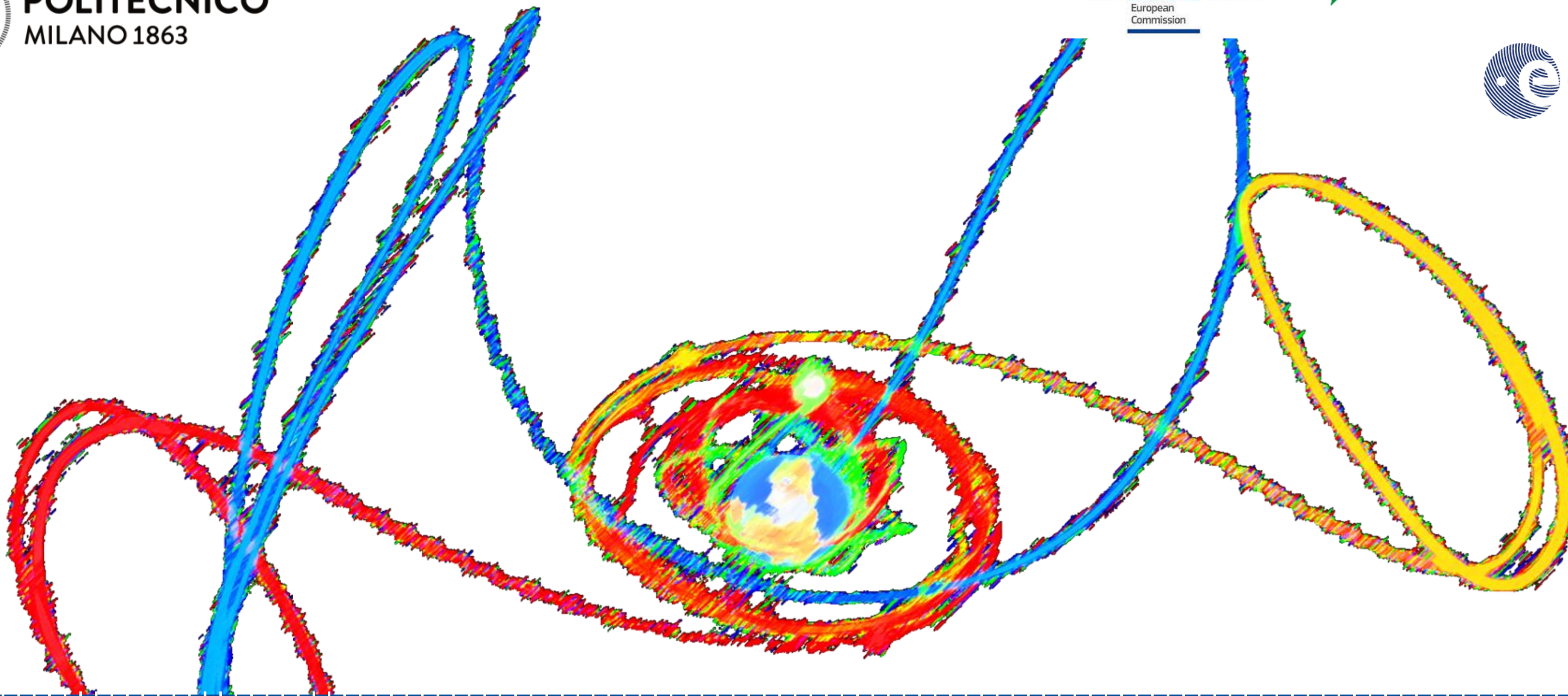


Close encounter characterisation and deflection design for planetary protection and defence

