

Occultations of HIP and UCAC2 stars down to 15^m by large TNO in 2004-2014

© 2004 D.V. Denissenko

Space Research Institute (IKI), Moscow, Russia

Received 27 February 2004

Occultations of stars brighter than 15^m by largest TNOs are predicted. Search was performed using the following catalogues: Hipparcos; Tycho2 with coordinates of 2838666 stars taken from UCAC2 (Herald, 2003); UCAC2 (Zacharias et al., 2003) with 16356096 stars between 12.00 and 14.99 mag to the north from -45 declination. Predictions were made for 17 largest numbered transneptunian asteroids, recently discovered 2004 DW and 4 known binary Kuiper Belt objects. 64 events occurring at solar elongation of 30° and more are selected, including exceptionally rare occultation of 6.5^m star by double (66652) 1999 RZ₂₅₃ on 2007 October 4th. Observations of these events by all available means are extremely important since they can provide unique information about the size of TNOs and improve their orbits dramatically.

INTRODUCTION

Over 800 Transneptunian Objects (TNO) are discovered since 1992 with 67 of them being numbered and 7 having proper names as of February 2004. No reliable measurements of their sizes have been obtained so far. Angular sizes even of the largest objects are about 0.04"±0.01" (Quaoar) which is at the limit of Hubble Space Telescope resolution. Most size estimates are based on the indirect methods strongly dependant on assumptions. Albedoes 0.04-0.08 are generally supposed for TNOs, but they are definitely varying among different objects.

The only direct method to measure sizes of single TNOs at present is observing stellar occultations by them. Over 500 occultations of stars by Main Belt asteroids have been observed so far, with 17% of them having 5 or more chords measured. For some objects size and shape were determined with an equivalent angular resolution of 0.002".

OCCULTATIONS BY TNO

TNOs are typically at 30-50 AU distances from the Earth corresponding to 0.2"-0.3" parallax. This means that occultation will only happen somewhere on the Earth if the geocentric path of the object passes within 200-300 mas from the star. Combined with a very slow angular motion of TNO (0.1-1 mas per second of time) it makes rate of stellar occultations by them about three orders of magnitude smaller than by main belt asteroids and about 100 times less than that of Jovian Trojans, approximately inversely proportional to $(a-1)^2$.

Estimates show that any given TNO will occult a star brighter than 15^m on average approximately every 4 or 5 years. For ~10⁵ HIPPARCOS stars brighter than 10-11^m we should be expecting one occultation in 10 years by 20 largest transneptunian objects, and only one event per century for ~10⁴ stars brighter than 6.5^m.

STAR CATALOGUES ACCURACY

Error in coordinates of occulted star will significantly increase the uncertainty of both event time and position. At 40 AU distance, 1 milliarcsecond is corresponding to 30 km. 0.25" error in star coordinates will shift the occultation path by ~1 Earth radius. Since the positions of Transneptunian objects are known to 0.25" uncertainty, 0.05" accuracy of the star coordinates will be acceptable. Before 2003, coordinates were known to milliarcsecond accuracy for ~100000 stars in HIPPARCOS catalogue. Tycho2 catalogue including ~2 Mln stars usually brighter than 12^m is essentially a by-product of the same HIPPARCOS project. It has systematic and statistical errors typically within 0.1"-0.2" but reaching 0.5"-1.0" in some fields. Thus Tycho2 is not satisfactory for predicting occultations by TNO.

Situation in astrometry was revolutionized in 2003 with the release of 2nd USNO CCD Astrograph Catalogue UCAC2 (Zacharias et al.) with coordinates and proper motions for 48 Mln stars between 8^m and 16^m. Position errors of 12^m stars in UCAC2 are 15-20 mas and 40-50 mas for 15^m. This catalogue does not cover areas to the north from +45..+52 declination, but that is not a problem since no objects involved in current search will reach ±45 declination during next 10 years.

