Space Mission Planning Advisory Group

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Task 5.4 - REFERENCE MISSIONS FOR DIFFERENT NEO THREAT SCENARIOS - Lead: ASI (Support by ESA, UKSA)

1. Define a number of typical NEO threat cases on the basis of relevant parameters such as time to closest approach, material characteristics, and dynamical properties.
2. Set of reference mission identified (e.g. mass; orbit; time-to-closest-approach) and evaluated in accordance with criteria defined (e.g. time between the impact alert and the launch window opening, etc).
3. Considering several deflection strategies
4. Sensitivity analysis on accuracy of orbit determination
5. Robust control on the magnitude and direction of the imparted delta-velocity, centre of impact point
6. For each reference mission investigate political and financial implications and constraints in the risk mitigation analysis

Technical Support

NEO Selection and orbit parameters

- ✓ Istituto di Astrofisica e Planetologia Spaziali (G. Valsecchi)
- ✓ NEO Coordination Centre (E. Perozzi)

Mission Analysis

- ✓ Politecnico di Milano (C. Colombo, P. Di Lizia)

System Engineering

- ✓ ASI (R. Bertacin, M. Albano, E. Vellutini)

Definition of Threat Scenarios

- Different NEO threat cases have been analysed and discussed to identify a restricted number of scenarios, to be adopted as reference use-cases for the mission definition .

- The evaluation process considered different elements, such as:
  - ✓ Dimensions of NEO
  - ✓ Type of orbit (direct-impact, resonant, …)
  - ✓ Time to closest approach
  - ✓ Amount of available information
  - ✓ <u>Representativeness of known NEOs population</u>

- In order to guarantee the representativeness of the scenarios a “reverse approach” has been adopted through a small “adjustment” of representative real NEO cases to fulfil all desired characteristics

Definition of Threat Scenarios

Adopted NEOs classification:

- ✓ **Small-size NEOs:** ~10m equivalent diameter
- ✓ **Medium-size NEOs:** ~100÷200m equivalent diameter
- ✓ **Large-size NEOs:** ~1000÷2000m equivalent diameter

Assumptions:

- NEOs up to 100 m equivalent diameter are neglected in this preliminary work:
  - ✓ *object fragmentation and final destruction due to atmospheric drag*
  - ✓ *tracking of bigger fragments potentially needed*

- Medium-Large NEOs with a short lead-time are excluded from the analysis:
  - ✓ *impossibility to design an efficient disruptive/deflection action*
  - ✓ *continuous orbit determination and impact point prediction*
  - ✓ *mitigation actions on impact point*

Definition of Threat Scenarios

On the base of previous considerations, two main reference threat cases have been selected:

Scenario A

- **Medium-size NEO** (~100m diameter), magnitude ~ 21÷20
- **Direct impact orbit**
- Lead-time ≥ **10 years**

Scenario B

- **Large-size NEO** (~500m diameter), magnitude ~ 17÷16
- **Resonant-type orbit**
- Lead-time ≥ **20 years**

2010 RF_{12} has been identified as representative NEO candidate to be adopted for both the scenarios.

2010 RF_{12}

- 2010 RF_{12} is a **small Near Earth Asteroid** (NEA); its absolute magnitude H is 28.4 corresponding to a diameter between 5 m and 12 m

- Currently it has **the highest probability of hitting the Earth**: in both the risk pages of NEODyS(*) and of Sentry (**) **the impact probability** is estimated to be **around 6%** for an impact on 6 September 2095

- The **energy liberated** by such an impact will be of the order of the **energy of the Hiroshima bomb**

- 2010 RF12 was discovered on 5 September 2010, and observed for 3 days, until 8 September, during a close encounter with the Earth that brought it, on 8 September, within 79 400 km from the centre of the Earth

* http://newton.dm.unipi.it/neodys/index.php?pc=1.1.2&n=2010RF12
** http://neo.jpl.nasa.gov/risk/2010rf12.html

2010 RF_{12}

Orbital evolution:

- The orbit of 2010 RF_{12} is currently characterized by

  $a = 1.060$ au, $e = 0.188$, $i = 0.88°$, $\Omega = 163.8°$, $\omega = 267.6°$

- Between the current epoch and September 2095, 2010 RF_{12} undergoes a number of encounters with the Earth: two shallow encounters, one in February 2059, that changes the orbit into