Camilla Colombo, Mathieu Petit, Matteo Romano

Hera Community Workshop, 15-16 November 2018

POLITECNICO MILANO 1863

INTRODUCTION

Introduction

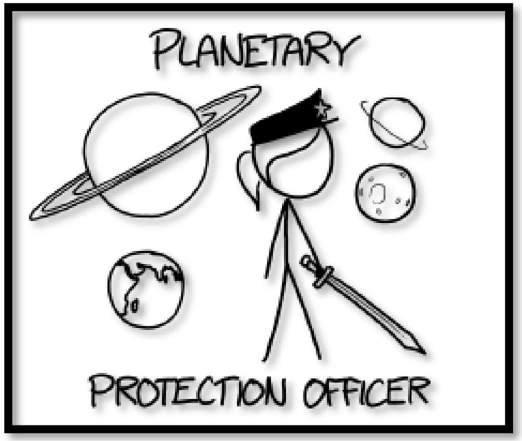
Planetary defence

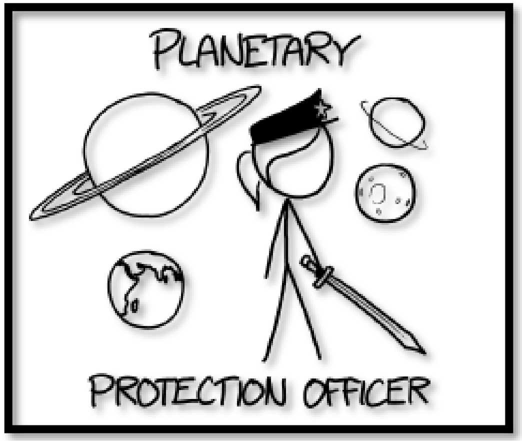
- Near Earth Asteroids can be a **threat** but also an **opportunity** for science, for material mining and utilisation.
- This is enabled by **mission to asteroids** and **demonstration mission for asteroid deflection.**

Introduction

Planetary protection

- Humans now routinely venture beyond Earth and send spacecraft to explore other planets and bodies.
- With this extraordinary ability comes **great responsibility**: do not introduce terrestrial biological contamination to other planets and moons that have potential for past or present life.
- For interplanetary missions and missions at Libration Point Orbit, **planetary protection analysis** need to be performed.





PLANETARY PROTECTION

Introduction

Planetary protection requirements for forward contamination

For interplanetary missions planetary protection analysis need to be performed (**Forward contamination**)

- Ensure that the impact probability of spacecraft and upper stages with planets and moons over 50-100 years is below the **required threshold** with a give **confidence level**.
- Compliance with requirements should be verified for
  - The nominal trajectory
  - Considering on-board failures
  - Considering uncertainties on orbit injection, s/c parameters or physical environment, NEO deflection actions

➢ G. Kminek. ESA planetary protection requirements. Technical Report ESSB-ST-U-001, European Space Agency, February 2012.

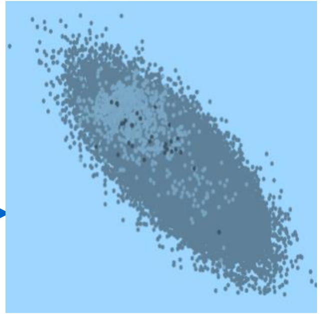
SNAPPshot

UNIVERSITY OF Southampton · esa

Suite for Numerical Analysis of Planetary Protection

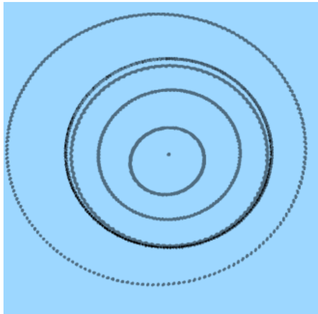
Input: **Uncertainty distribution**
Planetary protection requirement: max impact prob. and confidence level