PREDICTIONS FOR 2004-2014

Occultations from 2004 Jan 27 to 2014 Dec 31 were computed for the following objects:

a) Recently discovered largest known TNO 2004 DW with absolute mag $H_0=2.2-2.4$;

b) 17 numbered objects with $H_0<5.5$

2.6 (50000) Quaoar

3.2 (28978) Ixion

3.3 (55565) 2002 AW₁₉₇
 3.3 (55636) 2002 TX₃₀₀
 3.6 (55637) 2002 UX₂₅
 3.7 (20000) Varuna
 4.2 (42301) 2001 UR₁₆₃
 4.5 (19308) 1996 TO₆₆
 4.7 (26375) 1999 DE₉
 4.7 (38628) Huya
 4.8 (24835) 1995 SM₅₅
 4.9 (19521) Chaos
 4.9 (47171) 1999 TC₃₆ (binary)
 5.2 (26181) 1996 GQ₂₁
 5.3 (55638) 2002 VE₉₅
 5.4 (15874) 1996 TL₆₆
 5.4 (48639) 1995 TL₈

c) 3 numbered binary TNO

5.8 (26308) 1998 SM₁₆₅
 5.9 (66652) 1999 RZ₂₅₃
 6.6 (58534) 1997 CQ₂₉

Single body diameters were calculated from H_0 by the formula $\log D[\text{km}]=3.52-0.2*H_0$. This corresponds to assumed albedo of 0.16 and is a conservative estimate. For (50000) Quaoar this formula gives 1000 km which is in a good agreement with the lower limit from Hubble direct imaging (1260±300 km). If albedo is 0.04, actual size of TNO will be exactly twice the value listed in table. For binary asteroids with two bodies of the same size and albedo diameter of each component will be $0.71*D$.

Orbits of selected TNO from 2004 Jan. 27th version of astorb.dat (Bowell, 2004) were integrated through the end of 2014 and all geocentric conjunctions within 0.5" to HIP and UCAC2 stars were found. For the year 2004 occultations by 36 largest unnumbered objects with $H_0<5.5$ were also computed and 9 events have been found. Mean value of current ephemeris uncertainty (CEU) was 0.26" for the numbered objects and 1.0" for unnumbered ones.

OCCULTATIONS OF STARS BY TNO 2004-2014

Results of the search are presented in table. Intervals of time (rounded to 5 minutes) are given when occultation may happen on the night part of Earth with 0.25" uncertainty at both sides already taken into account. Due to the different speed of TNOs relative to Earth (from 25 km/s at opposition to 5 km/s and even less near the stationary point) these interval may vary from ~10 minutes to 1.5 hour in case of Varuna occultation in 2012. For double asteroids extra 0.25" were added since orbital distances in these pairs are also estimated as 6-8 thousand km.

Exceptional occultation of 6.5^m K0 star HIP 111398 = HD 213780 = SAO 146161 = ZC 3313 in Aquarius by binary object (66652) 1999 RZ₂₅₃ in 2007 should be noted. Additional observations of this TNO on the largest telescopes are extremely important to predict the separation and positional angle of components at the epoch of the event. International campaign involving observers in Australia, New Zealand, China, Japan, eastern Russia and Hawaii should be organized to measure the sizes and shape of this binary system.

Finder charts and preliminary path plots for occultations listed here are available at <http://hea.iki.rssi.ru/~denis/TNOocc.html> or by E-mail request to denis@hea.iki.rssi.ru.

OBSERVING METHODS

Observations can be performed by several techniques and different kinds of equipment. In principle, highest temporal resolution is not necessary for occultations by TNO. With event durations about several dozen seconds and even 2-3 minutes in some cases, 1-3 sec integration time will already give the unprecedented chord measurement accuracy. This is why one can use CCD imaging, CCD in drift-scan mode, photometers, high-sensitivity videocameras and even visual

observations with stopwatch. CCD readout time should be reduced to minimum by binning pixels and exposing small window instead of full frame. Optimal exposure time should be selected depending on the magnitude of occulted star and detector sensitivity. Precise absolute timing of star disappearance and reappearance is not critical since with 5-10 minutes uncertainty of event time even 1-second accuracy will improve the orbital position by two orders of magnitude. For bright occultations fast photometers can provide the measurements of occulted star diameter at unprecedented angular resolution. Since TNOs are moving at 0.1-1 mas/sec rate (500-5000 times slower than the Moon), new close binaries can be discovered which are impossible to resolve by any other methods.

