Contrib. Astron. Obs. Skalnaté Pleso **37**, 69 – 82, (2007)

Selected OrbFit impact solutions for asteroids (99942) Apophis and (144898) 2004 VD17

I. Wlodarczyk

Chorzow Astronomical Observatory (MPC 553), 41-500 Chorzow, Poland (E-mail: astrobit@ka.onet.pl)

Received: October 8, 2006; Accepted: March 27, 2007

Abstract. During the Meeting on Asteroids and Comets in Europe - in May 12-14, 2006 in Vienna - there have been presented certain results of computations of possible impacts of (99942) Apophis and (144898) 2004 VD17 on the Earth. These results were obtained from computations performed with the use of OrbFit software. The results were then compared with impact solutions presented by the JPL Sentry System and by NEODyS CLOMON2. In all author's computations two version of the OrbFit Software, Package: 3.3.1 and Package 3.3.2, were used. These packages are free downloadable from http://newton.dm.unipi.it/neodys/astinfo/orbfit/.

The influence of relativistic effects, radar observations, the number of additional perturbing asteroids, different JPL Ephemeris of Solar System and use of the multiple solution method were investigated. It became apparent that the greatest influence on computation of the exact impact solutions have relativistic effects and the close approaches of massive asteroids with (99942) Apophis and (144898) 2004 VD17. With the use of the free OrbFit software and its source code almost the same results of possible impact solutions for (99942) Apophis and for (144898) 2004 VD17 as those given on the NEODyS www page were obtained. Additionally, it was possible to change the output format and the kind of output results. The OrbFit is an interactive software which requires some knowledge of celestial mechanics as authors say.

Key words: asteroids – celestial mechanics

1. Introduction

The best systems with the exact impact solutions for dangerous asteroids are presented by the JPL Sentry System (http://neo.jpl.nasa.gov/risk/) and by the NEODyS CLOMON2
(http://131.114.72.13/cgi-bin/neodys/neoibo?riskpage:0;main).
For several months on the top of these lists there are two asteroids: (99942) Apophis and (144898) 2004 VD17. Thanks to the courtesy of those who made free available OrbFit software and its source code at:
http://newton.dm.unipi.it/neodys/astinfo/orbfit/ it is now possible to compute individually dates of possible impacts of selected dangerous asteroids or the

energy of impact and others impact factors. In this respect we investigated the motion of these recently discovered minor planets: (99942) Apophis and (144898) 2004 VD17 - the most dangerous for the Earth, according to the Impact Risk Page of NASA (*http://neo.jpl.nasa.gov/risk/*).

To compute exact impact solutions of asteroids it is necessary to include some additional small effects on the asteroid's motion. The influence of relativistic effects, the perturbing massive asteroids, different ephemeris of Solar System was investigated. To compute gravitational forces perturbing the motion of (99942) Apophis and (144898) 2004 VD17 from different massive asteroids, the free software Solex from A. Vitagliano was used:
http://chemistry.unina.it/ alvitagl/solex/. SOLEX computes positions of the solar system bodies by a method which is entirely based on the numerical integration of the Newton equation of motions (Vitagliano, 1997). With the use of Solex it was possible to compute all close approaches between (99942) Apophis and (144898) 2004 VD17 and all nearly 140000 numbered asteroids. Similar work with (15) Eunomia using Solex was done by Vitagliano and Stoss (2006).

Selected orbit solutions for (99942) Apophis and (144898) 2004 VD17 were presented during the Meeting on Asteroids and Comets in Europe - May 12-14, 2006 in Vienna, Austria.

The new version of OrbFit (3.3.2) gives better results of computations of impact probability mainly with the use of a non linear monitoring and multiple solutions method (Milani et al., 2002, Milani et al., 2005a and Milani et al., 2005b). The main goal of our work was to compare our results generated by OrbFit with the results presented by CLOMON2 SYSTEM which uses the same OrbFit software and with the results of JPL NASA SENTRY. The second purpose was to prove how differently small effects in motion of asteroid influence impact solutions. This was possible thanks to the source code of OrbFit.

The orbital uncertainty of an asteroid is viewed as a cloud of possible orbits centered on the nominal solution, where density is greatest. This is represented by the multivariate Gaussian probability density and the use of this probability density relies on the assumption that the observational errors are Gaussian (Milani et al., 2002).

