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VOLUME 19, 2002

An international journal of astronomy and astrophysics

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Publ. Astron. Soc. Aust., 2002, 19, 422–424

A Search for the Potentially Hazardous Asteroid 1998 OX_4: Implications for a Possible Close Encounter in 2014

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Received 2001 December 12, accepted 2002 May 21

Abstract: Small bodies of 100–500 m diameter can cause significant damage on impact with the Earth. Such objects are difficult to detect and track because they are intrinsically faint over most of their orbit. We failed to detect one such lost and potentially hazardous minor planet, 1998 OX_4, during two observing sessions in 2001, January. The positions searched were those calculated by Milani et al. (2000) with their Virtual Impactors method. Using some simple assumptions we estimate the probability that we failed to detect 1998 OX_4 due to it being obscured by objects in the field of our observations is $<2 \times 10^{-7}$. If the assumptions in the Virtual Impactor model are valid we conclude that an impact with 1998 OX_4 is unlikely in 2014, January. Furthermore, given the relatively large area we searched it is also unlikely that this minor planet will have a very close encounter with Earth in 2014.

Keywords: asteroids: impacts — orbit — 1998 OX_4

1 Introduction

Minor planet 1998 OX_4 was discovered by Scotti during observations with the Spacewatch telescope in 1998, July (MPEC 1998-O27). Around this time it was intrinsically faint and unfavourable conditions resulted in it only being observed over nine days (McMillan 1999). Given this short interval, its orbital parameters are not well known and it has not been observed since that time.

However, 1998 OX_4 is no ordinary minor planet. Orbit calculations by the NEODyS group[1] indicate it is a potentially hazardous asteroid and there is a small, but non-zero, probability that this object will collide with Earth. Furthermore, this is one of very few objects with a non-zero impact probability (see NEODyS risk page[2]) and this will remain the best probability estimate until it is observed again.

A non-zero probability of impact for a lost minor planet is obviously a matter for concern. In order to address this issue Milani et al. (2000) have developed a method for obtaining the potential orbits of a lost minor body. First, they calculate the dates of possible future very close encounters with Earth based on the known observations. Second, for each close encounter they calculated the family of orbits that are consistent with both the existing observations and an actual impact with Earth during the close encounter. Each of these is the 'orbit' of a Virtual Impactor (VI). Given these well-defined orbits they next search for favourable opportunities to observe these VIs. Null detection of a VI associated with a future close encounter then reduces the probability that any of this family of orbits is the actual orbit of the minor planet, and this in turn reduces the probability of impact during that encounter.

Milani et al. (2000) calculated one very favourable observing interval around 2001, January for the VI of 2014, January, and another two intervals (2001, February and 2003, February) were calculated for its VIs of 2038, 2044, and 2046. We acquired observations in 2001, January when the predicted VI brightness was well above our instrument's detection threshold.

In Section 2, we describe the instrument used to search for the 1998 OX_4 VI of 2014, and in Section 3, we provide the details of our observations. Section 4 provides an analysis of the observations and we present our conclusions in Section 5.

2 Instrument Parameters

Our observations were acquired using the Mike Candy Telescope (MCT) at Perth Observatory. This is an equatorially-mounted 25 cm aperture telescope with a SBIG ST-8 CCD camera at its Newtonian focus. Its focal ratio of 4.5 combined with the dimensions of the ST-8 camera give it a pixel size of $1''.6$, and a field of view approximately $35'$ by $22'$ in right ascension and declination, respectively. (In camera co-ordinates the declination axis is rotated 30° east of north.) This wide field is quite advantageous to the telescope's major application of performing astrometric observations of newly discovered minor bodies.

3 Observations

We obtained the predicted VI positions for our observing sessions by interpolating an ephemeris available from the NEODyS group at the time (see Milani et al. 2000).

[1]http://newton.dm.unipi.it/neodys
[2]http://newton.dm.unipi.it/cgi-bin/neodys/neoibo?riskpage:0;main

10.1071/AS02002 1323-3580/02/04422$05.00

Table 1. Predicted and observed parameters of the 1998 OX_4 VI of 2014

Date (UT)	Predicted position (h m s ° ′ ″)		R mag	Motion (″/min)	
2001 01 25.58	08 45 44	+05 17 43	14.6	1.0	
2001 01 29.75	08 49 25	+04 58 31	15.9	0.3	
	Observed position (h m s ° ′ ″)		Limiting R mag	Average FWHM (″)	Probability
2001 01 25.54	08 45 43	+05 13 48	17.1	5.4	0.015
2001 01 25.56	08 45 43	+05 13 56	17.1	5.0	0.014
2001 01 25.59	08 45 46	+05 13 54	17.1	5.1	0.015
2001 01 29.74	08 49 28	+04 57 40	17.5	4.9	0.011
2001 01 29.76	08 49 29	+04 58 28	17.5	4.6	0.009
2001 01 29.77	08 49 30	+04 58 34	17.5	4.8	0.009

R magnitudes were calculated from the V magnitudes using the standard minor planet colour transformation $V - R = 0.4$. On each of two nights we acquired three 300 s unfiltered exposures at the predicted position of the VI in accordance with standard procedures used in the Perth Observatory minor body astrometry programme. The details of the predictions and our observations are presented in Table 1.