Number of MC runs
Initial conditions

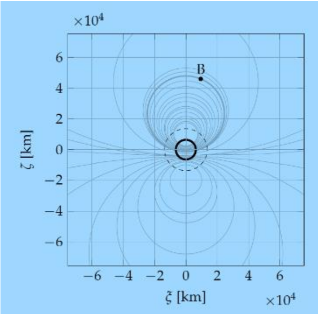


Monte Carlo initialisation

Trajectory propagation over 100 years



Trajectory propagation



B-plane analysis

Number of impacts

Verify planetary protection requirements

NO

Increase number of runs

YES

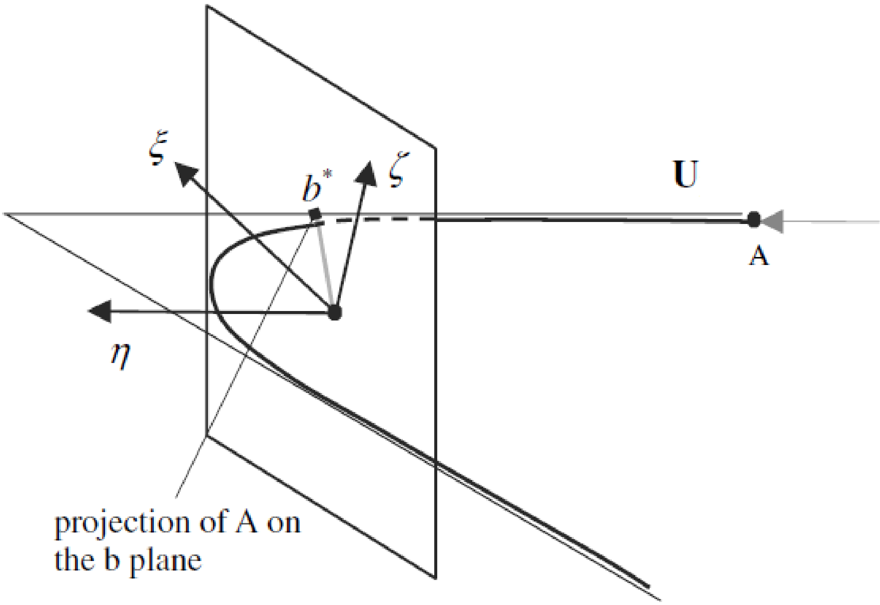
Output and graphics

Output: **minimum number of required MC runs**

➢ Colombo C., Letizia F., Van den Eynde J., R., Jehn, “SNAPPSHOT: ESA planetary protection compliance verification software, Final report”, ESA contract, Jan 2016

B-plane

Definition



- Intersection of the **incoming asymptote** and the b-plane: $\boldsymbol{b} =$ impact parameter
- η = 0 on the b-plane identifies a **fly-by**

Plane **orthogonal** to the object **planetocentric velocity** when the object enters the planet's sphere of influence

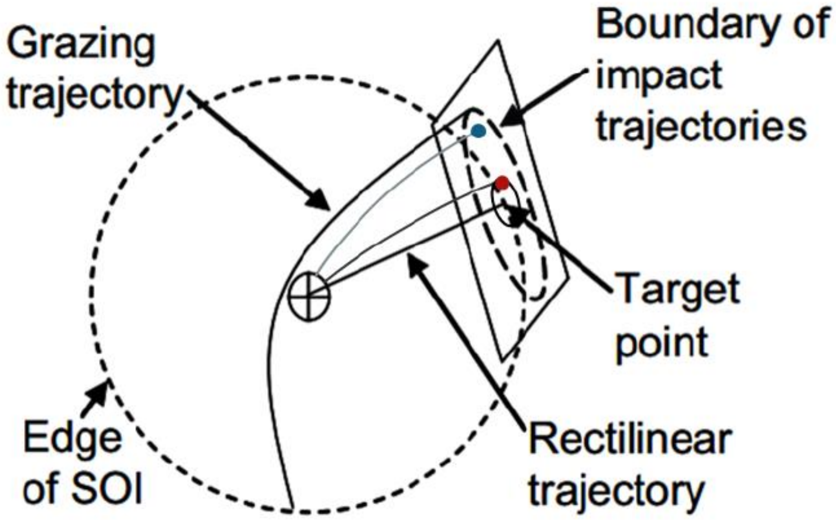
- η-axis: parallel to the relative velocity $\boldsymbol{U}$
- ζ-axis points in the opposite direction as the projection of the planet's velocity vector on the b-plane: **time shift at close approach**
- ξ-axis completes the right-handed reference frame: **geometrical minimum separation distance**

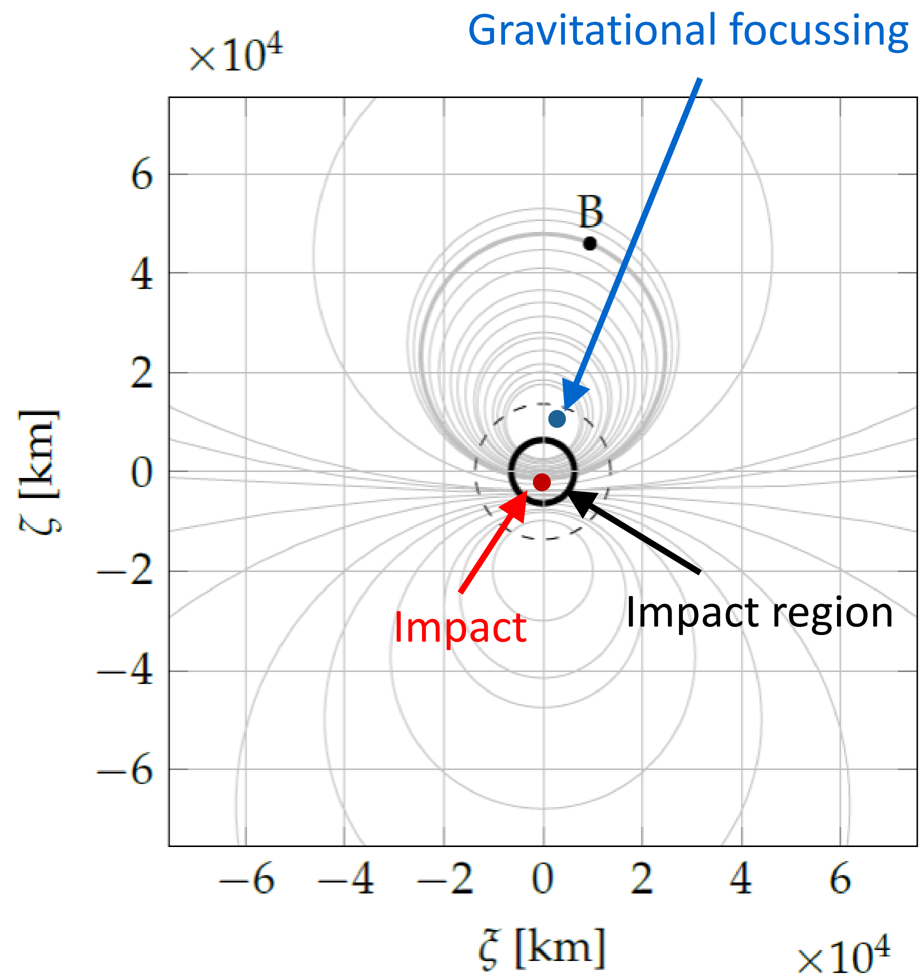
➢ (Öpik, 1976)