2. Some impact solutions for (99942) Apophis

2.1. The influence of σ and radar observation

The orbital elements of (99942) Apophis in Tab. 1 were computed by the author using all 1007 observations up to this date (Sep. 14th, 2006) and the software OrbFit where M - mean anomaly, a - semimajor axis, e - eccentricity, ω_{2000} - argument of perihelion, Ω_{2000} - longitude of the ascending node, i_{2000} - inclination of the orbit. These orbital elements are referred to the *J2000* equator and equinox.

Table 1. (99942) Apophis: orbital elements

M	$a[AU]$	e	ω_{2000}	Ω_{2000}	i_{2000}
(99942) Apophis - 1007 observations from 885 days (2004/03/15.11 - 2006/08/16.63), rms=0.302"					
nominal orbit: epoch 2006 Jun. 14.0					
333°.507245	0.92226793	0.19105946	126°.393030	204°.460151	3°.331317

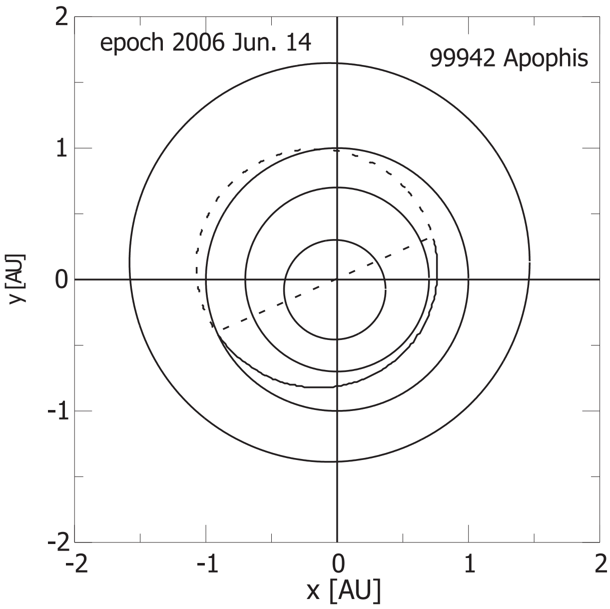

Figure 1. The orbit of (99942) Apophis projected to the ecliptic plane, where x-axis is directed to vernal equinox

Fig. 1 presents the orbit of (99942) Apophis projected to the ecliptic plane, where x-axis is directed to vernal equinox. The dotted lines indicate the part of the orbit below the ecliptic plane. It is clearly seen that the orbit of this asteroid crosses the orbit of the Earth and approaches that of Venus.

The influence of the radar observations in computations of impact solutions for (99942) Apophis were performed using all observations available before the date of MACE 2006. There were 987 optical observations (of which 6 were rejected as outliers) from 2004/03/15.108 to 2006/03/26.509, and also seven radar data points on 2005/01/27, 2005/01/29, 2005/01/31 and 2005/08/07.

Tab. 2 lists impact solutions for (99942) Apophis computed by the author for these settings: multiple solutions, use scaling, line of variation (LOV) with

the largest eigenvalue (Milani et al. 2002) in comparison with those published at the NEODYS CLOMON2 site:
http://newton.dm.unipi.it/cgi-bin/neodys/neoibo?riskpage:0;main
and at the NASA SENTRY site: http://neo.jpl.nasa.gov/risk/. The software OrbFit ver. 3.3.1 for UNIX was used. In this impact table everywhere weighing of observations was as CLOMON2. In Tab. 2 *date* is a calendar day for the potential impact; *dist.[RE]* - minimum distance, the lateral distance from LOV (line of variation, which represent the central axis of the asteroid's elongated uncertainty region); *impact probability* - computed with a Gaussian bidimensional probability density; *IW* - computed solutions by the author of this paper; *nr* denotes a solution without radar observations and σ - an approximate location along the LOV in sigma space; values of sigma are usually in the interval [-3,3] which represent 99.7 % probability of occurrence of real asteroid in this confidence region (Milani et al. 2002). The impact probability is not reported if the computed value is less than 1E-11. The presented σ are only the input data in the OrbFit software, not the real σ - positive or negative, along the LOV. For example σ=3 denotes that the real σ is between -3 and +3. The differences between the results from NEODyS and SENTRY are evident because they are independent systems as stated at:
http://neo.jpl.nasa.gov/risk/doc/sentry_faq.html.

