated by solar heating. The lack of activity, and of any spectral signature of water ice in the near IR, support this interpretation although we note that the spectrum does not rule out a weak ice feature, and that ice features can be masked by relatively small amounts of impurities. Table IV also shows that 1998 WU_{24} (and three objects known to show cometary activity) are less red than (5145) Pholus. Cruikshank et al. (1998) have argued that (5145) Pholus is a pristine comet recently moved inward from the

trans-Neptunian region. If the interpretation of 1998 WU_{24} as a deactivated or dormant comet is correct then this would support Cruikshank et al.'s conclusion that Pholus has an ancient surface relatively unaffected by cometary activity.

5 CONCLUSIONS

We find that 1998 WU_{24} has a rotation period of 7.283 $\pm$0.003 hr and amplitude of $\sim$ 0.54 magnitudes. Assuming a geometric visual albedo of 0.04, the mean diameter is 5.28 km. There is no compelling evidence for cometary activity. The visual and infrared colors of 1998 WU_{24} are consistent with D type asteroids and comet nuclei observed when quiescent. We conclude that 1998 WU_{24} is what might generally be regarded as the nucleus of a Halley-type comet which was not significantly active during its 1996 perihelion passage.

ACKNOWLEDGEMENTS

JKD thanks Mark Bailey, David Asher, Paul Weissman, Martin Duncan and Hal Levison for discussions about the likely dynamical origin of 1998 WU_{24}.

We thank the support staff of the JKT and UKIRT for their assistance during the observing at La Palma and Mauna Kea. Thanks also to J. Dvorak for operating the UH 2.24m telescope. The JKT is operated on the island of La Palma by the Isaac Newton Group in the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias. UKIRT is operated by the Joint Astronomy Centre on behalf of the Particle Physics and Astronomy Research Council (PPARC). Image processing and data reduction were performed using the STARLINK network and software. STARLINK is funded by PPARC. J. Hillier & M. Foster acknowledge the financial support of PPARC. DJT notes that some portion of this work was supported by NASA grant NAG5-4524

REFERENCES

Bailey, M.E. & V.V. Emelýanenko 1996. Dynamical evolution of Halley-type comets. *Mon. Not R. Astron. Soc* **278** 1087–1110

Bowell, E., B. Hapke, D. Domingue, K.Lumme, J. Peltoniemi & A.W. Harris, 1989. Application of Photometric Models to Asteroids. In Asteroids II (eds R.P Binzel, T. Gehrels M. S. Matthews) University of Arizona Press. 24–556

Brown, R.H., Cruikshank, D.P. and Pendleton, Y. 1999. Water ice on Kuiper Belt Object 1996 TO_{66} *Astrophys. J.* 519 L101–104.

Cruikshank, D.P. and 15 colleagues. 1998 The composition of Centaur Pholus. *Icarus* **135**, 389–407

Davies, J.K. McBride, N, Ellison, S.E. Green, S.F. and Ballantyne D. 1998a Visible and infrared observations of six centaurs. *Icarus* **134**, 213–227

Davies, J. K., N. McBride, S.F. Green, S. Mottola, U. Carsenty, D. Basran, K.A. Hudson, and M.J. Foster 1998b. The lightcurve and colors of unusual minor planet 1996 PW. *Icarus* **132**, 418-430

Foster, M.J., S.F.Green, N.McBride & J.K. Davies 1999. Detection of Water Ice on (2060) Chiron. *Icarus* **141**, 408–410

Harris, A.W., J.W. Young, E. Bowell, L.J. Martin, R.L. Millis, M. Poutanen, F. Scaltriti, V. Zappala, H.J. Schober, H. Debehogne and K.W. Zeigler 1989. Photoelectric observations of asteroids 3, 24, 60, 261 and 863. *Icarus* **77**, 171–186.

Landolt, A.U. 1992. UBVRI photometric standard stars in the magnitude range 11.5<V<16.0 around the celestial equator. *Astron. J.* **104**, 340–371.

Luu, J., Jewitt, D.C., Trujillo, C. 2000. Water ice in (2060) Chiron and its implications for Centaurs and Kuiper Belt Objects. *Ap. J. Letts* **531** L151-154

McBride, N., Davies, J.K., Green, S.F. and Foster, M.J. 1999. Optical and infrared observations of the Centaur 1997 CU_{26}. *Mon. Not. R. Astron. Soc* **306**, 799–805

Weissman, P.R, & H. F. Levison, 1996. Origin and evolution of the unusual object 1996 PW: Asteroids From the Oort Cloud? *Astrophys J.* **488**, L133–136.

