# The binary Kuiper-belt object 1998 WW31

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**The recent discovery[1,2] of a binary asteroid during a spacecraft fly-by generated keen interest, because the orbital parameters of binaries can provide measures of the masses, and mutual eclipses could allow us to determine individual sizes and bulk densities. Several binary near-Earth[3–5], main-belt[6–10] and Trojan[11] asteroids have subsequently been discovered. The Kuiper belt—the region of space extending from Neptune (at 30 astronomical units) to well over 100 AU and believed to be the source of new short-period comets[12]—has become a fascinating new window onto the formation of our Solar System since the first member object, not counting Pluto, was discovered in 1992 (ref. 13). Here we report that the Kuiper-belt object 1998 WW31 is binary with a highly eccentric orbit (eccentricity $e \approx 0.8$) and a long period (about 570 days), very different from the Pluto/Charon system, which was hitherto the only previously known binary in the Kuiper belt. Assuming a density in the range of 1 to 2 g cm$^{-3}$, the albedo of the binary components is between 0.05 and 0.08, close to the value of 0.04 generally assumed for Kuiper-belt objects.**

1998 WW31 was discovered at the Kitt Peak National Observatory (KPNO) 4-m telescope in November 1998 by R. Millis and his collaborators and reported[14] as a single Kuiper-belt object (KBO). There were only a few positions on a 42-day long arc following the discovery, and no recovery observations were made during its next opposition. Recovery is a very important step in the study of KBOs: based on positions on only a short arc, the orbit of a KBO is not well constrained and the possibility of losing it after a few years without new observations is very high. The uncertain orbital parameters of lost KBOs make them nearly useless for subsequent analysis of the Kuiper belt. Therefore, 1998 WW31 was included in the list of objects to be observed during a KBO photometry and recovery programme by C.V. and A.D. scheduled in late December 2000 on the Canada-France-Hawaii 3.6-m telescope (CFHT). A first image of the field of 1998 WW31 was taken on 21 December 2000, and two additional images were obtained the following night. A first look at the images immediately after the observations did not reveal the presence of 1998 WW31. But in April 2001 C.V. re-processed all the images of the run and the object was located. Figure 1 shows a composite of the recovery images.

A first analysis of these three images (Fig. 1a) did not show any significant relative motion of the two components. It was unclear from these few images if 1998 WW31 was a true binary object, or if it only appeared to be so, by chance superposition of two non-related KBOs in different orbits but seen close to each other with apparent motions similar enough to be indistinguishable over the course of two nights. In April 2001, the solar elongation angle of 1998 WW31 was too small to allow any observation. Fortunately, we had at our disposal data taken during the previous year, allowing us to look at the object farther in the past to determine whether it was binary. In searching the CFHT archives we found seven images of 1998 WW31 taken on 6 and 7 January 2000 by J. J. Kavelaars and A. Morbidelli. We generated a new ephemeris for 1998 WW31 including our new observations, and computed the position of the KBO for the dates on which these images were taken. Thus, we were able to find 1998 WW31 on those images, embedded in the halo of a very bright star on the first night and close to another star on the second night, explaining why the other team was not successful in locating the object. In many of these images, 1998 WW31 was clearly elongated or even resolved into two components. The orientation and the separation of the components were different from those seen in our observations nearly a year later (Fig. 1), confirming that 1998 WW31 is a binary KBO.

A further search through the CFHT observing log showed that another set of observations had been taken shortly after our December run at CFHT by H. Aussel for D. Tholen. In the *Minor Planet Electronic Circulars*[15], where our recovery had been published, two observations by M. Buie at KPNO were also reported from November 2000. Subsequently, J. Parker found 1998 WW31 on images he had taken on 29 and 30 November 2000 at KPNO, and examination of these images further confirmed the presence of both components.