From the results in Tab. 2 we can see that we must include radar observations in computations of impact solutions for (99942) Apophis. Without radar observations we have no impact solutions in 2042, 2044, 2053 and beyond 2063 year. Instead we have mistaken dates of possible impacts in 2035, 2046, 2055 and 2056 years. The usefulness of radar observations is presented, e.g., in the paper of Yeomans et. al. (1987).

No impact solutions for σ=1 were found. Time of computations of a single solution was about 3 hrs with a 1.7 Mhz processor.

2.2. (99942) Apophis: approaching asteroids

To compute exactly impact solutions for (99942) Apophis it is necessary to include gravitational perturbations of approaching massive asteroids. Usually SENTRY include 3 massive asteroids ((1) Ceres, (2) Pallas and (4) Vesta), CLOMMON2 - as SENTRY or 4 asteroids (Ceres, Pallas, Vesta and (10) Hygiea). Using the software Solex, ver. 9.0, we have investigated all close approaches of about 140,000 numbered asteroids known in Sept. 2006 with (99942) Apophis within 0.2 AU till 2100 year.

We have found 4 asteroids with several close approaches to (99942) Apophis: (433) Eros, (887) Alinda, (1685) Toro and (1866) Sisyphus. These selected asteroids together with the 4 massive ones (Ceres, Pallas, Vesta and Hygiea) were included in to equations of motion of (99942) Apophis. The computations of influence of gravitational perturbations of these asteroids for the motion of (99942) Apophis were performed using the software OrbFit, ver. 3.3.1. The masses of

Table 2. (99942) Apophis: influence of different σ and radar observations for computed impact solutions

date	dist.[RE]	impact probability	source
2035/04/14.131	1.36	1.82E-05	IW, 3σ, nr
2036/04/13.371	1.15	1.61E-04	CLOMON2
2036/04/13.370	0.53	1.6 E-04	SENTRY
2036/04/13.371	1.14	3.46E-05	IW, 3σ
2036/04/13.371	1.15	1.02E-04	IW, 3σ , nr
2036/04/13.371	1.14	3.46E-05	IW, 6σ
2037/04/13.644	1.36	1.96E-07	CLOMON2
2037/04/13.640	0.63	2.0 E-07	SENTRY
2037/04/13.644	1.36	2.46E-05	IW, 3σ, nr
2037/04/13.644	1.36	1.45E-08	IW, 6σ
2038/04/13.659	1.73	1.59E-10	CLOMON2
2040/04/13.135	1.65	8.17E-09	IW, 3σ
2040/04/13.173	1.11	3.40E-08	IW, 3σ, nr
2042/04/13.726	1.80	3.62E-07	CLOMON2
2042/04/13.710	0.99	4.6 E-07	SENTRY
2042/04/13.719	1.38	9.29E-08	IW, 3σ
2044/04/13.297	2.10	2.57E-07	CLOMON2
2044/04/13.296	2.08	5.89E-08	IW, 3σ
2044/04/13.264	1.79	6.23E-11	IW, 6σ
2046/04/13.797	1.98	3.84E-08	IW, 3σ, nr
2053/04/12.913	1.39	1.80E-07	IW, 3σ
2054/04/13.401	1.46	6.95E-09	CLOMON2
2054/04/13.400	0.60	7.2 E-09	SENTRY
2054/04/13.403	1.27	1.14E-06	IW, 3σ, nr
2054/04/13.404	1.30	4.79E-10	IW, 6σ
2055/04/13.730	1.25	4.33E-07	IW, 3σ, nr
2056/04/12.867	0.70	3.71E-08	IW, 3σ , nr
2059/04/13.954	2.08	4.31E-10	CLOMON2
2059/04/13.954	2.07	4.81E-08	IW, 3σ , nr
2059/04/13.953	2.07	3.48E-11	IW, 6σ
2063/04/13.796	1.30	1.80E-10	CLOMON2
2063/04/13.795	1.26	1.18E-11	IW, 6σ
2068/04/12.631	0.69	1.77E-06	IW, 3σ
2068/04/12.631	0.26	1.04E-06	IW, 6σ
2069/04/13.078	0.97	2.58E-07	CLOMON2
2069/04/13.078	0.99	2.46E-07	IW, 3σ
2069/10/15.972	0.48	1.20E-07	CLOMON2
2069/10/15.970	0.41	2.55E-07	IW, 3σ
2069/10/15.970	0.27	2.32E-07	IW, 6σ
2078/04/13.442	1.93	5.23E-09	CLOMON2

asteroids were taken from Michalak (2001) and from Solex as computed by A. Vitagliano. It is possible to compare these values with those on http://aa.usno.navy.mil/hilton/asteroid_masses.htm.