  $a = 1.057$ au, $e = 0.187$, $i = 0.90°$, $\Omega = 163.0°$, $\omega = 266.9°$

  and another one in February 2084, that slightly modifies the orbit into

  $\boldsymbol{a = 1.057}$ **au**, $\boldsymbol{e = 0.187}$, $\boldsymbol{i = 0.9°1}$, $\boldsymbol{\Omega = 162.8°}$, $\boldsymbol{\omega = 267.1°}$

  On this orbit 2010 RF_{12} encounters, and possibly impacts, the Earth in 2095

2010 RF_{12}

Reasons for choice

- Near Earth Asteroids (NEAs) move on a wide variety of orbits; no particular choice can be considered representative of the whole population

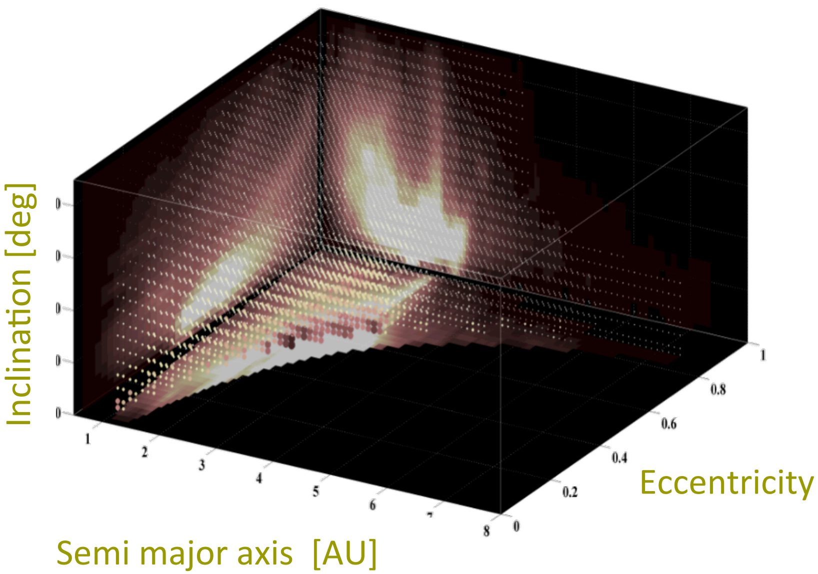
- 2010 RF_{12} will lead to either an impact the Earth, or a very close encounter with it, at the end of the current century

- It can be considered a “realistic" impactor orbit, and is as good as any other NEA impact orbit for the study of a defection mission

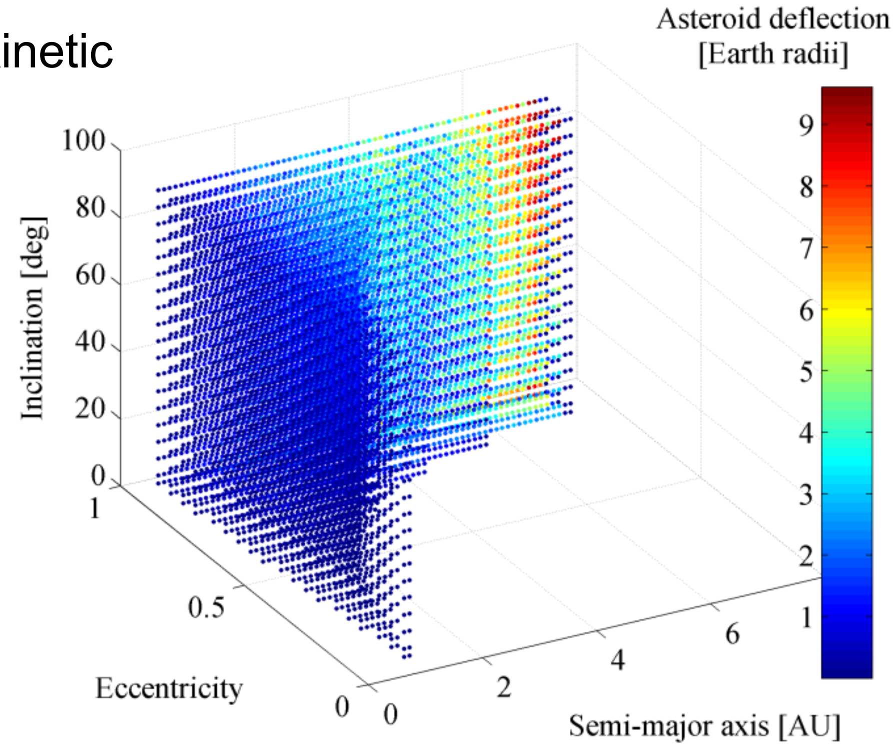
Mapping Threat Scenarios To Mission Types

