The Near-Earth Objects hazard and how we deal with it

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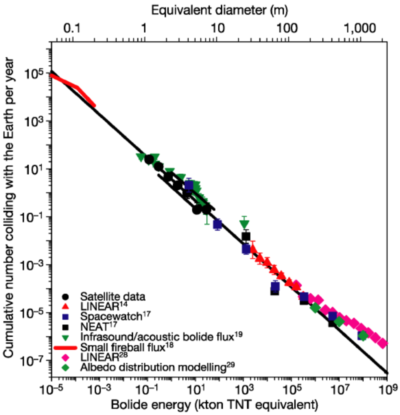
The problem

NEOs are asteroids and comets on orbits with $q \leq 1.3$ au.

At any given time, some of them are on Earth intersecting orbits and may collide with it.

Asteroids (NEAs) dominate the statistics at most sizes; comets (NECs) dominate at the largest sizes.



The plot of the impactor flux si taken from Brown et al. (2002).

The “dinosaur solution” (?!)

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;
- time scales involved;
- maneuverability of targets;
- strong chaoticity of the motion in the NEO case;
- chain reaction effect in the debris case.

Five steps to decrease the NEA risk

The strategy to deal with the risk associated with Near-Earth Asteroids (NEA) impacts on the Earth can be summarized in five steps (Valsecchi & Milani 2007).

We have to:

1) detect them;
2) determine their orbits;
3) compute collision possibilities;
4) exclude collision possibilities with further observations;
5) deflect/destroy, if necessary, those going to collide with our planet, or evacuate the affected region, when appropriate.

1) Detection

NEA detection is difficult because:

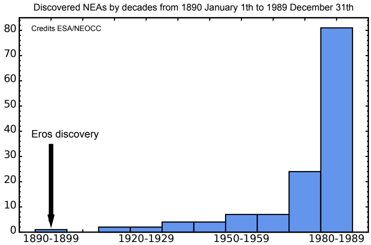
- their faintness;
- their rapid motion in the sky when they are close to the Earth and thus easier to detect;
- the geometry of their passages close to the Earth.

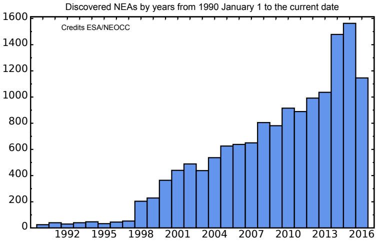
NASA funds all the major ground-based and space-based surveys aimed at the discovery of NEAs (e.g., Catalina Sky Survey, Mt. Lemmon Survey, Pan-STARRS).

Europe is setting up a ground-based telescopic survey that will complement the US surveys.

Other contributions to the detections are minor.

1) Detection: completeness level





Before the late ninenties the yearly discovery rate of NEAs was very low.

The rate increased enormously with the advent of CCD-based detectors, and continues to increase nowadays.

About 90% of the 1 km or larger NEAs have been discovered so far, but the completeness level at smaller sizes is considerably lower.

2) Orbit determination

The same factors that make NEAs difficult to detect make the initial determination of their orbits problematic:

- their faintness implies short observed arcs;
- their rapid motion in the sky requires immediate follow-up, that is not always available;
- in some cases the geometry of their apparitions makes the observed positions compatible with orbits of very different nature, while in other cases makes the follow-up impossible from the ground.

2) Orbit determination: the players

NASA funds the operations of the Minor Planet Center (MPC) of the International Astronomical Union, where astrometric data are collected, stored and made available to the astronomical community; the MPC computes orbits and gives official designations to all asteroids and comets.

Moreover, NASA operates the Planetary Defense Coordination Office at the Jet Propulsion Laboratory (JPL), where independent orbit computations are made.

In Europe, a major orbit-computing facility is the University of Pisa (Italy), whose NEODyS and AstDyS websites will migrate, in the next years, to the NEO Coordination Centre of the European Space Agency (ESA).

3) Impact monitoring

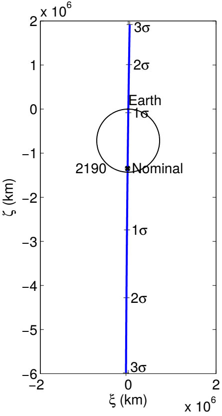
The difficulty of impact monitoring lies in the possibility of pre-collision planetary close encounters, that can greatly alter the orbit of the impactor, and originate the keyhole phenomenon.

A keyhole is a small region close to the Earth such that, if the NEA passes within it while encountering the planet, it will be put on an orbit that impacts the Earth at a subsequent encounter.

The first Impact Monitoring program came online at the University of Pisa, as part of NEODyS, in 1999; a second, independent program became operational at JPL in 2002 (Milani et al. 2000, 2005).

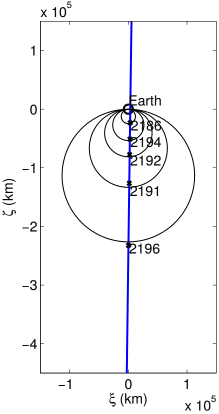
The two programs work in parallel since 2002, with the two teams in constant contact in order to improve performances and ensure reliability and redundancy.