The shape of the VI search region was approximately elliptical with extent 10′ in right ascension and 16′ in declination (Milani et al. 2000). This region was totally encompassed inside the camera's field of view because the latter was a factor of five larger. It should be noted that for the observations of 2001, January 25 the region is still encompassed inside the field of view. The rotation of the right ascension and declination axes with respect to the camera axes diminishes the effect of telescope pointing offsets in one axis (south in this case, see Table 1).

4 Data Analysis

All the images acquired were given the standard CCD pre-processing. A commercially available astrometry package was utilised to blink compare the processed data from each night. No moving objects were detected in the fields observed on either night. Such observations acquired in the Perth Observatory minor body astrometry programme can usually detect moving objects as faint as $V \sim 17.5$ ($R \sim 17.1$) with motion $<1''.5$/min (for example, see MPEC 2001-A04 and MPEC 2001-A08).

The astrometry software was also used to estimate the centre of each image in order to check the pointing of the telescope. These positions are given in Table 1. The Perth Observatory minor body astrometry programme routinely provides positions to the Minor Planet Center with an accuracy of $<1''$ (see for example MPEC 2000-Y24). However, given the wide field of view of the MCT, such accuracy is not required for the telescope pointing and this is reflected in Table 1.

An estimate of the magnitude of the faintest detectable source was undertaken for each image. The ST-8 camera is more sensitive at red wavelengths (Santa Barbara Instrument Group 1994) and so a crude calibration in R was undertaken. The R magnitudes for 10 sources near the centre and 10 sources in a corner of each field were extracted from the USNO-A2.0 catalogue (Monet et al. 1998) and the astrometry software determined their signal-to-noise ratios (S/Ns) in the observations. The weakest detectable source was estimated by fitting a straight line to the R − S/N data and finding the R value corresponding to $S/N = 20$. Coma distortion on the field edges caused the faintest detectable source to be nearly 0.2 magnitudes brighter in the corners compared to the centre of the field. These brighter magnitude estimates are quoted in Table 1 and they indicate that the faintest detectable sources are approximately 2.5 and 1.6 magnitudes fainter than that predicted for the 1998 OX_4 VI of 2014 in the earlier and later observations, respectively.

In order to check the sensitivity estimates in Table 1 the Minor Planet Center's checker facility[3] was used to search for any other known minor body in the field of view. This search revealed that minor planet 1990 WZ (19996) was the brightest object in either of the two fields, having $V \sim 17.8$ and motion of $\sim 0''.5$/min on 2001 January 25. However, this is 0.3 magnitudes below the sensitivity limit and was not detectable.

Minor body motion can cause the images to be trailed and this reduces the S/N and hence detectability. We estimated the magnitude of this effect by modelling the VI image using a Gaussian point spread function, with a FWHM the average of those quoted in Table 1, whose centroid moved according to the motion of the VI. This revealed that our observations with the MCT would suffer a reduction in VI peak signal of <0.3 magnitudes for the observations of January 25 and the effect is negligible in the later observations. Therefore, motion does not have a significant impact on our null detection.

An upper limit for the probability that the VIs were hidden in stellar and cosmic ray images was estimated in the

[3] http://scully.harvard.edu/~cgi/CheckMP

following way. First, the pixel value that corresponded to one half of the peak value in a stellar source with a magnitude predicted by Milani et al. (2000) for the VI was calculated. The probability that the VI was hidden was estimated by the number of pixels with values greater than or equal to the half-peak value divided by the total number of pixels. These probability values are given in Table 1. The probability that the VI was not detectable due to it being effectively hidden was estimated to have the value 3×10^{-12} by calculating the probability that the VI was hidden in all three images acquired in both observing sessions. A more conservative probability estimate of 2×10^{-7} was calculated by assuming that the VI was imaged in one of the three exposures in each session, but could not be identified because it was hidden in the other two exposures. It should be noted that we detected very few transient sources, and most were probably cosmic ray hits, and we therefore feel justified in claiming that the probability estimate is an upper limit. Furthermore, this is a very conservative upper limit as we used conservative detection limits and have not considered all the relevant VI parameters. For example, a more thorough search for VIs would use their predicted motion in order to restrict the number of stellar images that could actually hide them.

5 Conclusions

We failed to detect any moving object in both observing sessions. This is consistent with other searches (see NEODyS VI results[4]). A conservative analysis of the results presented here suggests that the probability of the existence of the 1998 OX_4 VI of 2014 as defined by Milani et al. (2000) is $<2 \times 10^{-7}$. The corollary to this is that if the method of Milani et al. (2000) is valid then it is unlikely that 1998 OX_4 will impact Earth in 2014. Presumably if 1998 OX_4 was detected just outside the VI region we searched it would imply that it will not impact but have a close encounter with Earth in 2014. A very close encounter also seems unlikely because our field of view was five times larger than the actual VI search region.

However, we cannot absolutely rule out a collision in 2014. Our conclusions rely on the VI magnitude estimates and Milani et al. (2000) warn that the paucity of 1998 OX_4 data precludes accurate magnitude input into their VI method.

Clearly, the best information about possible impacts with 1998 OX_4 awaits its recovery and monitoring. Only then can we be certain about its orbit.

Acknowledgements

JDB acknowledges the fine work of the Perth Observatory technical staff Arie Verveer and John Pearse for the design, construction, and ongoing maintenance of the MCT, and the taxpayers of the state of Western Australia for supporting this work. MS acknowledges the receipt of a Summer Studentship from the Department of Applied Physics, Curtin University of Technology, and Perth Observatory, during which this work was undertaken.

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