We contacted all the observers who had images of 1998 WW31. The ground-based observations since the 1998 WW31 discovery that had adequate seeing to resolve the components covered slightly more than two years in six main epochs. The data are of variable quality. Some of them were acquired under conditions of poor atmospheric seeing. Owing to the spacing of the observations, it was difficult to assess confidently the orbital period, though a long one (around 500 days) was more likely than a short one (150 days). To resolve this uncertainty, we obtained Director's Discretionary Time with the Hubble Space Telescope (HST) to observe 1998 WW31

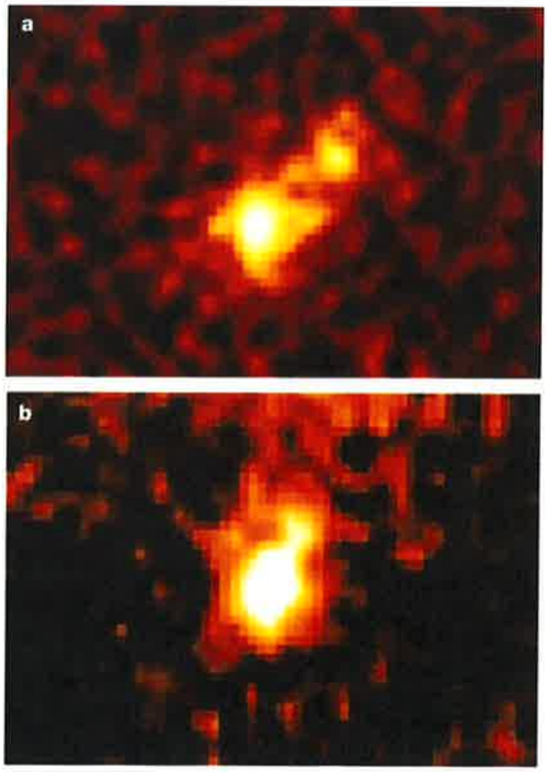

**Figure 1** 1998 WW31 on **a**, 22 December 2000 (binarity discovery image), and **b**, nearly a year earlier on 7 January 2000. The two images are composites of 3 (**a**) and 4 (**b**) raw images, respectively, taken with CFH12K, the wide-field imaging camera mounted at the prime focus of the Canada-France-Hawaii 3.6-m telescope. 1998 WW31 is clearly a double KBO, although the details of the orbit cannot be determined from these two images alone. The angular separation between the two sources is 1.2 arcsec in December 2000 and 0.8 arcsec in January 2000.

with the Wide-Field Planetary Camera 2 (WFPC2) instrument[16] once a month for three months. The first observations were scheduled at the earliest possible date, early July 2001, when the solar elongation angle of 1998 WW31 was larger than the HST solar avoidance angle. For each of our observations 1998 WW31 was centred on the planetary camera, giving a resolution of 0.046 arcsec pixel$^{-1}$.

With a separation on the sky of about 0.7 arcsec the two components were easily resolved (Fig. 2). Observations were obtained at three separate epochs: 12 July, 9 August, and 10 September 2001. At each epoch, two exposures were made through each of the F555W, F675W and F814W filters (comparable to the Johnson system V, R and I filters). Data were reduced using the standard WFPC2 pipeline[16]. We performed astrometric and photometric measurements with the Image Reduction and Analysis Facility[17] (IRAF) software. In parallel with the HST observations, we obtained ground-based observations from CFHT using the queued service observing mode operating the wide-field imager. With these coordinated observations, we were able to get a well-sampled series of images over three months (usually with excellent seeing conditions at CFHT). From all these positions, the orbit of the secondary component was determined using various weight combinations in the very inhomogeneous data set. The eccentricity was found to be at least 0.5 and not well constrained on the upper side owing to the lack of positions close to the pericentre. Even an orbit with an eccentricity as high as 0.9 could fit the observations reasonably well.

