NEO Encounter 2029

Orbital Prediction via Differential Algebra and Taylor Models

Executive Summary

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Available on the ACT website
http://www.esa.int/act

Theme: Mission Analysis.

Code and Title of the study: AO/1-5680/NL/CB Encounter 2029

Contract characteristics:

University/Department: Politecnico di Milano/Dipartimento di Ingegneria Aerospaziale

ACT researcher: Dario Izzo

Duration of the study: 4 months

Picture:

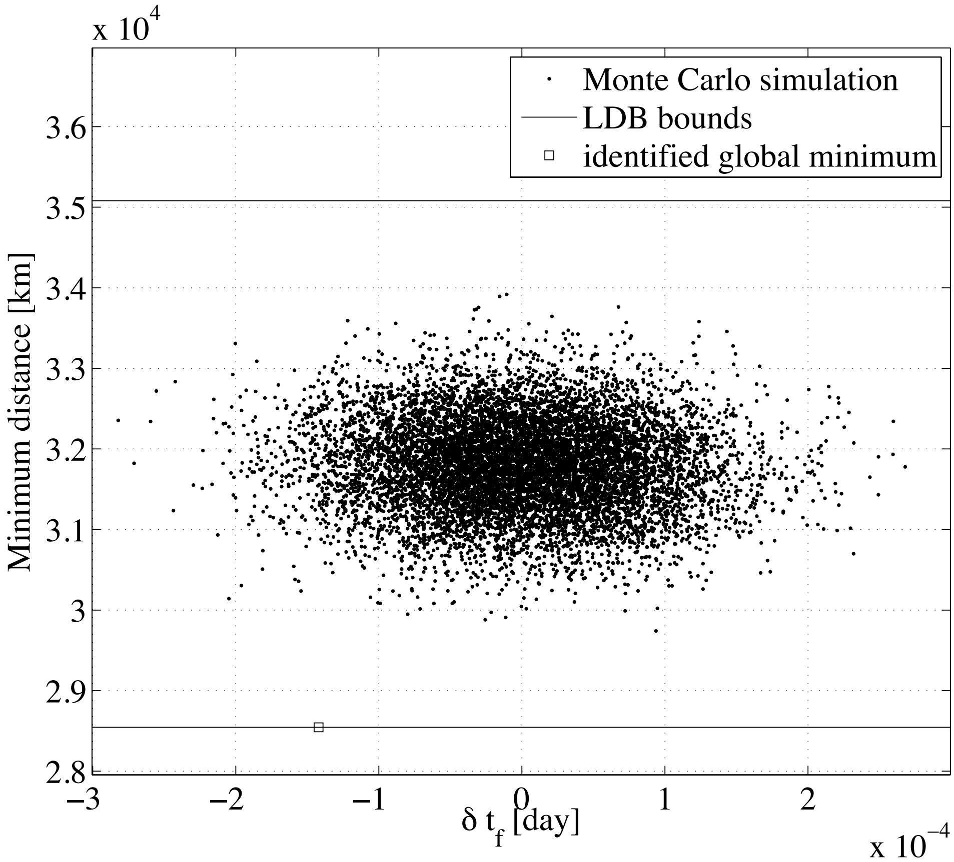

Figure 1 Identification of the close approach distances for Apophis in 2029: Monte Carlo simulation, range, and minimum value obtained using differential algebra.