First of all we must include Ceres in our gravitational model which has about 30 % of the mass of the main belt asteroids and the asteroids which have the closest approaches to (99942) Apophis. All results in Tab. 3 are computed using the JPL Planetary and Lunar Ephemerides DE405 and including relativistic effects.

The suitable results in Tab. 3 were computed based on 996 optical observations of which 5 are rejected as outliers from 2004/03/15.108 to 2006/07/27.614, and also on seven radar data points on 2005/01/27, 2005/01/29, 2005/01/31, 2005/08/07 and 2006/05/06.

In Tab. 3 and in all others SENTRY denotes the results from NASA and CLOMON2 from the NEODYS site. The author results are: *IW-a*: no perturbing asteroids; *IW-b*: Ceres and 4 close approaching asteroids to (99942) Apophis: Eros, Alinda, Toro, Sisyphus; *IW-c*: 4 perturbing asteroids: Ceres, Pallas, Vesta, Hygiea; *IW-d*: 5 perturbing asteroids: Ceres, Pallas, Vesta, Hygiea and approaching asteroid Eros; *IW-e*: 3 perturbing asteroids: Ceres, Pallas and Vesta.

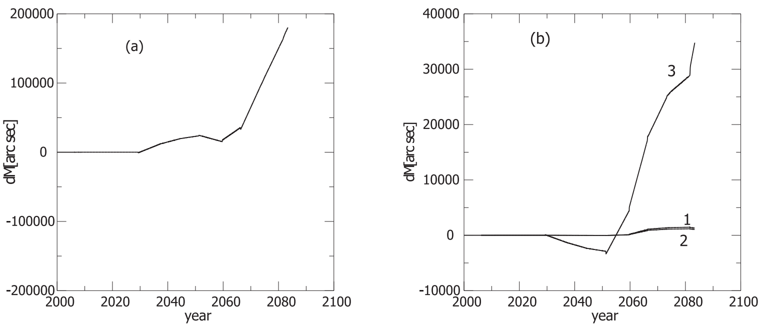

Figure 2. (99942) Apophis. Differences in the mean anomaly between nominal orbits from different solutions: *(a)* - 4 perturbing asteroids: relativistic/non relativistic effects included; *(b)* - different number of perturbing asteroids (see text)

Fig. 2 shows the changes of differences in the mean anomaly between asteroid (99942) Apophis on nominal orbits for different cases. In Fig. 2(a) there are differences in mean anomaly between (99942) Apophis with and no relativistic effects included. Fig. 2(b) presents differences in mean anomaly of (99942) Apophis between orbits computed without perturbing asteroids and with perturbation from: *1* - Ceres, Pallas and Vesta, *2* - Ceres, Pallas, Vesta, and Hygiea and *3* - Ceres, Pallas, Vesta, Hygiea and Eros.

Table 3. (99942) Apophis: Influence of approaching asteroids for impact solutions

date	dist.*[RE]*	impact probabillity	source
2036/04/13.370	0.53	2.2 E-05	SENTRY
2036/04/13.371	1.15	2.40E-05	CLOMON2
2036/04/13.371	1.15	2.40E-05	IW-a
2036/04/13.371	1.15	2.12E-05	IW-b
2036/04/13.371	1.15	2.39E-05	IW-c
2036/04/13.371	1.15	2.12E-05	IW-d
2036/04/13.371	1.15	2.39E-05	IW-e
2037/04/13.640	0.63	8.5 E-08	SENTRY
2042/04/13.715	2.06	6.59E-08	CLOMON2
2042/04/13.718	1.37	6.61E-08	IW-a
2042/04/13.717	1.40	6.09E-08	IW-b
2042/04/13.717	1.38	6.73E-08	IW-c
2042/04/13.717	1.40	6.11E-08	IW-d
2042/04/13.717	1.38	6.73E-08	IW-e
2044/04/13.296	2.09	4.07E-08	CLOMON2
2044/04/13.298	2.13	3.89E-08	IW-a
2044/04/13.294	2.11	3.70E-08	IW-b
2044/04/13.298	2.13	3.45E-08	IW-d
2053/04/12.913	1.39	1.27E-07	CLOMON2
2054/04/13.400	0.59	2.7 E-09	SENTRY
2068/04/12.630	0.62	1.79E-06	IW-a
2068/04/12.630	0.52	1.63E-06	IW-c
2068/04/12.633	0.48	8.19E-07	IW-d
2068/04/12.631	0.37	1.03E-06	IW-e
2069/04/13.079	2.00	4.43E-07	CLOMON2
2069/04/13.078	0.97	5.51E-07	IW-b
2069/04/13.079	0.96	4.72E-07	IW-c
2069/10/15.596	0.62	1.02E-07	CLOMON2
2069/10/15.972	0.49	2.63E-07	CLOMON2
2069/10/15.970	0.38	4.70E-07	IW-b
2069/10/15.972	0.59	2.90E-07	IW-c
2069/10/15.971	0.56	4.21E-07	IW-d
2077/04/13.166	1.79	4.33E-08	CLOMON2