Past work on sensitivity analysis of the deflection mission to NEA orbit

Capabilities to deflect with a 1000 kg kinetic impactor spacecraft a generic NEA



Theoretical NEO distribution, probability density in a, e, i



Resulting deflection

▶ Sanchez J. P., Colombo C., "Impact hazard protection efficiency by a small kinetic impactor", Journal of Spacecraft and Rockets, Vol. 50, No. 2, Mar.–Apr. 2013, pp. 380-393, doi: 10.2514/1.A32304, ISSN 0022-4650

Reference Mission

Target: 2010 RF_{12}

Hypothesis:

- Spherical shape and average density (standard NEA): 2600 kg/m^3
- Albedo for standard NEA: 0.154

- Absolute magnitude H 28.4

  Absolute magnitude H derived from astrometric observation via orbit determination

- Slope parameter G 0.15

- Diameter D 5 - 12 m

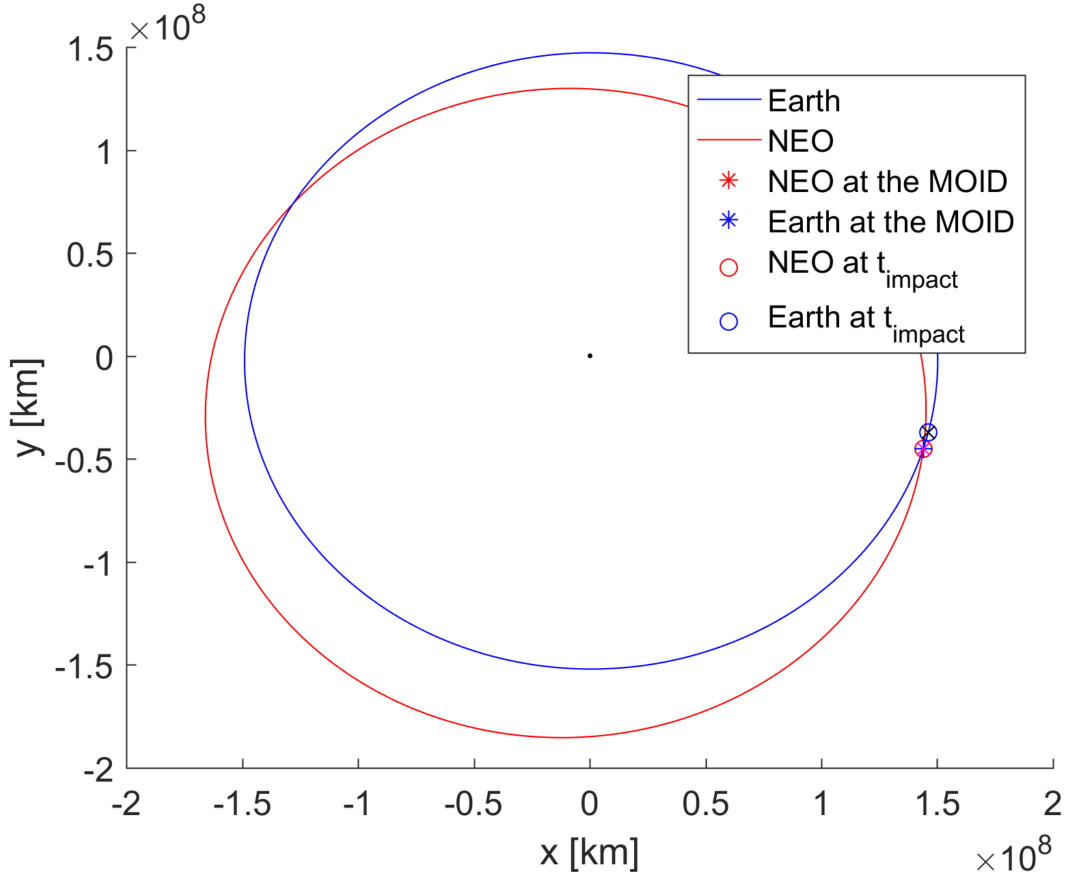
  Diameter range derived from H and assumed albedo for C and S type - 0.04 and 0.20 respectively