B-plane analysis in SNAPPshot

State characterisation

- Impact
- Gravitational focussing





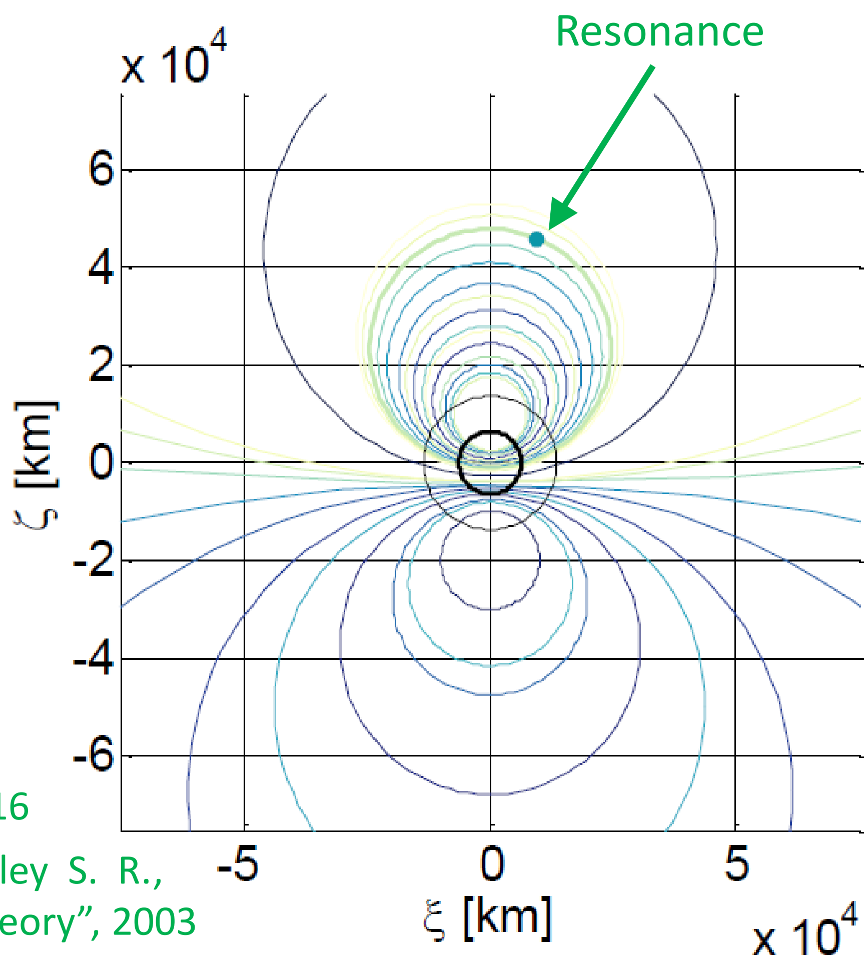
➢ Park and Ross

B-plane analysis in SNAPPshot

State characterisation

- Impact
- Gravitational focussing
- Resonances
  - **Severity**: measured by the value of *k* (planet's period repetitions): the lowest, the most critical.
  - **Resonance selection**: closest resonance or resonance with the lowest *k* (and below the period threshold)