It is clear from Fig. 2(a) that a relativistic effects play a great role in motion of an asteroid - over 30 degs difference in mean anomaly between asteroids with and no these effects in the next 100 years. However in Fig. 2(b) the influence of close approaching asteroids is evident.

The rapid changes in differences in the mean anomaly in Fig. 2 are connected with the close approaches of (99942) Apophis to the Earth in the years 2029 (0.00025 AU) and 2057 (0.022 AU) for the nominal orbits. Hence chaoticity of the motion of the asteroid appears (Włodarczyk, 2001). The influence of the relativistic effects and the number of perturbing asteroids on impact solutions for (99942) Apophis are listed in Tab. 3.

2.3. (99942) Apophis: JPL ephemerides

The question arose how the model of Solar System used influence the impact solutions of (99942) Apophis. Generally JPL Planetary and Lunar Ephemerides DE203, DE405 or DE406 (SENTRY), DE405 (CLOMMON2), DE406 (some in this paper) or DE405/WAW (Sitarski, 2002) were used. DE405 ephemerides (including both nutations and librations) are computed for the time span from JED 2305424.50 (1599 DEC 09) to JED 2525008.50 (2201 FEB 20). DE406 is a new "JPL Long Ephemeris" (including neither nutations nor librations). They work for the time span from JED 0624976.50 (-3001 FEB 04) to 2816912.50 (+3000 MAY 06). This is the same ephemeris as DE405, though the accuracy of the interpolating polynomials has been lessened.

Using the OrbFit software, v.3.3.2, for Linux and 994 optical observations of (99942) Apophis from 2004/03/15.108 to 2006/06/02.602, and also on seven radar data points on 2005/01/27, 2005/01/29, 2005/01/31, 2005/08/07 and 2006/05/06 we have found some impact results for different planetary ephemerides.

Table 4. (99942) Apophis: Influence of JPL Ephemerides on impact solutions

date	dist.*[RE]*	author	JPL
2036/04/13.371	1.15	CLOMON2	(DE405)
2036/04/13.371	1.15	IW	DE405
2036/04/13.371	1.15	IW	DE406
2042/04/13.720	1.41	CLOMON2	(DE405)
2042/04/13.718	1.37	IW	DE405
2042/04/13.718	1.37	IW	DE406
2044/04/13.295	2.09	CLOMON2	(DE405)
2044/04/13.295	2.08	IW	DE405
2044/04/13.295	2.05	IW	DE406

As we can see from Tab. 4 the results for JPL ephemerides DE405 and DE406 are almost the same. However, Andrea Milani in his e-mail on June 6, 2006, wrote: "A particularly good result (using DE405 or DE406), given the strong instability of these solutions, as a result of the very close approach in 2029. My congratulations for your very accurate computations."

3. Some impact solutions for (144898) 2004 VD17

3.1. The influence of σ and weighting

The orbital elements of (144898) 2004 VD17 presented in Tab. 5 were computed using all known observations up to September 14, 2006, by the author with the software OrbFit 3.3.2 for Linux where M - mean anomaly, a - semimajor axis, e - eccentricity, ω_{2000} - argument of perihelion, Ω_{2000} - longitude of the ascending node, i_{2000} - inclination of the orbit. These orbital elements are referred to the *J2000* equator and equinox.

