Near-Earth Objects' Forecast of Collisional Events (NEOForCE)

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Abstract

Here we present NEOForCE (Near-Earth Objects Forecast for Collisional Events) a new impact monitoring system developed at Institut de mécanique céleste et de calcul des éphémérides (IMCCE, Paris Observatory). This system is original and independent. As ephemeris of major planets and the Moon we use INPOP [3]. The asteroids' orbits and covariance matrices are taken from DynAstVO database [2]. For computing the impact probability we use the Line Of Variations (LOV) sampling method [5] but with significant modifications. The longest axis of the confidence ellipsoid is chosen to be sampled obtaining virtual asteroids. Each virtual asteroid's orbit is propagated from the time of discovery 100 years ahead with variational equations. Each virtual asteroid is a representative of its small vicinity and we apply the Partial Banana Mapping method (PBM) [7] for each of this vicinity to look for possible collisions. Then the results are combined and the procedure to find explicitly the initial conditions of the collisional trajectory is launched.

Introduction

Estimating the probability of a collision of asteroids with the Earth is an important task for planetary defense. There are systems that compute impact probabilities of near-Earth asteroids with the Earth on a regular basis: Sentry (Nasa, Jet Propulsion Laboratory) and CLOMON-2 (originally University of Pisa, now ESA). Here we present NEOForCE (Near-Earth Objects Forecast for Collisional Events) a new impact monitoring system which is being developed at Institut de mécanique céleste et de calcul des éphémérides (IMCCE, Paris Observatory).

Partial Banana Mapping method: search for virtual impactors

A robust linear method for impact probability computation (see poster #225 for more details).

- At the time of possible collision the uncertainty region is thin, curved and stretched mostly along the nominal asteroid's orbit.
- The collision happens when the Earth comes close to the nominal asteroid's orbit.
- The covariance matrix in orbital elements much better represents the actual shape of the uncertainty region (see Fig.1) in the two-body formalism (assume Gaussian distribution in orbital elements).
- At the epoch of a possible collision find the point on the main axis of curvilinear uncertainty region, which is closest to the Earth (point B in Fig. 1).
- Find in the original uncertainty region the orbital elements of the virtual asteroid that lead to point B:

$$\mathrm{Q}^{-1}[E^{min} - E] = [x_0^{min} - x_0] \tag{1}$$

where x_0 — state vector at epoch of observations, x — state vector at time of possible collision, E — Keplerian elements at time of possible collision, E^{min} — Keplerian elements of point B, x_0^{min} — state vector at epoch of observations that should lead to point B, and matrix Q is a multiplication of two partial derivative matrices:

$$\mathrm{Q} = \left[\frac{\partial E}{\partial x}\right]\left[\frac{\partial x}{\partial x_0}\right].$$

- Propagate the x_0^{min} and compute probability to it.

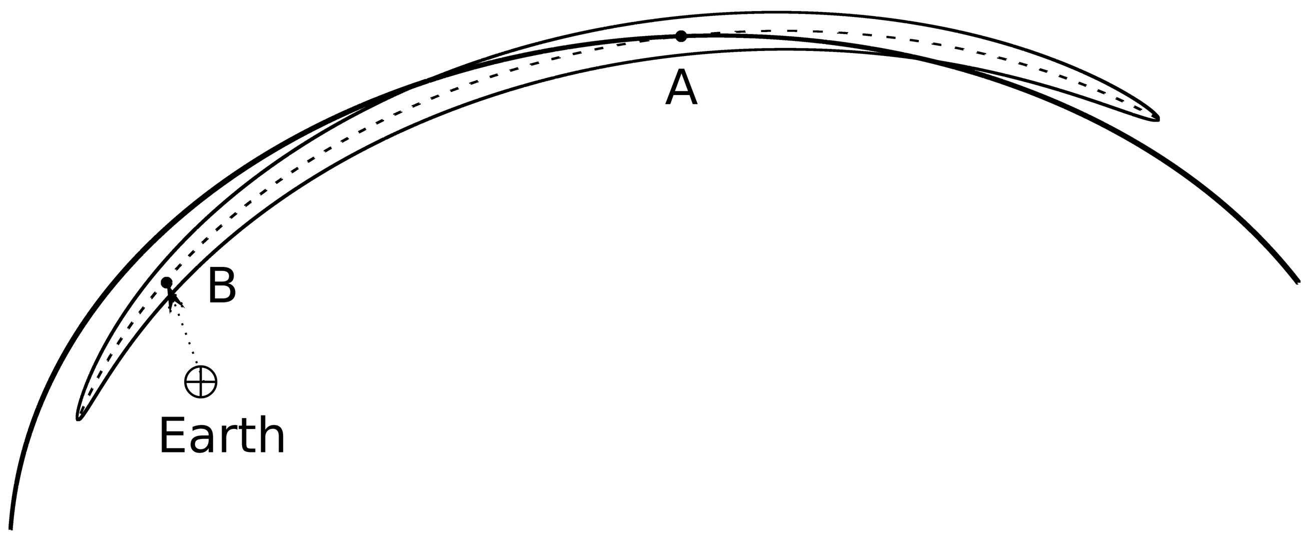

Figure 1. The scheme of the banana shaped uncertainty region of the asteroid. Point A is the nominal position of the asteroid, point B — the virtual asteroid of the main axis of the uncertainty region, which is closest to the Earth. The bold line is the nominal asteroid's orbit. The arrow is the direction of the Earth's relative velocity.