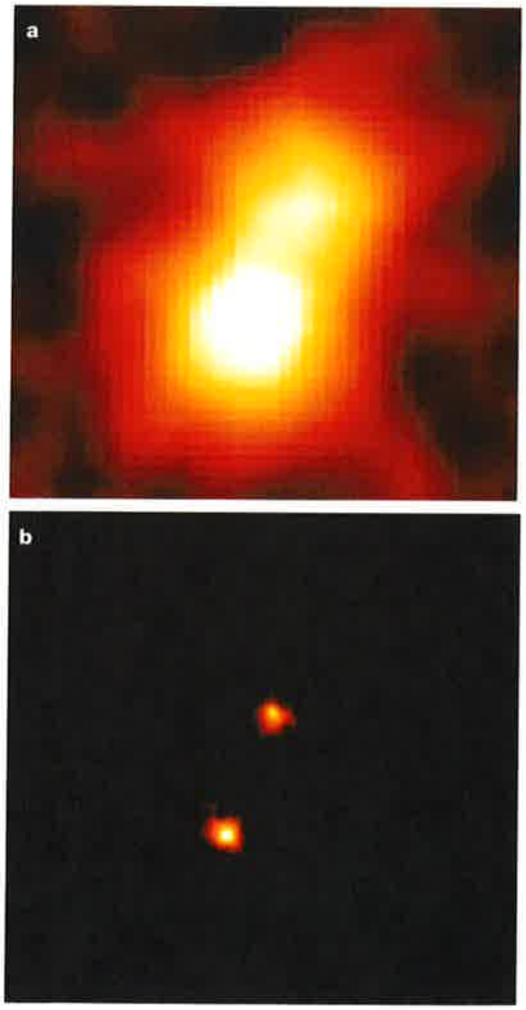

**Figure 2** 1998 WW31 seen **a**, from the ground at CFHT on 2001 September 12.5 with an excellent seeing of 0.5 arcsec, and **b**, from space with HST on September 9.7. The images are at the same scale. Separation of the components is 0.59 arcsec.

A moderate eccentricity of around 0.6 would place the date of the pericentre in early 2002, so additional HST visits were obtained on Director's Discretionary Time on 30 December 2001 and 19 January 2002 to refine the ellipticity of the orbit. An additional set of HST observations made on 13 December 2001, obtained as part of a separate programme, were made available to us by K. Noll. These observations, made through filters identical to those used in our observations did however place the image of 1998 WW31 on the wide-field camera, and hence were of resolution half that of our other HST observations.

Figure 3 shows our best fits to the observations. The orbit computation algorithms developed for WW31 were first checked and confirmed with the pair Pluto/Charon, using the HST observations[18]. The same algorithms were then applied to the 1998 WW31 pair. The uncertainties assigned to the observations and used for determining the formal uncertainty on the orbital elements, are outlined on Fig. 3. Two sets of orbital elements were computed: the first one uses only the HST observations, and the second one uses the whole set of observations. Results are given in Table 1. The HST observations, which cover one-third of the orbital period, comprise two short arcs (60 and 40 days long, respectively) separated by 100 days, with the pericentre occurring between them. The eccentricity is therefore well determined, but other elements, especially the period and the overall orbital geometry, are dramatically improved when all data are used, in spite of the lower quality of the early observations.

The 1998 WW31 pair is very different from the Pluto/Charon system, as seen on Table 1. The most unusual feature of the orbit is its eccentricity, the largest one found in a binary asteroid. Additional HST observations will allow us to follow the faint component as it goes through the apocentre and to determine better the period and

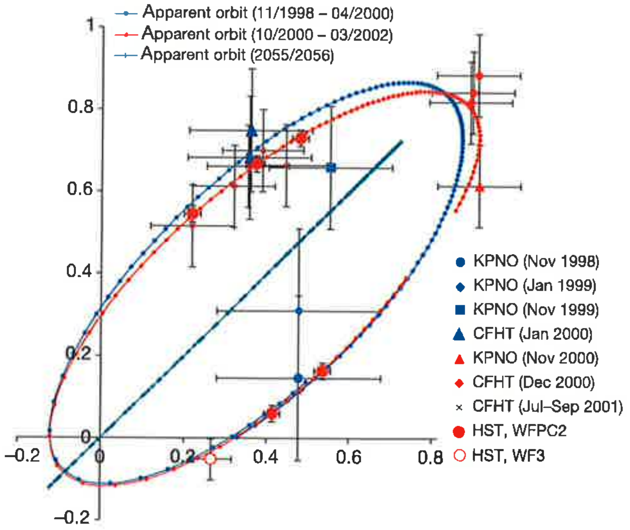

**Figure 3** 1998 WW31 observations, from the ground and from the Hubble Space Telescope. Coordinates are seconds of arc. North is up and East is to the right. The apparent orbits at the time of the observations are shown with one dot every five days. The apparent orbit in 2055/2056 (green line) is also plotted to show that mutual eclipses could happen at some point nearly 50 years from now (with a few years uncertainty). The following uncertainties were assigned on the relative apparent rectangular coordinates of the faint component relative to the main one (in arcsec): 0.02 for the HST WFPC2 observations (red circles), 0.05 for the WF3 observation (open red circle; pair poorly resolved), 0.1 for the data close to the apocentre (red triangle and diamonds), 0.2 for the two earliest ground-based observations (blue circles and diamonds), and 0.15 for all the others.