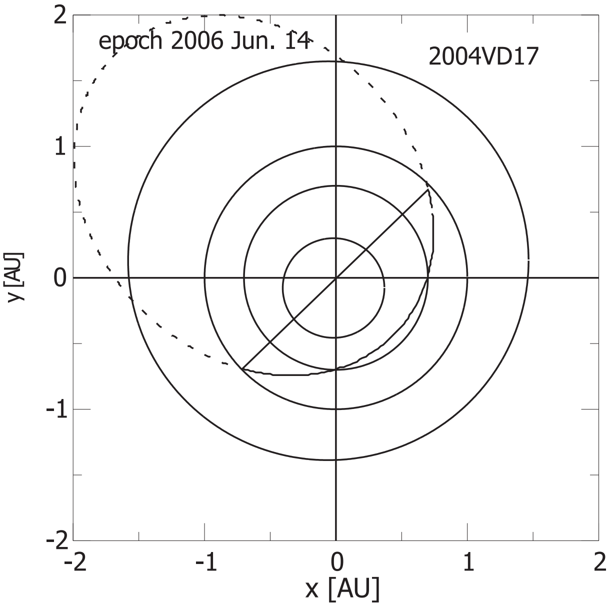

Figure 3. The orbit of (144898) 2004 VD17 projected onto the ecliptic plane, where x-axis is directed to vernal equinox

Fig. 3 presents the orbit of (144898) 2004 VD17 projected onto the ecliptic plane, where x-axis is directed to vernal equinox. The dotted lines indicate the part of the orbit below the ecliptic plane. The orbit of this asteroid crosses the orbit of the Earth and that of Venus.

The impact solutions of (144898) 2004 VD17 in Tab. 6 were computed using 891 optical observations (of which 1 was rejected as outlier) from 2002/02/16.462 to 2006/04/22.871. These observations were available up to date of MACE 2006. Tab. 6 shows that the influence of σ and weighting of observations has a small influence for impact solutions for (144898) 2004 VD17 . Mainly it has an effect on the value of impact probability. A similar problem of scaling of LOV (Mi-

Table 5. (144898) 2004 VD17: the orbital elements

M	$a[AU]$	e	ω_{2000}	Ω_{2000}	i_{2000}
(144898) 2004 VD17 - 933 observations from 1553 days (2002/02/16.46 - 2006/05/24.10), *rms*=0.351”					
The nominal orbit: epoch 2006 Jun. 14.0					
$340\overset{\circ}{.}212924$	1.5082009	0.58866739	$90\overset{\circ}{.}686443$	$224\overset{\circ}{.}242137$	$4\overset{\circ}{.}223018$

lani et al., 2002) is neglected in this case. Otherwise everywhere weighing is as CLOMON2, further settings are: multiple solution, use scaling, LOV with the largest eigenvalue; w=1 denotes without weighing of observations.

On the MPML (Minor Planet Mailing List) forum the problem was connected with the 4 first observations of (144898) 2004 VD17 recovered from 2002 year. It seems that adding these observations does not affect impact solutions considerably. In Tab. 6 *fn* denotes impact solutions without first four observations from 2002.

3.2. (144898) 2004 VD17: approaching asteroids

As for (99942) Apophis, to compute exactly impact solutions for (144898) 2004 VD17 it is necessary to include gravitational perturbations of approaching asteroids. Using the software Solex90 we have computed all close approaches of about 140,000 numbered asteroids known in Sept. 2006 with (144898) 2004 VD17 till 2110 year. We have found 5 asteroids with several close approaches to (144898) 2004 VD17 : (3) Juno, (6) Hebe, (7) Iris, (18) Melpomene and (51) Nemausa. These selected asteroids with the 4 massive ones were included into equations of motion of (144898) 2004 VD17 .

The computations of influence of gravitational perturbations of these asteroids for the motion of (144898) 2004 VD17 were performed using the software OrbFit 3.3.1. The masses of asteroids were taken from Michalak (2001) and from the Solex90 as computed by Vitagliano (1997). The computations were based on 902 optical observations (of which 3 are rejected as outliers) from 2002/02/16.462 to 2006/04/29.090. The results are given in Tab. 7 where:
IW-a: 3 perturbing asteroids: Ceres, Pallas and Vesta;
IW-b: 4 perturbing asteroids: Ceres, Pallas, Vesta, Hygiea;
IW-bnrel: as *IW-b* without relativistic effects included;
IW-c: 5 close approaching asteroids to (144898) 2004 VD17 : Juno, Hebe, Iris, Melpomene and Nemausa;
IW-d: no perturbing asteroids;
IW-f: all 9 perturbing asteroids: Ceres, Pallas, Juno, Vesta, Hebe, Iris, Hygiea, Melpomene and Nemausa.