3) Impact monitoring: keyholes



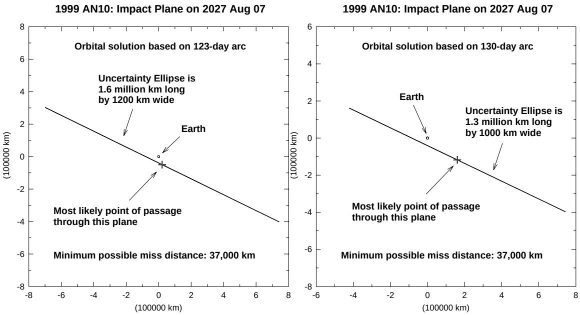
Left: Line of Variations (LoV) and *b*-plane circle corresponding to the 4/5 resonance.

Right: an enlargement, with LoV, cross-section of the Earth, and circles corresponding to the 1/1, 8/9, 6/7, 5/6, 9/11 resonances (Spoto et al. 2014).



The *b*-plane of the 2185 Earth encounter of (410 777) 2009 FD; keyholes are located near the intersections of the LoV with the circles corresponding to the resonances (Valsecchi et al. 2003).

4) Orbit improvement cycle



The shrinking uncertainty region for the 2027 Earth encounter of 1999 AN_{10}; left: 123-day arc, right: 130-day arc (image credit: Chodas, JPL).

Almost always collision possibilities are the consequence of our lack of sufficient knowledge about the orbit of a NEA.

4) Orbit improvement cycle: its effects

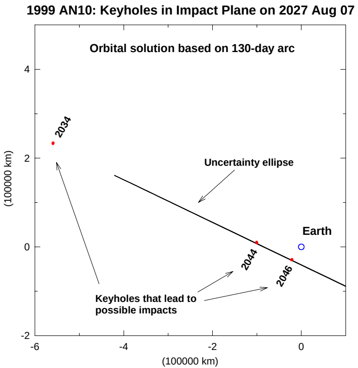


Image credit: Chodas, JPL.

The solution is astrometric follow-up, until all collision possibilities become incompatible with the observational record.

As the uncertainty region shrinks, collision probabilities may increase, before the corresponding collisions get out of the region.

5) Dealing with an actual impactor

This step falls more in the realm of civil protection than in that of astronomy, and may involve political decisions at the international level.

In case the probability of collision of a NEA becomes substantial, possible actions include (but are not limited to):

- the deflection or the destruction of the impactor, if sufficient time is available;
- the evacuation of the affected regions otherwise.

Major current players in the NEO arena

The annual NEO-related NASA budget went from 4M$ in 2010 to 20.4M$ in 2012, then to 40M$ in 2014, and has increased to 50M$ in 2016.

It is then not surprising that the greater part of the worldwide NEA-related activities are carried out by NASA-funded programs.

Elsewhere the contributions to the field have consisted mostly in the activity of astrometric follow-up done by skilled amateurs.

The NEO Segment of the Space Situational Awareness Program of ESA aims at contributing to NEO activities by setting up:

- an orbit computation and impact monitoring component, built upon the NEODyS heritage;
- a NEO survey component, based on innovative wide field-of-view telescopes.

The rôle of the United Nations

The United Nations, through the Committee on the Peaceful Uses of Outer Space (COPUOS), have promoted the establishment of:

- the International Asteroid Warning Network (IAWN), aimed at the discovery of hazardous asteroids and comets and the identification of those objects requiring action;
- the Space Mission Planning Advisory Group (SMPAG), whose task is to plan for a mitigation campaign for a possible impactor that includes deflection and/or disruption actions as well as civil defense activities.

Conferences on NEOs

- 1993, Tucson (USA): “Hazards due to Comets and Asteroids” (scientists);
- 1999, Torino (Italy): “International Monitoring Programs for Asteroid and Comet Threat (IMPACT)” (scientists);
- 2002, Arlington (USA): ”Workshop on Scientific Requirements for Mitigation of Hazardous Comets and Asteroids (scientists);
- 2003, Frascati (Italy): “OECD Global Science Forum Workshop on Near Earth Objects: Risks, Policies and Actions” (national delegates, scientists);
- 2004, Tenerife (Spain): “Comet/Asteroid Impacts and Human Society” (disaster managers, scientists);
- Prague (Czech Republic): “Near Earth Objects, our Celestial Neighbors: Opportunity and Risk”, IAU Symposium 236 (scientists).

Conferences on NEOs (contd.)

The series of “Planetary Defense Conferences” (engineers, scientists):

- 2004, Orange County, USA;
- 2007, Washington, D. C. (USA);
- 2009, Granada (Spain);
- 2011, Bucharest (Romania);
- 2013, Flagstaff (USA);
- 2015, Frascati (Italy);
- 2017, Tokyo (Japan).

References

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