The Potentially Dangerous Asteroid (410777) 2009 FD

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We computed impact solutions of the potentially dangerous asteroid (410777) 2009 FD based on 505 optical observations from 2009 February 24.36493 to 2019 April 15.17062, and eight radar observations from 2014 April 07 to 2015 November 04. We followed orbit of the asteroid (41077) 2009 FD forward in the future searching for close approaches with the Earth, which can lead to possible impacts up to the year 2190. According to the NEODyS website the asteroid (41077) 2009 FD belongs to the so-called 'special group' of asteroids: (99942) Apophis, (29075) 1950 DA, (101955) Bennu, and (410777) 2009 FD. They are subject to an individual procedure for calculating possible collisions with Earth.

1 Introduction

Asteroid (410777) 2009 FD is discovered on 2009 February 24 by (691) - Steward Observatory, Kitt Peak-Spacewatch, MPS 280489. Orbit type of asteroid is Apollo and Near-Earth Object. To compute possible impact solution of the asteroid (410777) 2009 FD with the Earth, we used the OrbFit[1] software with the JPL DE431 ephemerides, weighting and selecting observations according to the Near Earth Objects Dynamic Site (NEODyS)[2], the error model (Baer et al., 2011), and the Yarkovsky effects. We searched for the possible impacts using the non-gravitational parameter A_2, computed directly from observations using the pure gravitational model. We computed non-gravitational parameter $A_2 = 8.38 \times 10^{-14}\,\mathrm{au\,d^{-2}}$ with 1σ uncertainty $2.04 \times 10^{-14}\,\mathrm{au\,d^{-2}}$ in the motion of the asteroid (410777) 2009 FD.

2 Orbit of the (410777) 2009 FD Asteroid

The initial orbit of the (410777) 2009 FD asteroid is presented in Tab. 1. It is computed with astrometric RMS=0.4978", and brightness RMS= 0.4153 mag. The orbital elements are computed with the same method as in Wlodarczyk (2020), but they have smaller uncertainties.

3 Possible Impacts

Tab. 3 presents possible impacts of asteroid (410777) 2009 FD with Earth computed for 1201 clones with parameter $\sigma_{\mathrm{LOV}} = 5$. LOV is a one-dimensional segment of a (curved) line in the initial conditions space with the uniform sampling of the LOV parameter. σ_{LOV} denotes the position along the line of variation, LOV in the σ

[1] http://adams.dm.unipi.it/~orbmaint/orbfit/
[2] https://newton.spacedys.com/neodys/index.php?pc=4.1

Tab. 1: Initial nominal keplerian orbital elements of the (41077) 2009 FD asteroid. The angles ω, Ω, and i refer to Equinox J2000.0. Epoch: 2019 October 9=JD2458400.5 TDB. Orbital elements are computed with the non-gravitational parameter A_2.

a (au)	e	i (deg)	Ω (deg)	ω (deg)	M (deg)
		(410777) 2009 FD			
1.1637696055	0.49295201645	3.127694319	9.354562527	281.469427337	169.60748084
6.77×10^{-9}	9.06×10^{-9}	1.712×10^{-6}	8.59×10^{-6}	8.350×10^{-6}	6.037×10^{-6}
		A_2=(8.38±2.04)×10^{-14}au d^{-2}			

Tab. 2: Impact Table. The asteroid (410777) 2009 FD. The DE431 version of JPL's planetary ephemerides, 16 perturbing asteroids and Pluto; A_2=(8.38±2.04)×10^{-14}au d^{-2}; $\sigma_{\rm LOV} = 5$ and 1201 Virtual Asteroids.

Author	Date, UTC	σ LOV	Impact probability	exp. energy MT	PS
Now	2190/03/30.077	-4.388	3.07E-08	4.40E-06	-6.50

space. Values of σ are here in the interval (-5,5). Hence σ can be negative. We searched for impacts using the LOV method (hereafter LOV1) as is presented in Milani et al. (2005a) and Milani et al. (2005b), and we computed the probability of Earth impact and Palermo Scale (PS). We searched for possible impacts until 2200.

We searched also for impacts according to the another LOV method (hereafter, LOV2) described in Wlodarczyk (2019). It is difficult to compute impacts using this method, and in the case of asteroid (410777) 2009 FD we could not find them.

Using the LOV1 method we computed only one possible impact in 2190 with probability about 3.07×10^{-8}. There are presented similar possible impact dates at the NEODyS-2[3], the JPL NASA Sentry: Earth Impact Monitoring[4] website and in Del Vigna et al. (2019) where they used the 4-σ of LOV1. We used extended σ of LOV1 to 5. Also table of risk for asteroid of (410777) 2009 FD computed using different starting orbital elements and different Solar System models are earlier published, e.g., in Spoto et al. (2014), Wlodarczyk (2015a), and Wlodarczyk (2015b).

According to the JPL Small-Body Database Browser the absolute brightness of (410777) 2009 FD, H is 22.10 mag, and the diameter is equal to 472 m.

To compute the orbit of the asteroid and ephemerides for different dynamical cases we used the freely available OrbFit software v.5.0. This new version includes the new error model based on Baer et al. (2011). In all computations, we follow the same method of the weighting and selection of observations as the NEODyS website (Milani et al., 2005a,b) and Wlodarczyk (2015a). We used the JPL DE431 ephemerides and additionally 16 perturbing asteroids and Pluto according to Farnocchia et al. (2013).

[3] `https://newton.spacedys.com/neodys/index.php?pc=1.1.2&n=410777`
[4] `https://cneos.jpl.nasa.gov/sentry/details.html#?des=410777`

4 Lyapunov Time of the (410777) 2009 FD Asteroid

Using the OrbFit software we also computed the Lyapunov Time of the asteroid (410777) 2009 FD which has value LT=36 yr.

Based on Włodarczyk (2018) and using computed earlier non-gravitational parameter A_2=(8.38±2.04)×10^{-14}au d^{-2} we can asses non-gravitational parameter $\frac{da}{dt} = 40 \times 10^{-4}$ au Myr^{-1}. Hence, using the OrbFit software we can compute LT=46.5 yr, i.e., greater than without non-gravitational parameter.

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