DISCUSSION

Search was intentionally limited to the largest objects with ephemeris uncertainty of 0.3" or better. Although smaller objects might (and definitely will!) occult brighter stars, detection probability of those events would be much smaller compared to those listed here. It is preferable to concentrate on 2-5 "special" events each year. Success can only be achieved by the joint efforts planned well in advance. Worldwide observations by as many telescopes as possible are necessary. Prediction of events till 2014 will allow to make changes in tight observing schedules at the large scopes. Additional observations of selected TNOs to improve ephemeris and prediction accuracy are also encouraged. New large objects will definitely be found in the nearest future. Predictions of occultations by them will be posted at author's site together with updates on those listed here.

APPLICATIONS

Positive observation of stellar occultation by TNO will make significant impact in several areas of astronomy at once. It will allow to:

- measure the size and shape of these distant objects directly which is impossible by other means;
- give indications on their composition, and together with estimates of masses in binary systems directly determine their density;
- improve orbital position by 10-50 times assisting possible space missions to TNO;
- provide unique information valuable for understanding the theory of Solar system evolution;
- discover probable close binary objects with the separations between components of the order of 1000 km.

ACKNOWLEDGEMENTS

I would like to thank Alexander Yascovich for lending the copies of UCAC2 catalogue and Andrei Plekhanov for writing LinOccult program which was used to plot the maps of occultation paths posted on the website.

REFERENCES

- Bowell E., <http://www.lowell.edu/users/elgb> (2004)
- Brown M. E., Trujillo C. A., IAU Circular 7807 (2002)
- Dunham, D. W.; Goffin, E.; Manek, J.; Federspiel, M.; Stone, R.; Owen, W., Mem. Soc. Astr. Ital., Vol. 73, No. 3, p. 662 (2002)
- Herald, D., Cat.1291....0H (2003)
- Marsden B. G., Minor Planet Electronic Circular 2004-D15 (2004)
- Noll K., Stephens D., IAU Circular 7824 (2002)
- Noll K., Stephens D., IAU Circular 8143 (2003)
- Stone, R. C.; McDonald, S. W.; Elliot, J. L.; Bowell, E., The Astron. Journ., Vol. 119, No. 4, pp. 2008-2017 (2000)
- Trujillo C. A., Brown M. E., IAU Circular 7787 (2002)
- Zacharias, N.; Urban, S. E.; Zacharias, M. I.; Wycoff, G. L.; Hall, D. M.; Germain, M. E.; Holdenried, E. R.; Winter, L., Cat.1289....0Z (2003)