Table 6. (144898) 2004 VD17: Influence of different σ and weighting for impact soulutions

date	dist.*[RE]*	impact probability	source
2102/05/04.894	0.51	6.66E-4	CLOMON2
2102/05/04.890	0.44	6.7 E-4	SENTRY
-	-	-	IW, 1σ
2102/05/04.894	0.52	6.71E-4	IW, 1.5σ
2102/05/04.894	0.52	6.22E-4	IW, 1.5σ, w=1
2102/05/04.894	0.52	6.71E-4	IW, 2σ
2102/05/04.894	0.52	6.71E-4	IW, 2σ, w=1
2102/05/04.894	0.52	6.66E-4	IW, 3σ
2102/05/04.894	0.52	6.22E-4	IW, 3σ, w=1
2102/05/04.894	0.52	6.30E-4	IW, 3σ, no scal.
2102/05/04.894	0.52	9.37E-4	IW, 3σ,fn
2102/05/04.894	0.52	6.71E-4	IW, 4σ
2102/05/04.894	0.52	6.71E-4	IW, 5σ
2102/05/04.894	0.52	6.71E-4	IW, 6σ
2104/05/04.373	0.58	3.26E-7	CLOMON2
-	-	-	SENTRY
-	-	-	IW, 1 σ
2104/05/04.372	1.05	3.29E-7	IW, 1.5σ
2104/05/04.377	1.15	3.14E-7	IW, 1.5σ, w=1
2104/05/04.374	0.54	3.29E-7	IW, 2σ
2104/05/04.374	0.54	3.29E-7	IW, 2σ, w=1
2104/05/04.373	0.74	3.29E-7	IW, 3σ
2104/05/04.374	0.52	3.10E-7	IW, 3σ, w=1
2104/05/04.374	0.55	3.15E-7	IW, 3σ, no scal.
2104/05/04.375	0.58	4.80E-7	IW, 3σ, fn
2104/05/04.374	0.52	3.31E-7	IW, 4σ
2104/05/04.376	0.88	3.38E-7	IW, 5σ
2104/05/04.374	0.54	3.36E-7	IW, 6σ
2105/05/04.655	0.41	3.84E-8	IW, 3σ, no scal.
2109/05/04.637	0.62	9.72E-9	IW, 1.5σ, w=1

All results in Tab. 7 are computed with DE405 ephemeris and taking into account relativistic effects (without case *IW-bnrel*).

Fig. 4 shows the changes of differences in the mean anomaly between asteroid (144898) 2004 VD17 on nominal orbits for different cases. In Fig. 4 (a) there are differences in the mean anomaly between (144898) 2004 VD17 with and without relativistic effects included. Fig. 4 (b) presents differences in mean anomaly of (144898) 2004 VD17 between orbits without perturbing asteroids (solution *IW-d*) and with ones: 1 - solution *IW-a* (Ceres, Pallas and Vesta included), 2 - *IW-b* (Ceres, Pallas, Vesta, Hygiea), 3 - *IW-c* (Juno, Hebe, Iris, Melpomene, Nemausa), 4 - *IW-f* (Ceres, Pallas, Juno, Vesta, Hebe, Iris, Hygiea, Melpomene,

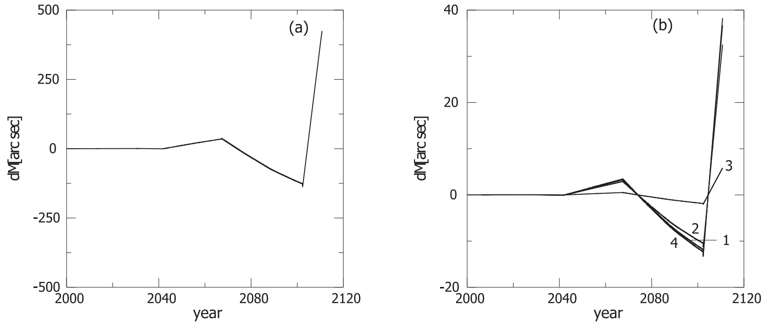

Figure 4. (144898) 2004 VD17. Differences in the mean anomaly between nominal orbits from different solutions: (a) - 4 perturbing asteroids: relativistic/non relativistic effects included; (b) - different number of perturbing asteroids (see the text)