Line of Variations

- The uncertainty region of an asteroid at the epoch of observations is quite small and well represented by an ellipsoid (6 dimensional ellipsoid, since we have uncertainty in coordinates and velocities). Determined by a covariance matrix C.
- The major axis of the uncertainty ellipsoid is several orders of magnitude larger than the other ones (Line Of Variations [4, 5]).
- Sample virtual asteroid on the main axis of this 6-dimensional uncertainty ellipsoid (see Fig. 2).

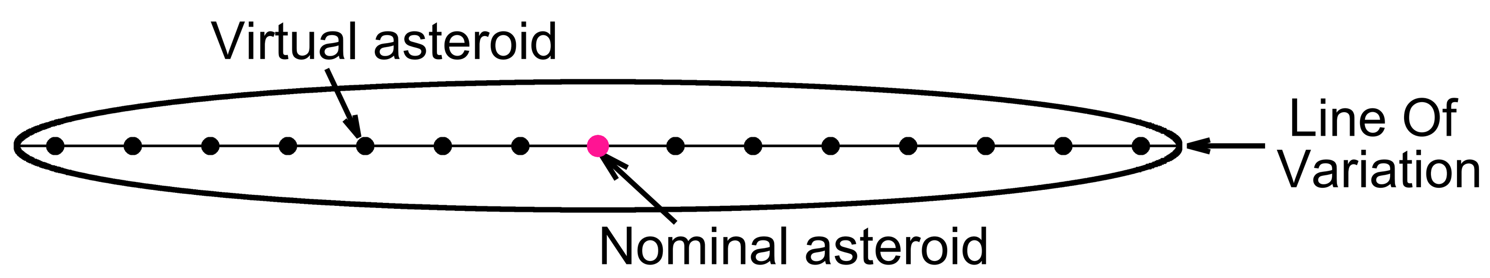

Figure 2. The schematic illustration of the uncertainty region at the epoch of observations. The horizontal line is the main line of the uncertainty ellipsoid (Line of Variations) and the black dots are the virtual asteroids.

- Consider each virtual asteroid to be a representative of its vicinity (green area in Fig. 3).
- Find covariance matrix for the virtual asteroids.
  Spectral decomposition of matrix C

$$\mathrm{C} = \mathrm{V}^{\mathrm{T}}\mathrm{D}\mathrm{V} \tag{2}$$

where D is a diagonal matrix of eigenvalues, and V is an orthogonal matrix consisted of eigenvectors of matrix C.
Decrease the major eigenvalue $\mathrm{D}^*(1,1) = \mathrm{D}(1,1)/n$.
The covariance matrix for a virtual asteroid:

$$\mathrm{C}^* = \mathrm{V}^{\mathrm{T}}\mathrm{D}^*\mathrm{V}. \tag{3}$$

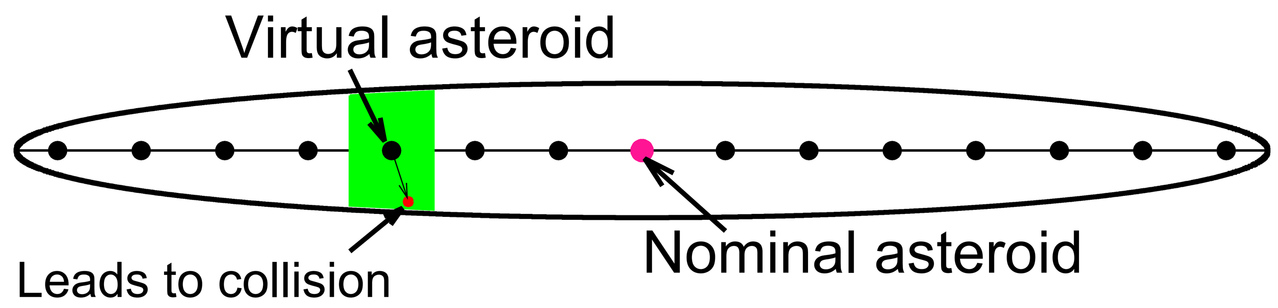

Figure 3. The schematic illustration of the uncertainty region at the epoch of observations. The horizontal line is the main line of the uncertainty ellipsoid (Line of Variations) and the black dots are the virtual asteroids. The green area is the vicinity of a virtual asteroid that it represents. The red dot is the virtual asteroid that collides with the Earth in future.