OCCULTATIONS OF STARS BY TNO 2004-2014

Date of event		Time	Asteroid	size	Dur	Star	R.A. (2000.0) Dec					Mag		
Year	Mon	DD	(UT)	name	km	sec	Name	hh	mm	ss.sss	dd	mm	ss.ss	
2004	Jan	29	23:35-23:55	2003 AZ84	568	23.4	2UCAC 36806754	07	12	19.883	+14	04	20.02	14.5
2004	Feb	14	22:10-22:35	2001 XR254	255	14.2	TYC 1343-00785-1	06	54	14.687	+21	37	48.10	11.6
2004	Mar	07	03:15-03:30	2000 CO105	268	14.7	2UCAC 39141168	08	23	16.013	+20	33	01.42	12.3
2004	Mar	08	02:10-02:25	1999 CC158	241	11.6	2UCAC 40185292	09	15	58.264	+23	38	56.76	13.7
2004	Mar	20	13:35-13:45	1996 TL66	275	10.5	2UCAC 36232084	03	00	28.306	+12	40	40.89	13.4
2004	Mar	27	00:20-00:40	2002 KW14	302	21.2	2UCAC 24855750	15	34	29.721	-18	18	28.41	13.6
2004	Apr	07	10:30-11:00	2001 KD77	252	24.7	2UCAC 23658681	16	58	51.823	-20	36	51.67	11.7
2004	Jun	26	19:55-20:05	Chaos	347	11.6	2UCAC 40137180	04	08	53.436	+23	56	34.41	13.2
2004	Jun	29	18:25-19:10	1997 CQ29	158	9.5	2UCAC 34467578	11	04	07.504	+07	39	54.56	14.5
2004	Aug	08	23:15-23:30	2001 QD298	257	10.5	2UCAC 24989527	21	52	30.098	-18	08	13.32	14.5
2004	Nov	15	09:00-09:25	2000 CN105	340	32.5	2UCAC 35937214	10	34	08.639	+11	59	33.61	14.3
2005	Mar	13	21:25-21:35	2002 UX25	631	21.6	2UCAC 34953654	01	37	42.194	+09	22	06.65	13.2
2005	May	07	01:05-01:40	1999 RZ253	219	14.9	2UCAC 28298467	22	29	21.656	-10	02	41.04	14.9
2005	Sep	29	07:50-08:10	1995 SM55	363	16.6	2UCAC 39255131	02	07	19.531	+21	06	25.09	14.1
2005	Oct	24	08:05-08:30	1998 SM165	229	9.4	2UCAC 33162437	01	31	09.061	+04	23	37.99	14.4
2005	Dec	27	09:15-09:35	Huya	380	17.9	2UCAC 30864992	14	20	27.168	-02	54	42.58	11.7
2006	Jun	18	20:25-20:50	1999 KR16	229	17.4	2UCAC 28922119	14	18	38.914	-08	29	05.17	13.7
2006	Jul	26	07:55-08:25	Ixion	759	55.9	2UCAC 22945926	16	34	14.971	-22	04	37.89	13.7
2006	Oct	07	19:30-19:45	Ixion	759	36.0	2UCAC 22946030	16	35	05.045	-22	11	08.86	13.8
2007	Aug	04	04:20-04:35	2002 VE95	288	15.8	2UCAC 35331886	04	14	47.942	+10	08	18.19	13.0
2007	Oct	04	11:10-11:50	1999 RZ253	219	11.2	HIP 111398	22	34	06.604	-09	36	30.64	6.5
2008	Jan	22	06:55-07:30	Chaos	347	26.0	2UCAC 40810575	04	21	06.919	+25	33	26.70	10.8
2008	Feb	11	04:20-04:40	Varuna	603	28.8	TYC 1913-00670-1	07	18	50.100	+25	43	19.31	11.3
2008	Sep	10	12:25-13:15	Quaoar	1000	149.5	2UCAC 26249129	17	05	49.913	-15	20	44.26	13.7
2008	Sep	30	07:20-07:40	Ixion	759	44.6	2UCAC 22496420	16	44	05.610	-23	18	07.11	13.6
2008	Oct	07	19:40-19:55	Ixion	759	37.3	2UCAC 22496543	16	44	33.933	-23	19	19.45	12.8
2008	Dec	07	01:55-02:20	Varuna	603	29.0	2UCAC 40846256	07	29	48.171	+25	40	07.71	14.8
2009	Mar	10	08:25-08:40	2002 VE95	288	19.7	2UCAC 34960757	04	17	00.297	+09	18	45.63	13.3
2009	May	01	13:50-14:15	Quaoar	1000	54.1	2UCAC 26252549	17	18	12.542	-15	24	49.90	14.3
2009	Jul	18	04:40-04:50	2002 VE95	288	10.8	HIP 21308	04	34	30.274	+10	00	58.46	7.7
2009	Aug	22	10:40-11:15	2002 UX25	631	68.5	2UCAC 35326247	02	09	00.114	+10	07	56.40	14.1
2009	Sep	25	11:05-11:30	1995 TL8	275	15.1	TYC 1223-00579-1	02	40	23.728	+15	46	01.74	11.6

DENISSENKO D.V.