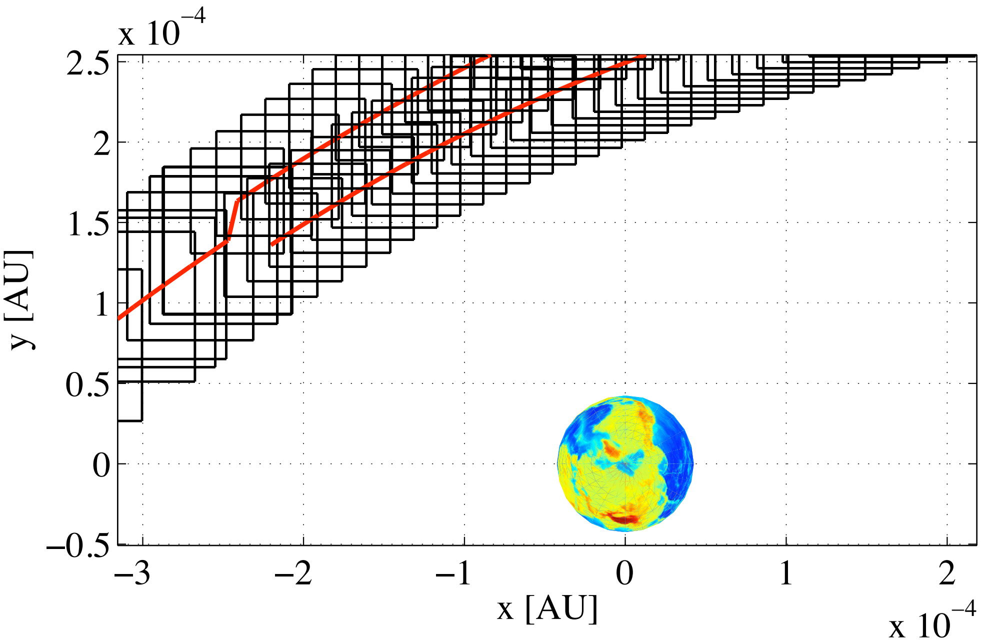

Figure 2 Details of the validated integration of Apophis close encounter in 2029 (reference solution in red and TM interval enclosure in black). Domain splitting occurs right before the closest encounter.

Methodology:

The application of differential algebra (DA) and Taylor models to the analysis and prediction of near Earth objects close encounters is investigated. The high order expansion of the flow of ordinary differential equations obtained by DA is exploited to develop tools for the prediction of planetary encounters and potential impacts, which takes into account the uncertainties due to measurement accuracy. Furthermore, Taylor model integrators are employed for the long-term rigorous integration of the motion of near Earth objects, considering the set of possible initial conditions expressed as interval boxes. A variety of dynamical models and ephemeris functions are developed, tailored to the evaluation in the differential algebra and Taylor model frames. Apophis close encounter in 2029 and the resonant return in 2036 are used as test cases.

Results:

A set of tools for the analysis of near Earth objects close encounter are developed, including

- a computationally efficient Monte Carlo simulation algorithm based on a single DA integration and thousands flow map evaluations,
- a technique based on Taylor map inversion for the automatic evaluation of both Earth's close encounter distances and epochs for all the virtual asteroids belonging to the initial uncertainty cloud,

- an impact leading condition algorithm that computes, for any desired epoch, conditions that would lead to an Earth impact,
- methods for identifying, within a set of possible conditions, those that lead to hazardous resonant returns
- the validated integration of Apophis including the Earth close encounter.

Publications:

R. Armellin, P. Di Lizia, F. Bernelli-Zazzera, M. Berz, *Efficient Techniques for Small Bodies Uncertainties Propagation and Impact Leading Condition Identification,* 1st IAA Planetary Defence Conference, Granada, Spain, April 27-30th, 2009.

A number of articles (2/3) are scheduled for submission to international journals.

Highlights:

The study shows that differential algebra can be profitably used either to improve the numerical efficiency (e.g., of Monte Carlo simulations) or to surpass the limitations (e.g., of linear expansion of the flow) of already existing methods for NEO's impact hazard study, and to develop brand-new algorithms. It is demonstrated that Taylor model based integrators outperform the validated schemes based on interval analysis. In particular, TM-based schemes are capable of integrating wide sets of initial conditions for several orbital revolutions without showing significant overestimation. The new flow operator, the step size control, and the dynamic domain decomposition techniques enable the management of the high nonlinearities of the dynamics associated to the Earth's close encounter, even when a large set of initial conditions is propagated.