Resonance plotted according to their k value: dark low k, light low k



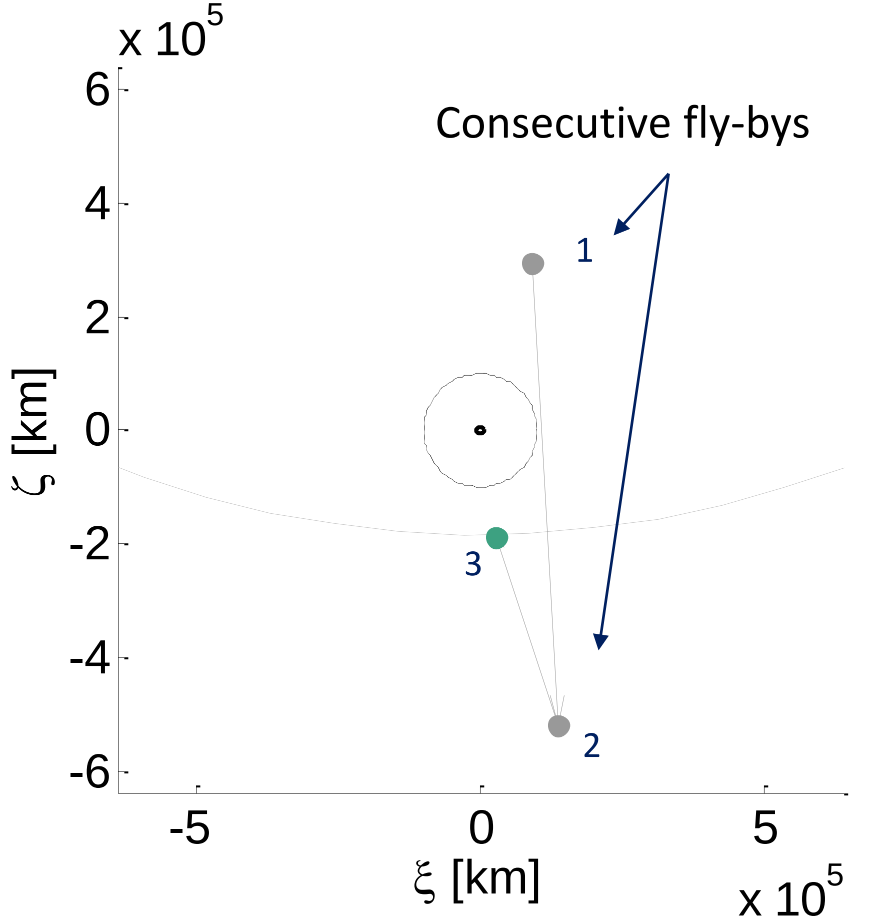
- Letizia F., Van den Eynde J., Colombo C., R., Jehn, 2016
- Valsecchi G. B., Milani A., Gronchi G. F. and Chesley S. R., "Resonant returns to close approaches: Analytical theory", 2003

B-plane analysis in SNAPPshot

State characterisation

- Impact
- Gravitational focussing
- Resonances
- When **multiple fly-bys** are recorded, for the Monte Carlo analysis **first or worst encounter** are analysed.
- **Sorting of multiple encounters:** identify the most critical ones (e.g. impact with Earth > resonance with Mars)

Evolution of one GAIA Fregat trajectory on the Earth's b-plane for 100 years of propagation



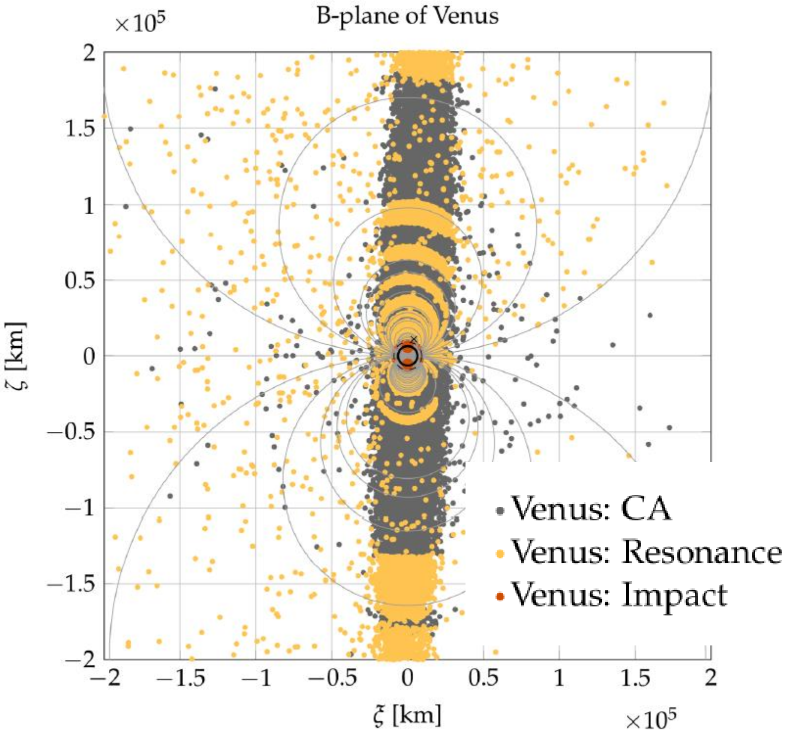
➢ Letizia F., Van den Eynde J., Colombo C., R., Jehn, 2016