- Use Partial Banana Mapping for each of the virtual asteroid with covariance matrix C^* (see Fig. 4).

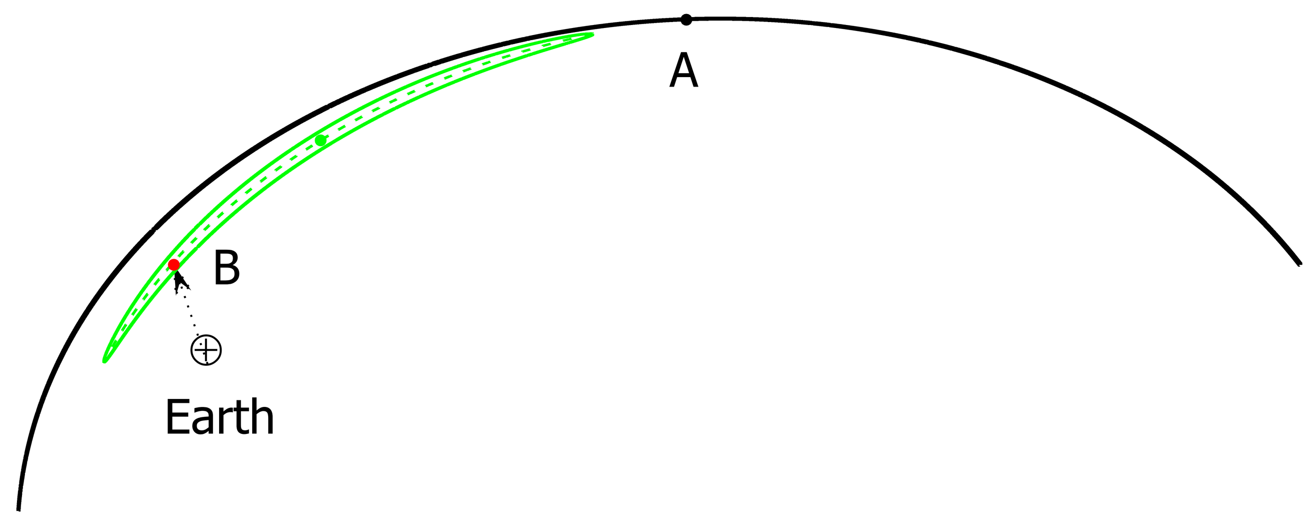

Figure 4. The scheme of the banana shaped uncertainty region of the vicinity of virtual asteroid. Point A is the nominal position of the asteroid, point B — the virtual asteroid that collides with the Earth. The bold line is the nominal asteroid's orbit. The arrow is the direction of the Earth's relative velocity.

- Combine the results.

Results

Table 1. Impact probabilities computed by different centers.

Date	NEOForCE	CLOMON-2	Sentry
2030-02-26	$4.28 \cdot 10^{-5}$	$1.7 \cdot 10^{-5}$	$3.8 \cdot 10^{-5}$
2038-02-26	$6.83 \cdot 10^{-6}$	$8.1 \cdot 10^{-6}$	$1.6 \cdot 10^{-5}$
2038-02-26	$3.58 \cdot 10^{-9}$	$4.1 \cdot 10^{-9}$	-
2038-02-26	$9.64 \cdot 10^{-9}$	$8.4 \cdot 10^{-8}$	$7.1 \cdot 10^{-9}$
2041-02-26	$1.41 \cdot 10^{-9}$	-	-
2048-02-26	$5.93 \cdot 10^{-6}$	$6.1 \cdot 10^{-6}$	$1.3 \cdot 10^{-5}$
2048-02-26	$3.02 \cdot 10^{-8}$	$1.7 \cdot 10^{-6}$	$3.4 \cdot 10^{-6}$
2059-02-26	$2.99 \cdot 10^{-12}$	$1.5 \cdot 10^{-10}$	$1.6 \cdot 10^{-10}$
2062-02-26	$3.53 \cdot 10^{-9}$	-	-
2083-02-26	$2.92 \cdot 10^{-12}$	$2.2 \cdot 10^{-8}$	-
2083-02-26	$3.55 \cdot 10^{-13}$	-	-
2083-02-26	$1.43 \cdot 10^{-12}$	-	-
2105-02-27	-	$1.5 \cdot 10^{-10}$	-
2107-02-26	$1.63 \cdot 10^{-11}$	$1.9 \cdot 10^{-9}$	-
2107-02-26	$2.63 \cdot 10^{-11}$	$2.1 \cdot 10^{-9}$	-

Conclusions

The NEOForCE monitoring system will be using orbits of asteroids from DynAstVO database [2] and planetary ephemerids INPOP [3] from Institut de mécanique céleste et de calcul des éphémérides (IMCCE). The system has original approach of collisional analysis based on Partial Banana Mapping method. Hence the system provides an independent assessment of the impact probability, which is crucial for planetary defense campaign.

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