Figure captions

Figure 1. The R band data from the JKT. The final lightcurve deduced from the entire dataset plotted as a line.

Figure 2. V Band data from the UH 2.24 m telescope compared with the final lightcurve.

Figure 3. The composite lightcurve comprising data from all three telescopes in all filters.

Figure 4. Surface brightness profile of 1998 WU_{24} compared with field stars. Error bars are plotted only for 1998 WU_{24} but are similar for each profile. The faint test star (Star2) was of similar brightness to 1998 WU_{24}

Figure 5. The combined K band spectrum of 1998 WU_{24}. A model water ice spectrum kindly supplied to us By D. C. Jewitt is plotted as a solid line.

Figure 6. Relative reflectances of objects listed in Table IV.

TABLE I

Observing Circumstances

UT Date	r AU	Δ AU	$\alpha°$	Telescope	Observer	Observations
1998 Dec 19	2.158	1.412	21.2	UKIRT	THK	Spectrum
1999 Jan 17	2.425	1.530	12.5	UH 2.24 m	RJW	BVRI
1999 Jan 17	2.425	1.530	12.5	UKIRT	DT,JKD,EM	JHK
1999 Jan 18	2.434	1.538	12.04	UH 2.24 m	RJW	BVRI
1999 Jan 18	2.434	1.538	12.04	UKIRT	DJT,JKD,EM	JHK
1999 Jan 19	2.443	1.546	11.93	UKIRT	DJT,JKD,EM	J and spectrum
1999 Jan 22	2.478	1.581	11.69	JKT	JKD,SFG,MJF	R
1999 Jan 23	2.488	1.591	11.67	JKT	JKD,SFG,MJF	R
1999 Jan 22	2.498	1.601	11.67	JKT	JKD,SFG,MJF	R

TABLE II

Optical Photometry from the UH 88 2.24 m Telescope

UT	Filter	Mag
1999 Jan 17 08.8433	V	19.127± 0.019
1999 Jan 17 08.9139	V	19.133± 0.021
1999 Jan 17 08.9894	R	18.691± 0.013
1999 Jan 17 09.0672	V	19.224± 0.020
1999 Jan 17. 09.1406	I	18.303± 0.022
1999 Jan 17 09.2153	V	19.276± 0.021
1999 Jan 17 09.2875	B	20.125± 0.031
1999 Jan 17 09.3619	V	19.349± 0.021
1999 Jan 17 09.4328	V	19.377± 0.020
1999 Jan 17 09.5175	B	20.134± 0.031
1999 Jan 17 09.5928	V	19.459± 0.026
1999 Jan 17 10.1231	V	19.360± 0.024
1999 Jan 17 10.1939	V	19.388± 0.022
1999 Jan 17 10.3878	V	19.208± 0.023
1999 Jan 17 10.4728	R	18.595± 0.026
1999 Jan 17 10.5425	V	19.107± 0.030
1999 Jan 17. 10.6214	I	18.072± 0.057
1999 Jan 17 10.7458	V	19.125± 0.020
1999 Jan 17 10.8439	B	19.863± 0.015
1999 Jan 17 10.9431	V	19.044± 0.017
1999 Jan 17 12.4258	V	19.084± 0.015
1999 Jan 17 12.5078	R	18.618± 0.011
1999 Jan 17 12.5822	V	19.128± 0.014
1999 Jan 17 12.6592	I	18.212± 0.018
1999 Jan 17 12.7389	V	19.225± 0.017
1999 Jan 17 12.8267	B	19.985± 0.025
1999 Jan 17 12.9019	V	19.298± 0.019
1999 Jan 18 08.5344	V	19.164± 0.024
1999 Jan 18 08.5928	R	18.537± 0.017