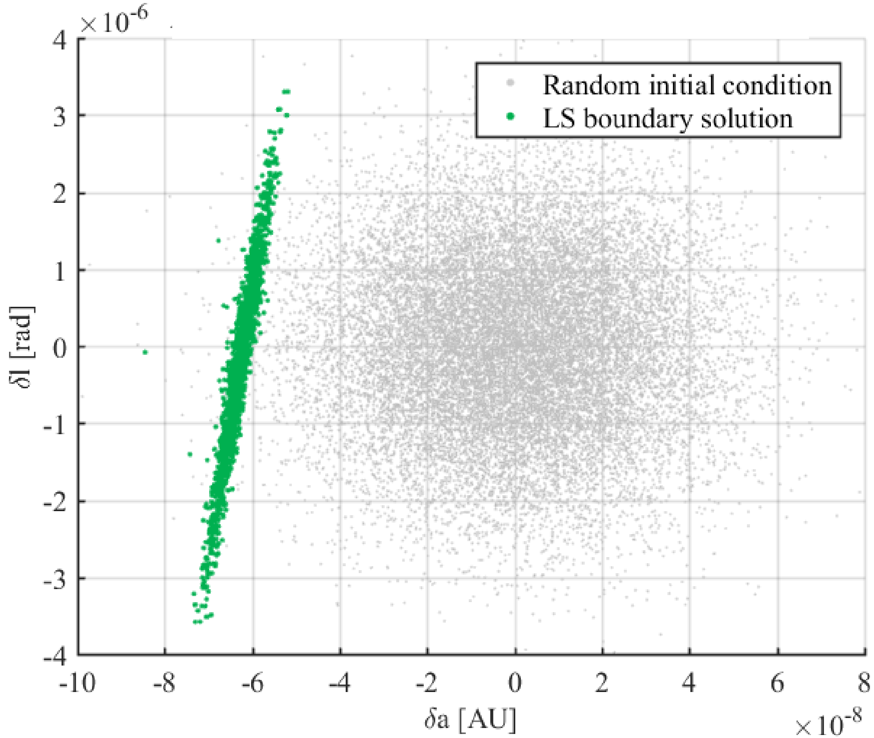
Results

Planetary protection analyses

Representation of the worst close approaches for the 1000 Monte Carlo runs of the launcher of Solo mission on the b-plane of Venus.

Apophis return in 2036 (according to observations in 2009)





- Letizia F., Van den Eynde J., Colombo C., R., Jehn, 2016
- http://newton.dm.unipi.it/neodys