► NeoDys: http://newton.dm.unipi.it/neodys/index.php?pc=1.1.9&n=2010RF12

► Chesley, S. R., Chodas, P. W., Milani, A., Valsecchi, G., and Yeomans, D. K., “Quantifying the Risk Posed by Potential Earth Impacts,” Icarus, Vol. 159, No. 2, 2002, pp. 423–432. doi:10.1006/icar.2002.6910

Reference Mission

Target: 2010 RF_{12}



2095 close approach after shallow encounter with the Earth on 02-2084

Reference Mission

Target: modified 2010 RF_{12}

- Same orbit but increased diameter wrt real case: D = 100 m
- Corresponding to absolute magnitude of 22.65

$$D = \frac{1}{\sqrt{p_v}} \cdot 1329 \cdot 10^{H/5} \quad [km]$$

Type of event	Approximate range of impact energies (MT)	Approximate range size of impactor	Relative event frequency
Airburst	1 to 10 MT	15 to 75 m	~177,000 of 200,000
Local Scale	10 to 100 MT	30 to 170 m	~20,000 of 200,000
Regional Scale	100 to 1,000 MT	70 to 360 m	~2400 of 200,000
Continental Scale	1,000 MT to 20,000 MT	150 m to 1 km	~600 of 200,000
Global	20,000 MT to 10,000,000 MT	400 m to 8 km	~100 of 200,000
Mass Extinction	Above 10,000,000 MT	>3.5 km	~1 of 200,000

Seriousness of an impact based on the impact energy

Power law distribution

- Chesley, S. R., Chodas, P. W., Milani, A., Valsecchi, G., and Yeomans, D. K., "Quantifying the Risk Posed by Potential Earth Impacts," Icarus, Vol. 159, No. 2, 2002, pp. 423–432. doi:10.1006/icar.2002.6910
- Sanchez J. P., Colombo C., "Impact hazard protection efficiency by a small kinetic impactor", Journal of Spacecraft and Rockets, Vol. 50, No. 2, Mar.–Apr. 2013, pp. 380-393, doi: 10.2514/1.A32304, ISSN 0022-4650

Reference Mission

Deflection mission

- Direct hit
- Resonant encounter

2010 RF_{12} is a good target for both mission cases

Lead time: from discovery to potential impact

Direct hit mission settings

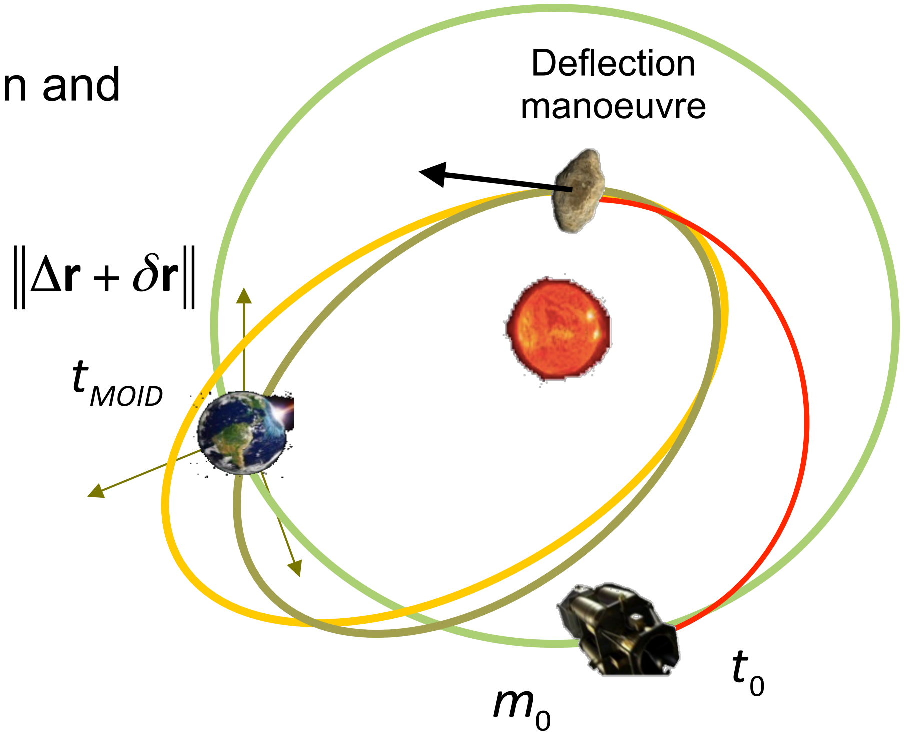
- Warning time (between launch and CA targeted for deflection): 10 years
- Hyperbolic excess velocity: 2.5 km/s
- Initial wet mass s/c: 1000 kg
- I_{sp}: 300 s
- Momentum enhancement factor: 1