UT	Filter	Mag
1999 Jan 18 08.6522	V	19.087± 0.025
1999 Jan 18 08.7178	I	18.050± 0.032
1999 Jan 18 08.7767	V	19.019± 0.021
1999 Jan 18 08.8397	B	19.757± 0.030
1999 Jan 18 08.9258	V	18.999± 0.010
1999 Jan 18 09.0458	I	17.997± 0.018
1999 Jan 18 09.1656	V	18.960± 0.009
1999 Jan 18 11.9511	V	19.228± 0.015
1999 Jan 18 12.0353	V	19.165± 0.013
1999 Jan 18 12.1219	R	18.584± 0.009
1999 Jan 18 12.2114	V	19.123± 0.012
1999 Jan 18 12.3031	I	18.035± 0.014
1999 Jan 18 12.3936	V	19.051± 0.012
1999 Jan 18 12.4903	B	19.794± 0.017
1999 Jan 18 12.5767	V	18.907± 0.019
1999 Jan 18 12.6628	R	18.482± 0.009
1999 Jan 18 12.7494	V	18.997± 0.011
1999 Jan 18 12.8397	I	17.982± 0.013
1999 Jan 18 12.9292	V	19.000± 0.012
1999 Jan 18 13.0869	B	19.751± 0.016
1999 Jan 18 13.1725	V	18.890± 0.011
1999 Jan 18 15.0153	V	19.498± 0.032
1999 Jan 18 15.0742	R	18.893± 0.018
1999 Jan 18 15.1544	V	19.420± 0.017
1999 Jan 18 15.2464	I	18.427± 0.020
1999 Jan 18 15.3361	V	19.292± 0.015
1999 Jan 18 15.4325	B	20.057± 0.022
1999 Jan 18 15.5217	V	19.253± 0.015
1999 Jan 18 15.6067	R	18.722± 0.012
1999 Jan 18 15.6933	V	19.202± 0.023
1999 Jan 18 15.7786	I	18.089± 0.014
1999 Jan 18 15.8644	V	19.114± 0.016
1999 Jan 18 15.9497	B	19.883± 0.031
1999 Jan 18 16.0353	V	19.121± 0.024

TABLE III

Infrared photometry from UKIRT

UT	Filter	Mag
1999 Jan 17 09:10:36	J	17.644 ±0.026
1999 Jan 17 09:21:57	H	17.280 ±0.033
1999 Jan 17 09:33:47	K	17.215 ±0.063
1999 Jan 17 10:03:32	J	17.661 ±0.026
1999 Jan 17 10:14:59	H	17.072 ±0.029
1999 Jan 17 10:26:49	K	16.758 ±0.043
1999 Jan 17 12:27:19	J	17.475 ±0.022
1999 Jan 17 12:38:46	H	17.233 ±0.032
1999 Jan 17 12:50:35	K	17.028 ±0.052
1999 Jan 17 15:57:40	J	17.398 ±0.036
1999 Jan 18 08:23:57	J	17.437 ±0.09
1999 Jan 18 08:37:48	H	17.011 ±0.043
1999 Jan 18 08:49:39	K	16.643 ±0.047
1999 Jan 18 09:07:09	J	17.233 ±0.06
1999 Jan 18 12:22:21	J	17.342 ±0.05
1999 Jan 18 12:33:41	H	16.874 ±0.027
1999 Jan 18 12:45;21	K	16.589 ±0.041
1999 Jan 18 15:09:08	J	17.686 ±0.03
1999 Jan 18 15:20:28	H	17.182 ±0.033
1999 Jan 18 15:32:09	K	16.983 ±0.055
1999 Jan 18 15:43:04	J	17.433 ±0.00?
1999 Jan 19 07:56:17	J	17.417 ±0.025
1999 Jan 19 15:34;10	J	17.641 ±0.027
1999 Jan 19 15:45:59	J	17.677 ±0.027
1999 Jan 19 15:57:57	J	17.826 ±0.030
1999 Jan 19 16:09:55	J	17.721 ±0.031

TABLE IV

VRI-JHK colors

Object	V−R	V−I	V−J	V−H	V−K	Notes
5145 Pholus	0.75±0.02	1.59±0.02	2.58±0.02	2.96±0.02	2.9±0.02	Centaur
(7060) Nessus	0.80±0.07	1.49±0.10[a]	2.29±0.04	2.57±0.1	2.57±0.1	Centaur
1996 PW	0.56±0.04	1.03±0.06	1.80±0.0	2.19±0.05	2.32±0.05	Inactive Comet?
1998 WU_{24}	0.53±0.037	0.99±0.035	1.66±0.043	2.10±0.076	2.33±0.102	Inactive Comet?
(10199) Chariklo	0.46±0.02	1.02±0.02	1.74±0.02	2.15±0.02	2.25±0.02	Centaur
49P/Arend-Rigaux	0.47±0.01	0.98±0.02	1.63±?	1.99±?	2.13±?	Comet
28P/Neujmin 1	0.45±0.05	0.99±0.04	1.66±0.06	2.06±0.06	2.15±0.05	Comet
1P/Halley	0.44±0.03	0.92±0.07	1.66±0.19	-	2.31±0.19	Comet
(8405) Asbolus	0.41±0.02	0.96±0.03	1.65±0.02	2.02±0.06	2.11±0.05	Centaur
1995 DW_2	0.41±0.10	0.87±0.15[c]	1.31±0.1	–	–	Centaur