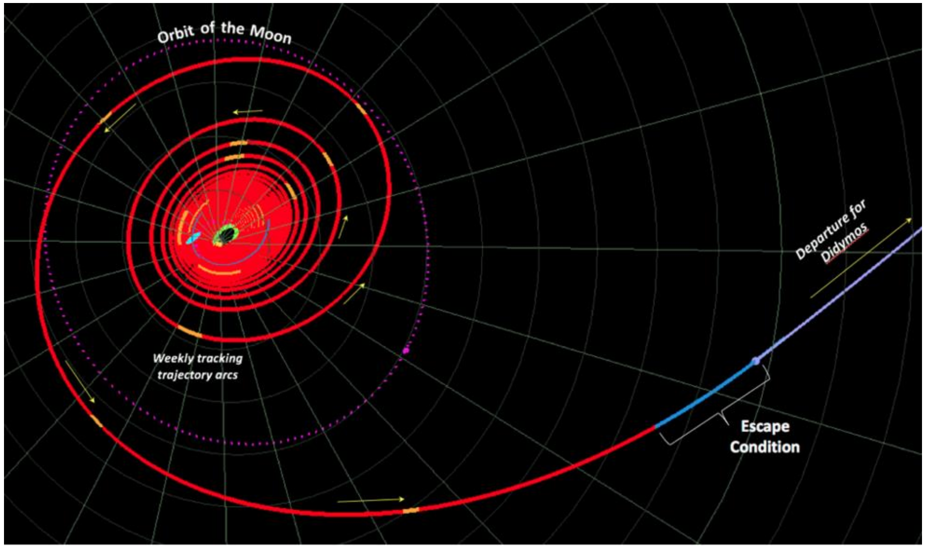

Image credits: ESA Space in Images – AIM at Didymos

OPTIMAL DEFLECTION OF NEAR-EARTH OBJECTS USING THE B-PLANE

Introduction

Objectives for asteroid deflection missions

- Perform planetary protection analysis on the trajectory
- Determine the optimal deflection direction to maximise the displacement on the b-plane
- Design an optimal deflection strategy aimed at avoiding resonant returns of the asteroid following the deflection manoeuvre



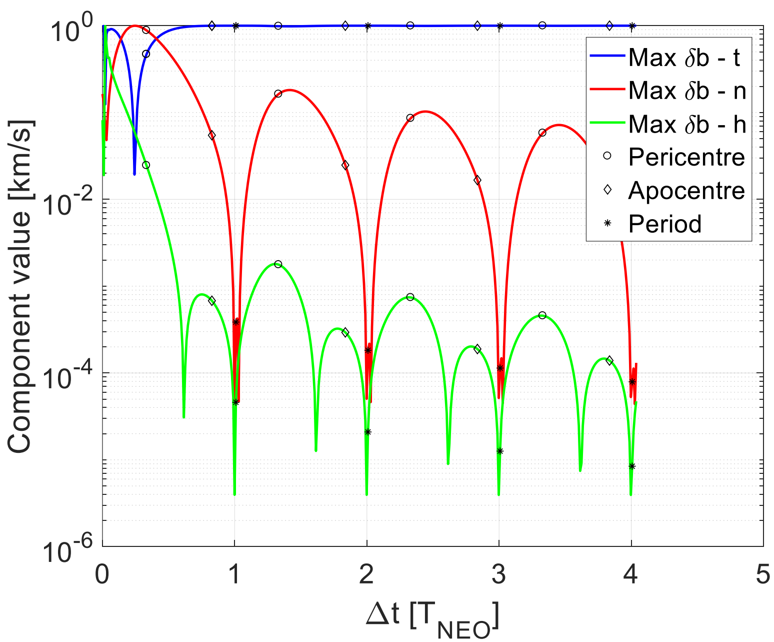
➢ Image credits: NASA Planetary Defense - DART

Deflection manoeuvre

Maximise miss distance versus avoid keyholes

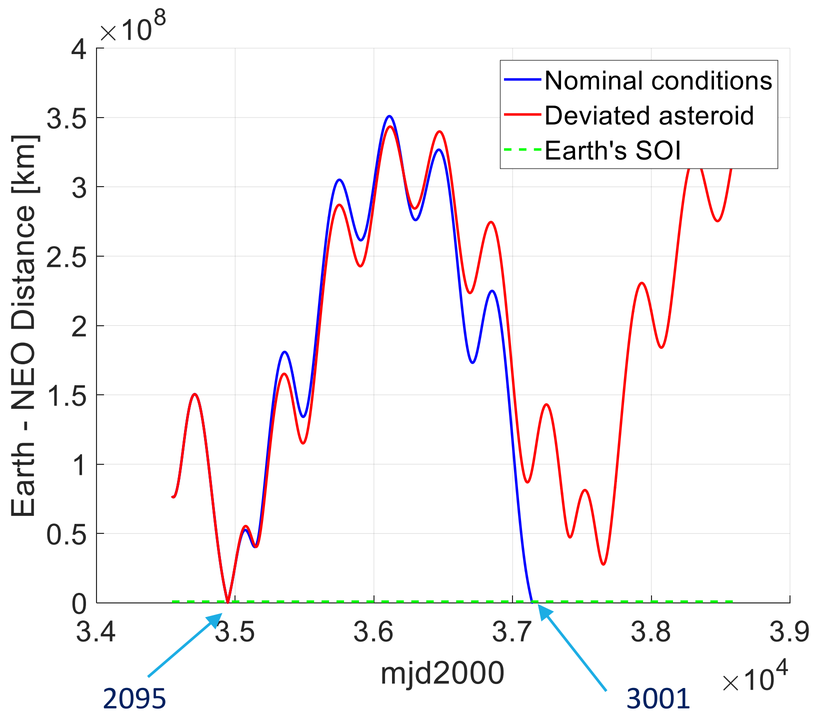
Strategy 1: maximise miss distance on the b-plane

