Dangerous asteroids and the study of their orbits

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Abstract. As a result of a numerical experiment using a new method, asteroids have been found, during the movement of which possible close approaches and collisions with the Earth occur, Jupiter, Mars, other planets of the Solar system, with the Moon. The paper describes the method and gives only a part of the structured results obtained, including the cumulative probabilities of collisions of some asteroids with planets The solar system and the Moon, as well as the probability of a possible collision with the Earth and the Moon, depending on the number of virtual asteroids. It is important that asteroids that do not yet belong to the number of "near-Earth asteroids", whose perihelion distance is greater than 1.3 au, can also pose a danger to the Earth. The definition of such objects has become possible with the use of modern computing tools.

Introduction

The Department of Celestial Mechanics of St. Petersburg State University for searching for possible collisions and approaches of asteroids with planets. The first method has been developed since about 2009. It assumes a search of the data on a one-dimensional manifold, minimization of the planetocentric distribution of the asteroid and a number of other techniques (as, for example, in [1, 2]). With this method, many previously unknown impacts of dangerous asteroids have been found, including for Apophis. The use of the Monte Carlo method is difficult in this method due to the high computational complexity. In this regard, a new method was proposed in 2021 [3], which made it possible to identify a large number of asteroids, to identify dangerous ones according to for which close approaches and collisions with the Earth, Moon and other planets are possible. Estimates of the probabilities of these events using the Monte Carlo method are also obtained. Asteroids that are usually dangerous to the Earth are searched for among those q less than 1.3 AU (near-Earth asteroids, NEA). However, the orbits of asteroids evolve, especially strongly in close encounters with planets. As a result, it is possible to switch to the ASP class of the object that was in As is known, the approach to Jupiter can significantly change the orbit of the asteroid, the approach to Mars is significantly less. In order to distinguish the NEA class from a large number of asteroids, a numerical study of the possible movements of a large number of known asteroids was carried out. Asteroids have been found with perihelion distances exceeding 1.3 au. Next, we examined these 24 asteroids in detail using the first method. They have close approaches and even collisions with the Earth, Moon and other planets in the time interval of 2020-2200 years.

1. Description of the numerical experiment

Let's describe a numerical experiment developed at the Department of Celestial Mechanics St. Petersburg State University in 2021-2023, using a software package [3]. Asteroids with a perihelion distance q greater than 1.8 au and at the same time having an aphelion distance (data were taken on 03/06/2021 from the above-mentioned NASA database [4, 5]). Small asteroids with an absolute value of H>26 are also excluded. Of all the known asteroids (about a million are known), thousands of objects. Here are the stages of a numerical experiment to find dangerous asteroids. The technique of the experiment is that at each stage we exclude asteroids that do not approach planets less than a given distance. For each real asteroid under study, N is the number of virtual asteroids. The motion of virtual asteroids is being studied in the time interval 2132 years. The first stage. For each real asteroid out of the remaining (127 thousand objects), at N=2000 virtual asteroids, possible approaches are searched for- standing less than 1000 radii of one of the planets or the Moon. If there are no it is excluded. There are 11 thousand asteroids left, which are taken to the next second stage. For each of the remaining objects, at N=20 thousand virtual asteroids, possible approaches to a distance of less than 100 radii of one of the planets or the Moon are searched. If there are none, the asteroid is excluded over 3,000 asteroids left, which are being taken to the next stage. The third stage. Each remaining asteroid is modeled by N = 200,000 separate virtual instances. Possible approaches of 100, 10 and 1 radius are being searched for each of the planets and the moon.