Table 7. (144898) 2004 VD17: Influence of approaching asteroids on impact solutions

date	dist.*[RE]*	impact probability	source
2102/05/04.894	0.51	5.58 E-04	CLOMON2
2102/05/04.894	0.52	5.53 E-04	IW-a
2102/05/04.894	0.52	5.61 E-04	IW-d
2102/05/04.894	0.52	5.54 E-04	IW-b
2102/05/04.893	0.53	6.37 E-04	IW-bnrel
2102/05/04.894	0.52	5.59 E-04	IW-c
2102/05/04.894	0.52	5.53 E-04	IW-f
2102/05/04.890	0.44	7.35 E-04	SENTRY
2103/05/05.130	0.96	1.48 E-08	CLOMON2
2103/05/05.132	0.74	1.52 E-08	IW-b
2104/05/04.376	0.91	2.77 E-07	CLOMON2
2104/05/04.374	0.53	2.77 E-07	IW-a
2104/05/04.374	0.53	2.76 E-07	IW-d
2104/05/04.372	1.08	2.68 E-07	IW-b
2104/05/04.373	0.61	3.08 E-07	IW-bnrel
2104/05/04.376	0.87	2.78 E-07	IW-c
2104/05/04.377	1.09	2.74 E-07	IW-f
2109/05/04.515	0.84	7.60 E-09	IW-f

Nemausa). The curves 1, 2 and 4 in Fig. 4 are very similar, so that the most perturbing effect comes from Ceres, Pallas and Vesta.

As in the case of (99942) Apophis the greatest influence on the motion (144898) 2004 VD17 have relativistic effects. We must also use perturbing massive asteroids for computed impact solutions as Tab. 7 states. The rapid changes in differences in the mean anomaly in Fig. 4 are connected with the close approaches of (144898) 2004 VD17 to the Earth in the years: 2041 (0.01 AU), 2067 (0.03 AU) and 2102 (0.03 AU) for the nominal orbits. Hence chaoticity of the motion of the asteroid appears similar to this of (99942) Apophis but in case of (144898) 2004 VD17 motion is less influenced.

3.3. (144898) 2004 VD17: JPL ephemerides

As in the case of (99942) Apophis using JPL Ephemerides DE405 and DE406 does not affect the computed impact solutions in this short, about 100 years long, time span.

4. Summary

To compute precisely the impact solutions of (99942) Apophis and (144898) 2004 VD17 it is necessary to include relativistic effects as well as close approaching asteroids. The use of the software OrbFit is helpful in computing exact possible impacts of asteroids on the Earth. Thanks the OrbFit Consortium! Also the free software Solex was useful in this work.

Acknowledgements. My thanks go to the researches from the OrbFit Consortium working in six research laboratories:
http://newton.dm.unipi.it/~neodys/astinfo/orbfit/OrbFit/doc/help.html#authors for their free software and source code. I am indebted to Andrea Milani and Geny Sansaturio for discussions during the MACE 2006 and for it help through e-mails. I also thank Aldo Vitagliano for his discussion about the Solex during Mace 2006.

I would like to thank Prof. Grzegorz Sitarski from the Space Research Center, of the Polish Academy of Sciences in Warsaw, for his impact solutions of (99942) Apophis and (144898) 2004 VD17 and profound and fruitful help.

I also would like to thank Rafal Bączkowicz for help with the unix version of OrbFit. Many thanks to Marek Kmiecik from ASRC, the University at Albany (SUNY), for proofreading the English version.

I am also grateful for the suggestions given by the referee, Dr. Leonard Kornoš.

References

Michalak, G.: 2001, *Astron. Astrophys.* **374**, 703

Milani, A., Chesley, S.R., Chodas, P.W., Valsecchi, G.B.: 2002, in *Asteroids III*, eds.: W.F. Bottke Jr., A. Cellino, P. Paolicchi and R.P. Binzel, Univ. of Arizona Press, Tucson, 55

Milani, A., Chesley, S.R., Sansaturio, M.E., Tommei, G., Valsecchi, G.B.: 2005a, *Icarus* **173**, 362

Milani, A., Sansaturio, M.E., Tommei, G., Arratia, O., Chesley, S. R.: 2005b, *Astron. Astrophys.* **431**, 729

Sitarski, G.: 2002, *Acta Astron.* **52**, 471

Vitagliano, A.: 1997, *Cel. Mech. Dyn. Astron.* **66**, 293

Vitagliano, A., Stoss, R.: 2006, *Astron. Astrophys.* **455**, L29
Wlodarczyk, I.: 2001, *Acta Astron.* **51**, 357
Yeomans, D.K., Ostro, S.J., Chodas, P.W.: 1987, *Astron. J.* **94**, 189