- Analytical modelling of deflection and maximisation



Strategy 2: deflect and avoid keyholes

- Avoid regions of the b-plane leading to a subsequent encounter



➢ Petit and Colombo, "Optimal deflection of Near Earth Asteroids on the B-plane, 2018

Conclusions

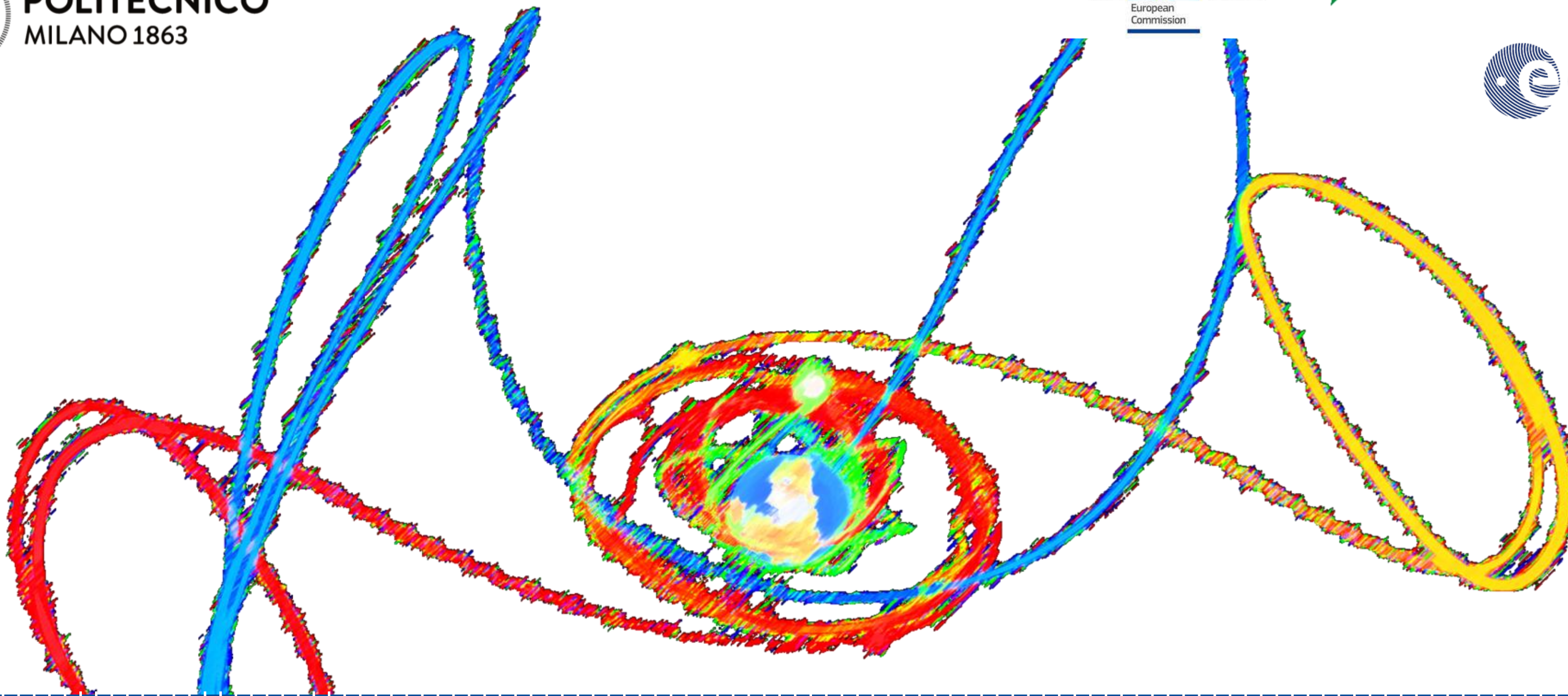
Near Earth Object deflection and planetary protection

Deflection manoeuvre design

- An analytical correlation between the deflection and the displacement on the b-plane is obtained
- It allows optimisation of impulsive deflection direction
- Deflection technique to avoid the keyholes as preliminary design for n-body propagation

Planetary protection analysis

- Uncertainty in initial conditions, spacecraft parameters, engine failures effect on 100 propagation for interplanetary space mission and deflection missions
- Minimum numbers of MC or line sampling runs for ensuring compliance to planetary protection requirements



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