

Close encounters of Near Earth Objects with large asteroids

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Abstract. Close encounters of Near Earth Objects (NEOs) with large asteroids are a possible source of systematic errors in trajectory propagations and asteroid mitigation. It is, thus, necessary to identify those large asteroids that have to be considered as perturbers in NEO orbit modeling. Using the Standard Dynamical Model we searched for encounters between the 1649 numbered Near Earth Asteroids (NEAs) and 2191 large asteroids having sizes greater than 20 km. Investigating the 21st century A. D. we have found 791 close encounters with 195 different large asteroids that lead to a substantial scattering of NEOs.

Keywords. asteroids, Near-Earth objects, ephemerides

1. Introduction

Close encounters of NEAs with the nearby planets and the Moon are known to be the source of strong gravitational perturbations on the trajectories of the former. In contrast, the influence of massive asteroids has not received a lot of attention. Yet, close encounters with massive asteroids can be the sources of systematic errors in trajectory propagation, asteroid mitigation and sample return missions, see e.g. Eggl *et al.* (2013), Chesley *et al.* (2014) and references therein. The purpose of the current research is to identify those massive asteroids that should be considered in the trajectory propagation of known NEAs.

2. Dynamical Model and Massive Asteroids

The Standard Dynamical Model for orbit propagation of asteroids introduced by Giorgini *et al.* (2008) includes all relativistic gravitational forces caused by the Sun, the planets, the Moon, as well as Ceres, Pallas and Vesta. However, the present research differs in one important aspect from the standard model.

Since NEAs can have close encounters not only with the Earth, but also with the Moon, Venus and Mars, the additional forces due to asphericity of these bodies should be taken into consideration in some cases. The PHA (99942) Apophis, for instance, will have encounters closer than 0.1 au with other bodies than the Earth within the next 15 years. In fact, it comes close to Venus on April 24, 2016 (distance of 0.0782 au) and the Moon on April 14, 2029 (distance of 0.00064 au). For this reason we argue that it is necessary to include the influence of the J_2 gravitational harmonic for the Earth, the Moon, Venus, and Mars whenever a NEA appeared within the gravitational sphere of influence of one of the above mentioned bodies. The Sun's J_2 gravitational harmonic was considered as well.

Table 1. Sample from the list of closest encounters of NEOs with large asteroids.¹

Perturbing asteroid	NEA	JD	Calendar date	Minimum distance, au	Relative speed, au/day	Hill's radius	Deflection, arcsec	Visual deflect., arcsec	Solar elong., deg.
1	8013	2454388	2007-10-14	0.02178	0.004119	12.6	0.225	0.185	147
52	184266	2458552	2019-03-09	0.00292	0.003119	4.1	0.127	0.057	13
1	3551	2461874	2028-04-12	0.02554	0.005619	15.7	0.103	0.090	150

Notes:

¹The complete list encompasses 791 encounters between the numbered NEOs and 195 massive perturbing asteroids and is available <http://www.imcce.fr/~ivantsov/nea21cy.txt>

Cross-referencing asteroid diameters (D) listed in the NEOWISE project Mainzer *et al.* (2011) with JPL's Small-Body Database lead to a preselection of 2191 massive asteroids with $D > 20$ km that were used as potential perturbers in our simulations. The bulk-density adopted for the calculation of gravitational parameters for the perturbing asteroids was 3 g/cm^3 .

All asteroid trajectories were propagated using an Adams-Moulton integrator of variable step and order, while the positions and velocities of all the major bodies were interpolated from the recent JPL DE430 ephemerides. Initial conditions for the asteroids were taken from the JPL HORIZONS system. The equations of motion were integrated for a century starting from J2000.

3. Close Encounter Detection

We searched for those close encounters between the preselected asteroids greater than 20 km in size and all known 1649 NEAs that would result in a two-body deflection angle greater than 0.1 arcsec. Table 1 contains a small sample of the encounter parameters and observational conditions for specific close encounters between NEAs and perturbing asteroids. The visual deflection angle represents the deflection as visible from the Earth, thus allowing to estimate whether the deflection event will be or has been observable.

4. Conclusions

An accurate orbit prediction of NEOs requires a more detailed gravitational interactions than suggested in the Standard Dynamical Model. In the case of close encounters between NEOs and the nearby planets as well as the Moon planetary asphericities should be considered. Some encounters with larger asteroids are also non-negligible. Including only the three largest bodies in the main belt (Ceres, Pallas, Vesta) may lead to inaccurate orbit predictions. The gravitational effect of 195 main belt asteroids should be taken into account for the current NEO population. Rectifying the dynamical model is especially important for the orbital prediction of Potentially Hazardous Asteroids, such as (99942) Apophis. In a next step we will investigate the robustness of our results with respect to non-gravitational forces.

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References

- Eggl, S., Ivantsov, A., Hestroffer, D., Perna, D., Bancelin, D., & Thuillot, W. 2013, *Proc. Journées SF2A-2013*, 237
- Chesley, S. R., Farnocchia, D., Nolan, M. C., & 13 other authors. 2014, *Icarus*, 235, 5
- Giorgini, J. D., Benner, L. A. M., Ostro, S. J., Nolan, M. C., & Busch, M. W. 2008, *Icarus*, 193, 1
- Mainzer, A., Bauer, J., Grav, T., & 32 other authors. 2011, *ApJ*, 731, 53