2. Some results of the numerical experiment

The results of the numerical experiment are presented on the website [6]. In particular asteroids with a perihelion distance of more than 1.3 au have been found, having possible approaches to the Earth at a distance of less than 100 o . For almost all of these asteroids, approaches and possible collisions with Jupiter have been recorded, and there are many approaches to Mars. A other planets have also been found. Let's take asteroid 2011 XD3 as an example. Here data: the perihelion distance is 1.53 AU, the accuracy is 0.0008 au (1 sigma). The maximum distance is 5.16 AU, the accuracy is 0.07 AU (1 sigma). As a result of the experiment, we obtain two approaches to the Earth by less than 100 of its radii, 6 approaches to

Mars by less than 100 of its radii, 3751 approaches to Jupiter by less than 100 of its radii, 512 approaches to Jupiter by less than 10 of its radii, 103 possible collisions with Jupiter. Asteroids with perihelion distance 1.3 and more.e. and convergent with the Earth at a distance of less than 100 and its radius to 2132 year: 2020 KH, 2011 XD3, 2006 CQ, 2020 RJ8, 2019 YH3, 2010 UC8, 2019 WY6, 2019 UQ10, 2009 LB. Note that for the asteroid 2006 CQ, we found a possible collision with the Earth in 2169. The cumulative probabilities of collisions of various asteroids with planets and the Moon are multiplied by 200,000 for ease of recording and comparison. Then we will write down the cumulative collision probabilities obtained in the form of a list below: — Earth: 2000 SG344 — 709, 2008 HJ — 53, — Moon: 2015 AZ43 — 12, 2008 JL3 — 9, — Mercury: 2009 UM1 — 5, 2018 VB1 — 2, — Venus: 2009 CE — 144, 2020 MA1 — 132, — Mars: 2007 WD5 — 34, 2006 BX39 — 9, — Jupiter: 2018 BJ11 — 463, 2019 JD14 — 303. Let's explain the meaning of these numbers using the example of asteroid 2000 SG344. At the third stage of the experiment, 200,000 virtual asteroids were started. For the asteroid under consideration, 709 possible impacts with the Earth were obtained in the time interval 2020 — 2132 years. This means that the probability of impact is 709/200000=3.5e-3. On the NASA website, in the dangerous asteroids section, the probability for this asteroid is 2.7e-3 in the time interval 2069-2122 years. This is logical for other asteroids. The change in probabilities depending on the number of virtual asteroids was also considered. For asteroid 2021 the probabilities P (multiplied by 10 5) of an impact with the Earth and the Moon are in Table 1.

N	Earth ($P * 10^5$)	Moon ($P * 10^5$)
10^4	10.0	10.0
10^5	13.0	6.0
10^6	16.0	5.3
10^7	15.0	4.5

TABLE 1. The probability of impact (multiplied by 10^5) with the Earth and the Moon asteroid 2021 QM1, depending on the number of virtual asteroids

Conclusion

As a result of a numerical experiment using a new method, asteroids have been found, the movement of which possible close approaches and collisions with the Earth occur, Jupiter, Mars, other planets of the Solar system, with the Moon. The paper describes the method and gives only a part of the structured results obtained, including the cumulative probabilities of collisions of some asteroids with planets The solar system and the Moon, as well as the probability of a possible collision wi and the Moon, depending on the number of virtual asteroids. It is important that asteroids that do not yet belong to the number of "near-Earth asteroids", whose perihelion distance is greater than 1.3 au, can also pose a danger to the Earth. The definition of modern computing tools.

References

[1] Petrov N, Sokolov L., Polyakhova E., Oskina K. Predictions of asteroid hazard to Earth for the 21st century // AIP Conference Proceedings 1959, 040012 (2018); doi: 10.1063/1.5034615 [2] Petrov N.A., Vasiliev A.A., Kuteeva G.A., Sokolov L.L. On the trajectories of asteroids 2015 RN35 and Apophis colliding with the Earth // Astronomical Bulletin Exploration of the Solar system. 2018. Vol. 52. No. 4. C. 330-342. [3] Balyaev I. A. Acceleration of numerical integration of the equations of motion of asteroids, Sol. Syst. Res. 54, 557–566 (2020). https://doi.org/ 10.1134/S0038094620330011 [4] Jet Propulsion Laboratory. California Institute of Technology. Small-Body Databa Lookup. Electronic resource: https : //ssd.jpl.nasa.gov / (accessed March 30 , 2024) [5] Jet Propulsion Laboratory. California Institute of Technology. Electronic resour https : //sneos.jpl.nasa.gov / (accessed March 30, 2024) [6] Astronomy at St. Petersburg University. Electronic resource: http : //www.astro.spbu.ru/sites/def ault/f iles/stats 2 00000.xls (accessed March 30 , 2024)

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