Date of event		Time	Asteroid	size	Dur	Star	R.A. (2000.0) Dec						Mag	
Year	Mon	DD	(UT)	name	km	sec	Name	hh	mm	ss.sss	dd	mm	ss.ss	
2009	Oct	09	10:15-10:35	2002 TX300	724	28.6	2UCAC 41650964	00	37	13.610	+28	22	22.98	13.1
2009	Oct	15	17:55-18:10	Quaoar	1000	45.8	2UCAC 26023237	17	12	33.132	-15	30	54.97	15.0
2010	Feb	19	22:55-23:20	Varuna	603	32.3	TYC 1914-00301-1	07	29	22.470	+26	07	23.23	11.0
2010	Jul	19	01:35-02:05	Ixion	759	42.4	2UCAC 22032118	16	54	25.862	-24	24	22.86	11.5
2011	Feb	22	02:25-02:50	1995 TL8	275	18.3	2UCAC 37301105	02	39	37.120	+15	41	48.75	13.6
2011	Jun	01	11:05-11:25	Ixion	759	30.3	2UCAC 21584537	17	03	39.446	-25	01	27.82	14.7
2011	Aug	03	22:35-23:10	1999 RZ253	219	10.8	2UCAC 29384710	22	59	38.963	-07	02	53.38	14.6
2011	Nov	04	00:35-00:50	Quaoar	1000	35.9	2UCAC 26027484	17	24	23.771	-15	38	43.34	14.6
2011	Dec	18	11:40-12:50	1999 TC36	347	40.7	2UCAC 32137136	01	35	51.911	+01	13	15.69	14.1
2012	Apr	16	04:20-04:55	Ixion	759	55.9	TYC 6816-00401-1	17	12	26.791	-25	34	10.85	10.8
2012	May	01	03:35-03:55	1999 RZ253	219	10.2	2UCAC 29759182	23	04	54.428	-06	29	06.50	14.9
2012	Jun	01	17:55-18:15	Quaoar	1000	41.3	2UCAC 26259184	17	32	11.415	-15	24	30.06	13.5
2012	Jun	04	01:10-01:30	1996 GQ21	302	14.0	2UCAC 28386513	15	19	25.744	-09	50	28.94	14.8
2012	Oct	07	04:30-04:45	2002 AW197	724	30.2	2UCAC 32701289	09	34	01.570	+02	31	43.27	14.7
2012	Oct	28	19:50-21:25	Varuna	603	144.8	2UCAC 41016878	07	53	29.509	+26	05	51.86	13.4
2013	Jan	29	06:10-06:30	Varuna	603	24.2	2UCAC 41187592	07	47	50.499	+26	31	18.27	14.8
2013	Feb	18	11:40-12:50	Chaos	347	93.9	2UCAC 41496855	04	49	59.491	+27	50	52.79	14.4
2013	May	28	18:35-18:55	1999 KR16	229	10.1	2UCAC 29288802	15	13	08.695	-07	07	13.91	11.7
2013	Jun	02	22:20-22:35	Ixion	759	30.4	2UCAC 21139770	17	14	19.280	-26	08	23.27	14.4
2013	Oct	23	13:20-13:35	Ixion	759	31.3	2UCAC 21137306	17	10	57.419	-26	07	23.91	14.2
2013	Dec	06	09:10-09:20	Huya	380	11.0	TYC 5025-00448-1	15	39	28.493	-05	37	11.16	10.1
2013	Dec	20	14:05-14:40	2002 TX300	724	55.4	TYC 2276-01081-1	00	52	46.890	+31	03	39.18	11.4
2013	Dec	27	17:20-17:50	1995 SM55	363	23.4	2UCAC 42006839	02	40	01.674	+29	27	23.90	13.3
2014	Jan	24	01:35-01:50	Quaoar	1000	34.9	2UCAC 26041319	17	43	03.235	-15	45	10.63	14.6
2014	Mar	01	16:30-16:45	2004 DW	1200	45.9	TYC 5476-00882-1	09	58	22.549	-08	16	55.27	12.1
2014	Mar	10	15:25-15:55	1997 CQ29	158	6.3	2UCAC 32542503	11	58	36.918	+02	28	27.68	11.9
2014	Apr	15	01:50-02:00	1996 TL66	275	9.9	2UCAC 34961430	04	26	07.463	+09	23	13.78	14.7
2014	Jul	24	14:20-15:10	Huya	380	51.0	TYC 5024-00589-1	15	36	41.149	-04	36	29.35	11.7
2014	Aug	14	21:40-22:40	1996 GQ21	302	48.1	HIP 75882	15	29	58.355	-10	03	19.73	9.1
2014	Sep	13	08:35-09:20	2002 VE95	288	27.1	2UCAC 34784210	05	31	16.439	+08	55	17.49	12.3
2014	Oct	20	14:45-15:25	1999 RZ253	219	12.4	2UCAC 29941401	23	09	49.521	-05	59	47.15	14.5
2014	Nov	08	22:00-22:15	Quaoar	1000	35.4	2UCAC 26039148	17	40	27.392	-15	41	59.91	13.9