Direct Hit Mission

Design of asteroid interception phase and asteroid deflection phase

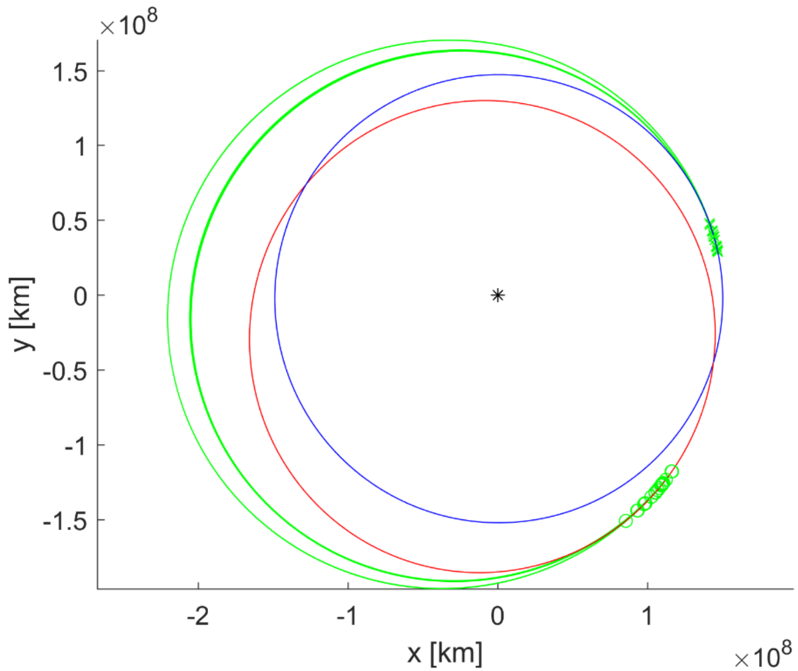
- Formulation of the asteroid deviation problem

