Near Earth Objects Dynamic Site

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What NEODyS is

NEODyS is a website providing information and services for all Near Earth Asteroids.

In it, each NEA has its own dynamically generated set of pages.

The website was started in late 1999, at the Department of Mathematics, University of Pisa, mostly by Milani and Chesley.

The first generation of impact monitoring program, the software robot CLOMON, came online, as part of NEODyS, almost from the start, and was based on research by Milani, Chesley and Valsecchi.

What NEODyS is

Starting from late 2011 NEODyS is sponsored by ESA, and is currently maintained by SpaceDyS srl, a company of Cascina (Pisa, Italy), promoted by the same research group that has built and operated NEODyS from its beginning.

The current version of the website is NEODyS-2, with important improvements in the way orbits are computed.

The software used for NEODyS-2 is OrbFit version 4.2.

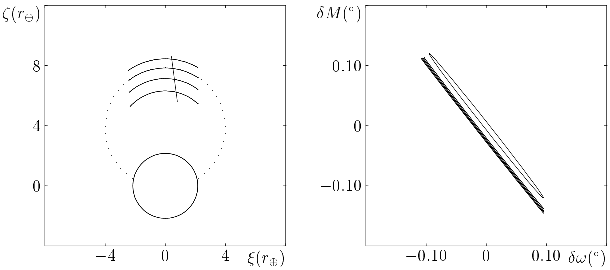
The orbit computations of the website are reproducible by using the free distribution of the OrbFit software suite.

NEA impacts vs space debris collisions

There is a certain degree of similarity between NEA impacts on Earth and space debris impacts on artificial satellites; there are, however, some important differences:

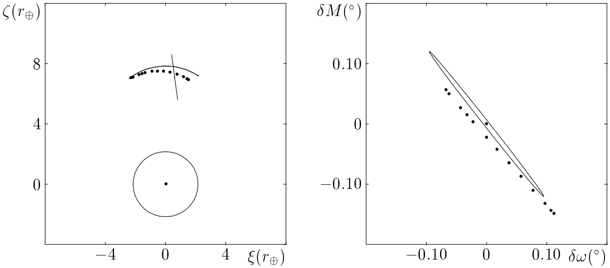
- nature and number of targets to be protected;
- maneuverability of targets;
- strong chaoticity of the motion in the NEO case;
- chain reaction effect in the debris case.

Why NEA impacts are difficult to predict: Apophis keyholes



Left: LOV and theoretical keyholes for impacts in 2034, 2035, 2036, 2037 on the 2029 *b*-plane; Earth radius includes focussing, dots show the 6/7 resonance. Right: same keyholes, and pre-image of the Earth, in the $\delta\omega$-δM plane; the origin is a "central" 2029 collision.

Apophis keyholes in practice



Left: LOV and 2036 theoretical keyhole, together with dots showing numerically found impact solutions; one of them is a "central" collision, the others are inside the "real" 2036 keyhole. Right: same impact solutions in the $\delta\omega$-δM plane.

Computing impact possibilities

Before 1998 the problem of computing all possible impact solutions for objects with a given set of observations had not been solved.

Since orbital evolution is deterministic and is computable with the required accuracy, why do we have a problem? And why do we need to talk about probability?

Actually, there is not such a thing as the orbit of an asteroid determined from the observations. There is always a range of possible orbits, all compatible with the observations.

Probability is then just a measure of our ignorance.

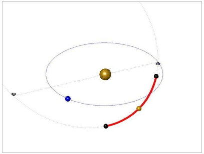
Virtual asteroids and impactors

The orbits compatible with the observations of an asteroid can be described as a swarm of Virtual Asteroids (VAs): only one of them is real, but we don't know which one.

Each VA follows its own orbit; if one of them has an impact with the Earth, we call it a Virtual Impactor (VI), with an associated Impact Probability (IP) depending upon the statistics of the observational errors.

If a NEA has an IP of $1/1\,000$, through the computation of $1\,000$ VAs we can expect to find one VI. However, if the IP is $1/1\,000\,000$, to find a VI by brute force we need to compute $\approx 1\,000\,000$ VAs: too much, even for current computers.

NEO impact monitoring



Detecting VIs with low IP can be done by arranging VAs along a string.

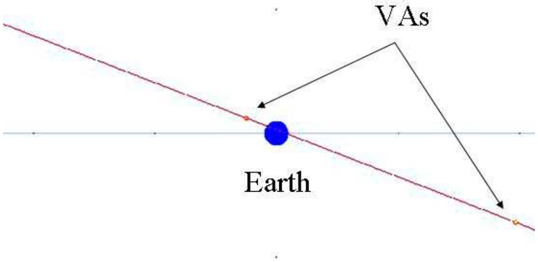
As the VAs proceed on their separate orbits the string stretches, mostly along track, until it wraps around a large portion of the orbit.

If there is a point where the orbits are close to the Earth's orbit, some VAs have close approaches to the Earth.

Detecting VIs

Interpolation on the string is possible. If two consecutive VAs straddle the Earth, an intermediate VA can be built to find the minimum possible approach distance.

The efficiency gain with this computational strategy is more than a factor 1 000.



Impact Monitoring Robots

In March 1999 we (Milani, Chesley, Valsecchi) could detect a VI with IP 1/1 000 000 000 with only 1 000 VAs (asteroid 1999 AN_{10}).

In November 1999 the software robot CLOMON began operations in Pisa. Each new NEA is monitored for possible impacts in the next century. When VIs are found, they are posted on the Risk Page of NEODyS (http://newton.dm.unipi.it/neodys/).

In 2002 the 2$^{\mathrm{nd}}$ generation impact monitoring robots CLOMON2 and Sentry (at JPL, Pasadena, http://neo.jpl.nasa.gov/risk/) became operational.

Cross-checking has solved the problem of verification, and indeed has increased reliability.

Dissemination of information

If no VI is found, a NEA is safe.

The fact that a NEA has some associated VIs can change only as a result of observations. In these cases, the astronomical community has to provide further observations.

After an initial turbulent period, the publication of VIs on the WWW has become a well established procedure that does not lead anymore to frequent (and counterproductive) media storms.

This procedure makes sure that the essential information (i.e., the need for further observations) reaches all interested parties.

Eliminating Virtual Impactors

VIs are posted on the NEODyS and Sentry risk pages. Usually, observers react quickly.

Probability changes when the available information changes. New observations can push IPs both up and down. In the end, an IP can only go to 0 or 1.

If an asteroid is lost while it still has a VI, then the IP cannot change until it is recovered by chance. This currently happens especially for small asteroids.

Final remarks

Impact monitoring on the time scale of the next century has been succesfully going on for almost 15 years.

The combined experience embodied within NEODyS/CLOMON2 and JPL/Sentry is considerable.

The cross-check routinely conducted between the two impact monitoring groups adds to the credibility of the overall system.