**Table 1 Relative orbital elements of 1998 WW31 binary system**

| | All observations | HST only | Charon |
|---|---|---|---|
| Period (days) | 574 (10) | 521 (133) | 6.3872 |
| Semi-major axis (km) | 22,300 (800) | 21,200 (2,400) | 19,366 |
| Eccentricity | 0.817 (0.05) | 0.800 (0.10) | 0.0076 |
| Inclination (degrees) | 41.7 (7) | 43.8 (10) | 96.16 |
| Node longitude (degrees) | 94.3 (8) | 94.6 (10) | 223.0 |
| Pericentre longitude (degrees) | 253.8 (7) | 251.8 (9) | |
| Mean longitude at epoch (degrees) | 43.4 (4) | 48.7 (16) | |
| Epoch (Julian date) | 2,452,300.5 | 2,452,300.5 | |
| R band magnitudes | | | |
| Pair | 23.6 | | |
| A | 24.2 | | |
| B | 24.6 | | |
| Same albedo | | | |
| Diameter ratio | 1.2 | | |
| Mass ratio | 1.74 | | |
| Same density 2.0 g cm$^{-3}$ (similar to Pluto) | | | |
| Diameters (A, B) | 118 km, 98 km | | |
| Albedo | 0.086 (0.007) | | |
| Same density 1.5 g cm$^{-3}$ | | | |
| Diameters (A, B) | 129 km, 108 km | | |
| Albedo | 0.071 (0.006) | | |
| Same density 1.0 g cm$^{-3}$ | | | |
| Diameters (A, B) | 148 km, 123 km | | |
| Albedo | 0.054 (0.005) | | |

The orbital elements (mean equator and equinox of J2000.0) of the secondary component, B, of the 1998 WW31 system with respect to its primary, A. (Formal uncertainties in brackets are based on the uncertainties assigned to the individual measurements used as outlined in Fig. 3.) Also shown are the physical properties of the 1998 WW31 components derived from the mass of the system as determined from the orbital parameters (period and semi-major axis), for various assumptions on their density. The orbital elements based only on the HST data are shown to stress the importance of the ground observations in spite of their poorer quality. Charon's elements are from ref. 14.

semi-major axis; however, even the values presented in this paper are accurate enough to lead to a good estimate of the mass of the system.

The orbit is not determined well enough to predict with precision when mutual eclipses could happen. With the present solution, eclipses could take place in 2055 or 2056. The HST observations scheduled for the next opposition will allow a better prediction of when mutual events will occur.

Using both ground-based and HST observations, the two components are found to have a magnitude difference in R band of 0.4 and a total magnitude of 23.6. If we assume that they have the same albedo, their diameter ratio is 1.2. If they have the same density, it is possible to get the mass of each component. The diameters can be estimated assuming a given density. An albedo can then be derived from the observed magnitude and the estimated diameter. Table 1 summarizes the results obtained assuming various densities from 1 to 2 gm cm$^{-3}$ (Pluto's density is about 2 gm cm$^{-3}$). The associated albedo values are in the range 0.05 to 0.08. The albedo of cometary nuclei, 0.04 (ref. 19), is the value generally assumed and used for KBO size estimation; however, if we use that low albedo value for 1998 WW31, then the KBO would have a very low density of roughly 1 gm cm$^{-3}$, considerably less than the density of Pluto.

The announcement of the binarity of 1998 WW31 was the first of what has become a series of binary KBO discoveries. Within less than a year after our announcement of the binarity of 1998 WW31, six other KBOs have been discovered to be binaries: 2001 QT297 (ref. 20) and 2001 QW322 (ref. 21) using ground-based observations, and 1999 TC36 (ref. 22), (26308) 1998 SM165 (ref. 23), 1997 CQ29 (ref. 24), and 2000 CF105 (ref. 25) using HST. We now know of seven binary systems in a sample of nearly 600 objects. Although we have to be careful when dealing with small numbers, binarity is definitely not uncommon in the Kuiper belt, comprising at least 1% of the currently known KBO population. ☐

Received 5 December 2001; accepted 27 February 2002.