- Integrated design of the interception and deflection phase

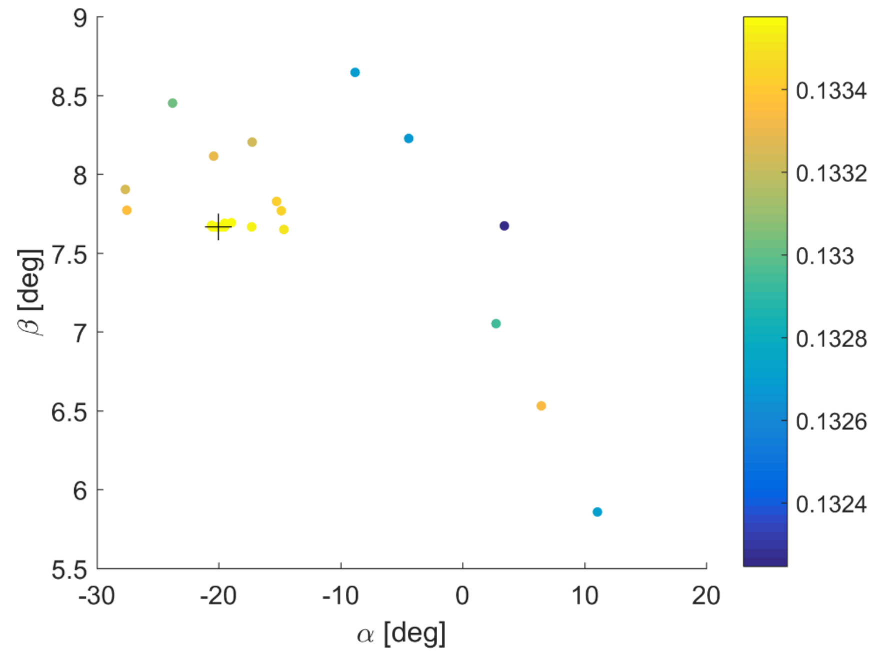


Preliminary design

Direct Hit Mission



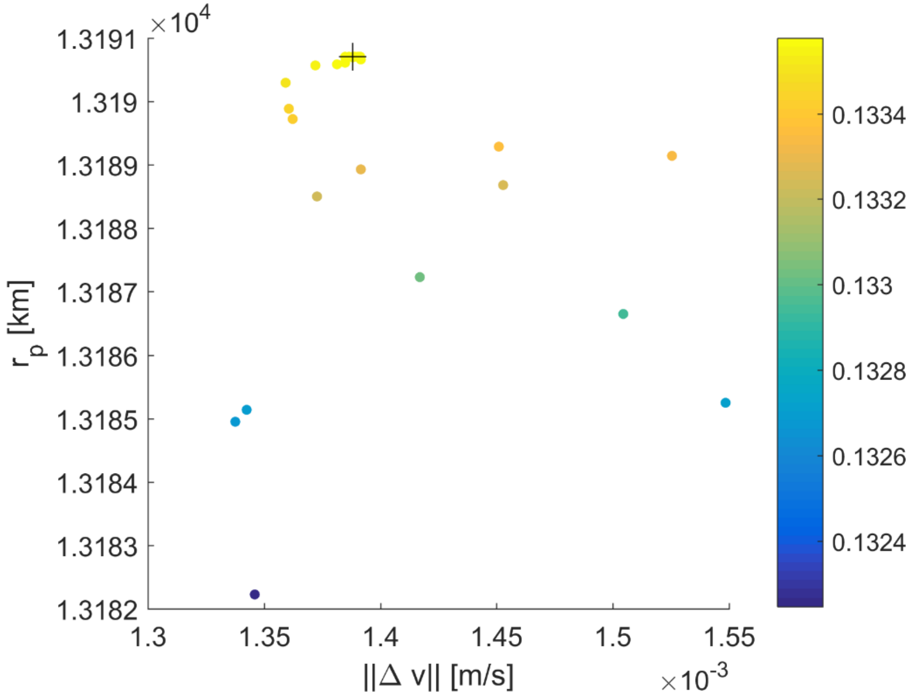
Direct transfer to 2010 RF$_{12}$

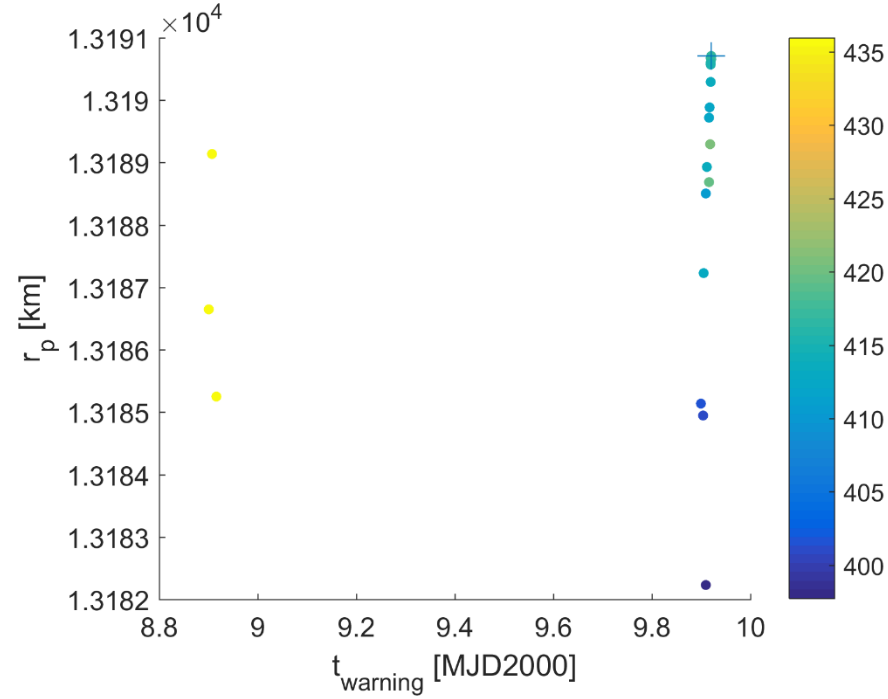


Deflection manoeuvre

Preliminary results

Direct Hit Mission





Preliminary results

Plan for Future Work

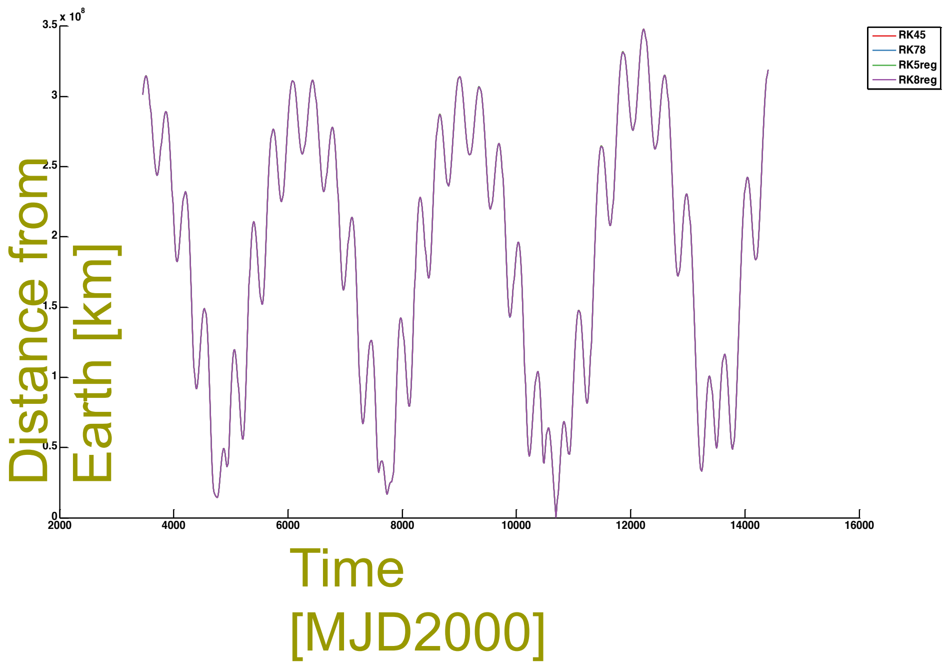
- Include **orbit determination** process during transfer phase
- Spacecraft **system design**
- Design of **robust deflection manoeuvre**
  - ✓ Uncertainties on asteroid characteristics (response, rotational rate)
  - ✓ Uncertainties in orbit
  - ✓ Manoeuvre error
- **Multiple** kinetic impactor for robust deflection
- **Sensitivity analysis** on asteroid mass and characteristics

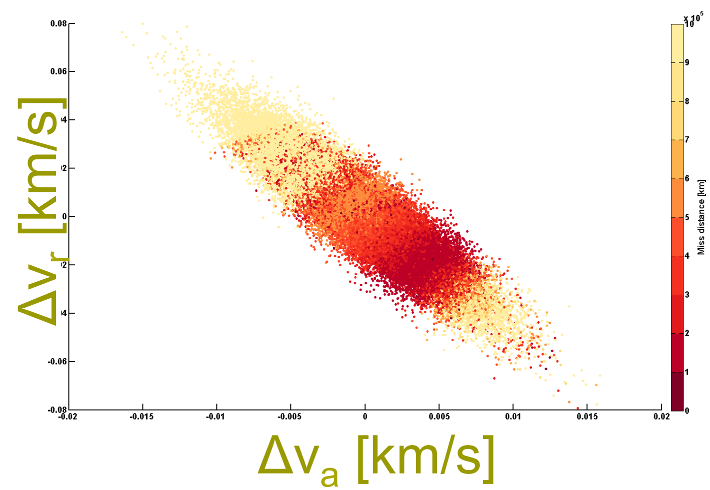
Plan for Future Work

Resonant encounter mission

- Multiple encounters with the Earth are present
- **Robust deflection**, i.e. do not deflect into a keyhole
- **SNAPPshot** tool for planetary protection will be used

Resonant encounter example: Apophis





► Letizia F., Colombo C., Van den Eynde J. P.J.P., Armellin R, Jehn R., SNAPPshot suite for numerical analysis of planetary protection, ICATT, 2016, Darmstadt, Germany.