1. Chapman, C. R. *et al.* Discovery and physical properties of Dactyl, a satellite of asteroid 243 Ida. *Nature* **374,** 783–785 (1995).
2. Belton, M. J. S. *et al.* The discovery and orbit of 1993 (243)1 Dactyl. *Icarus* **120,** 185–199 (1995).
3. Margot, J. L. *et al.* Satellites of minor planets. *IAU Circ.* 7503 (2000).
4. Benner, L. A. M. *et al.* 1999_KW4. *IAU Circ.* 7632 (2001).
5. Nolan, M. C. *et al.* 2000_UG11. *IAU Circ.* 7632 (2000).
6. Merline, W. J. *et al.* Discovery of a moon orbiting the asteroid 45 Eugenia. *Nature* **401,** 565–567 (1999).
7. Merline, W. J. *et al.* Discovery of companions to asteroids 762 Pulcova and 90 Antiope by direct imaging. DPS Meeting 32, abstr. no. 13.06 (American Astronomical Society, 2000).
8. Brown, M. E. & Margot, J. L. S/2001 (87) 1. *IAU Circ.* 7588 (2001).
9. Merline, W. J. *et al.*; Margot, J. L. & Brown, M. E. S/2001 (22) 1. *IAU Circ.* 7703 (2001).
10. Merline, W. J. *et al.* S/2002 (3749) 1. *IAU Circ.* 7827 (2002).
11. Merline, W. J. *et al.* S/2001 (617) 1. *IAU Circ.* 7741 (2001).
12. Duncan, M., Quinn, T. & Tremaine, S. The origin of short-period comets. *Astrophys. J.* **328,** L69–L73 (1988).
13. Jewitt, D. C. & Luu, J. X. 1992 QB1. *IAU Circ. 5611* (1992).
14. Millis, R. L. *et al.* 1998 WW31. *Minor Planet Electron. Circ. 1999-B24* (2001).
15. Veillet, C. *et al.* 1998 WW31. *Minor Planet Electron. Circ. 2001-G29* (2001).
16. Holtzman, J. *et al.* The performance and calibration of WFPC2 on the Hubble Space Telescope. *Publ. Astron. Soc. Pacif.* **107,** 156–178 (1995).
17. Image Reduction and Analysis Facility. (http://iraf.noao.edu).
18. Tholen, D. J. & Buie, M. W. The orbit of Charon. *Icarus* **125,** 245–260 (1997).
19. Jewitt, D., Aussel, H. & Evans, A. The size and albedo of the Kuiper-belt object (20000) Varuna. *Nature* **411,** 446–447 (2001).
20. Elliot, J. L., Kern, S. D., Osip, D. J. & Burles, S. M. 2001 QT_297. *IAU Circ. 7733* (2001).
21. Kavelaars, J. J. *et al.* 2001 WQ_322. *IAU Circ. 7749* (2001).
22. Trujillo, C. A. & Brown, M. E. 1999 TC_36. *IAU Circ. 7787* (2001).
23. Brown, M. E. & Trujillo, C. A. (26308) 1998 SM_165. *IAU Circ. 7807* (2001).
24. Noll, K. *et al.* 1997 CQ_29. *IAU Circ. 7824* (2002).
25. Noll, K. *et al.* 2000 CF_105. *IAU Circ.* 7857 (2002).

**Acknowledgements**

C.V., A.D., D.J.T. and M.C. are visiting astronomers at the Canada-France-Hawaii Telescope (CFHT), operated by the National Research Council of Canada, the Centre National de la Recherche Scientifique of France and the University of Hawaii. J.Wm.P. and M.B. are visiting astronomers at the Kitt Peak National Observatory, National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc. (AURA) under cooperative agreement with the National Science Foundation. This work, supported by funding from NASA, is partly based on observations made with the NASA/ESA Hubble Space Telescope, obtained at the Space Telescope Science Institute, which is operated by AURA under a NASA contract.

**Competing interests statement**

The authors declare that they have no competing financial interests.

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# Electrical detection of spin precession in a metallic mesoscopic spin valve

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**To study and control the behaviour of the spins of electrons that are moving through a metal or semiconductor is an outstanding challenge in the field of 'spintronics', where possibilities for new electronic applications based on the spin degree of freedom are currently being explored[1–5]. Recently, electrical control of spin coherence[6] and coherent spin precession during transport[7] was studied by optical techniques in semiconductors. Here we report controlled spin precession of electrically injected and detected electrons in a diffusive metallic conductor, using tunnel barriers in combination with metallic ferromagnetic electrodes as spin injector and detector. The output voltage of our device is sensitive to the spin degree of freedom only, and its sign can be switched from positive to negative, depending on the relative magnetization of the ferromagnetic electrodes. We show that the spin**