Instrumentation for an asteroid kinetic-impactor demonstration mission

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Summary

For selecting instruments to fulfill the objectives of a mission to impact an asteroid, it is important to get an idea of the effects of such an impact event. Therefore the expected crater and ejecta cloud have to be calculated. The calculations need to take into consideration the properties of the asteroid as well as the impactor. The main objective of the NEOTωIST mission is to transfer angular momentum by impacting the asteroid far from the rotation axis to change the rotation period as well as observe the resulting ejecta cloud and possibly the crater. There are three different mission concepts, the 1st includes only an impactor spacecraft, the 2nd adds a flyby subunit the 3rd one to two chasers. Due to the fact that the three concepts have different mission objectives the instrumentation of the concepts are different.

Keywords: *Near-Earth Asteroids, Near-Earth Objects, impact, payload, ejecta cloud, crater*

1 Introduction

Earth is continuously colliding with fragments of asteroids and comets. Even a small asteroid, like in 2013 the 18 meter-sized asteroid, which exploded over the Russian million-inhabitant city of Chelyabinsk, can cause a great damage.[1]

A kinetic-impact demonstration mission is important to improve our understanding and ability of asteroid deflection by collisional means.

2 Mission

The mission is a kinetic-impact demonstration mission to show the possibility to change the spin rate of an asteroid. To lower the cost for such a mission, a well known target asteroid has been chosen. The asteroid Itokawa was characterized by the Hayabusa space mission and therefore a reconnaissance spacecraft to observe the asteroid, before the impact event happens, is not crucial.

3 Mission concepts

The NEOTωIST mission can be designed in different ways, see also figure 1:

1. Impactor spacecraft
2. Impactor spacecraft and flyby subunit
3. Impactor spacecraft, flyby subunit and chasers

The 1st concept is feasible with only the impactor. In that case information of the impact event will be provided only by Earth-based observatories. By adding an ejectable flyby subunit, the mission can be expanded. The flyby subunit of the 2nd concept will observe the impact event and its effects, and also act as a relay node for the impactor during its final approach. An ejectable flyby subunit is a cheaper variant compared to having a separate reconnaissance spacecraft from a second deep-space mission. Mission concept 3 is another extension to concept 1 and 2. In the 3rd concept small subunits, called chasers, would be added to the impactor. Slightly before the impact, the chasers would be ejected, to observe the impact event in close up views from inside the ejecta cone. The flyby subunit would buffer the data from the chasers and act as a relay node.

In table 1 the scientific objectives of the subunits for the kinetic-impact demonstration mission are shown.

Subunit	**Objectives**
Impactor	Momentum transfer via impact Observation of the impact point close up
Flyby	Observation of impact event Observation of ejecta cloud •Particle size •Particle velocity •Ejecta density •Ejecta angle •Ejecta expansion
Chasers	Close–up view of impact event Observation of crater formation •Crater diameter •Crater depth Observation of ejecta cloud from inside the plume

Table 1: Scientific objectives of the subunits for the kinetic-impact demonstration mission.

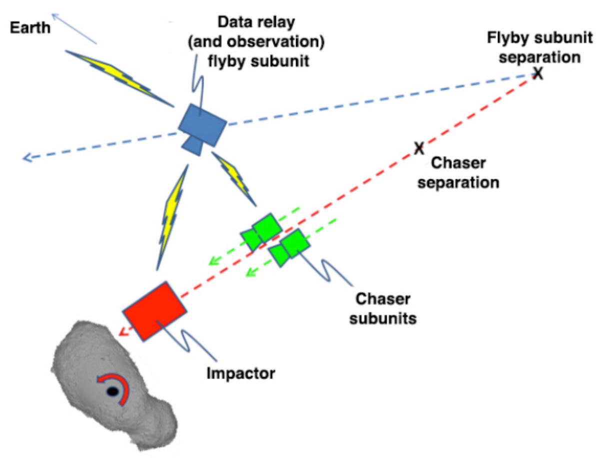

Figure 1: Overview of mission concepts. Credit: L. Drube[2]

4 Target

Itokawa is an Apollo asteroid, whose orbit crosses the Earth's orbit but is mostly outside it. Itokawa is a stony-type asteroid with a size of $535 \times 294 \times 209$ m.[3] Due to the form, Itokawa's structure is divided in two parts, "Head" and "Body", with mostly rough terrain but also three smooth areas, see figure 2. Its rotation period is about 12.1 h.[4] Close-up images from the Hayabusa space mission indicate that there might be a particle cut-off size of ~ 1 cm for the surface material.[5]

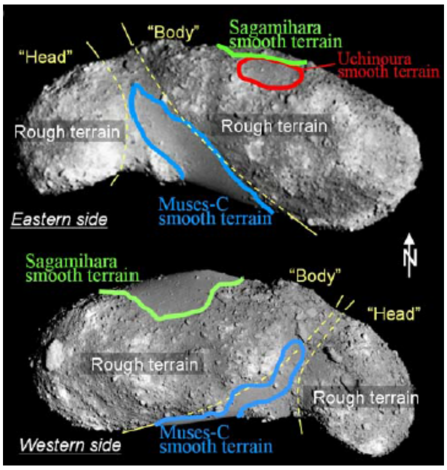

Figure 2: Asteroid Itokawa. Credit H. Miyamoto[5]

5 Methods and results

For calculation of impact events and the resulting crater and ejecta properties the following equations are required. The main characterizations are the crater radius R, ejecta mass M and ejecta velocity v.

$$R = \{[H_2(\frac{\rho}{\delta})^{\frac{1-3\nu}{3}}(\frac{Y}{\rho U^2})^{\frac{-\mu}{2}}]^3(\frac{m}{\rho})\}^{\frac{1}{3}} \quad (1)$$

$$M = m\frac{3k}{4\pi}\frac{\rho}{\delta}[(\frac{x}{a})^3 - n_1^3], n_1 a \le x \le n_2 R \quad (2)$$

$$v = UC_1[\frac{x}{a}(\frac{\rho}{\delta})^{\nu}]^{\frac{-1}{\mu}}(1-\frac{x}{n_2 R})^p, n_1 a \le x \le n_2 R \quad (3)$$

For more information about equations (1 - 3) see Housen and Holsapple.[6]

But also the ejecta particle size distribution and the total number of ejecta particles is of interest, to get the chance to measure the total ejecta mass from observation of the ejecta cloud. The number of particles N is described by a power-law distribution with an exponent -2.8[5] over the minimum (d_{min}) and maximum (d_{max}) size of the ejecta particles and the scaling factor N_r. For more information about equation (4) see Yu et al.[7]

$$N(>d) = N_r d^{-2.8}, d_{min} \le d \le d_{max} \quad (4)$$

6 Instruments

Preliminary studies show that we expect the largest amount of ejected mass in small size particles. Due to the fact, that the calculations of the expected crater and ejecta is not finished yet, the detailed selection for the space qualified instruments for the three mission concepts is still in progress.

Possible instruments to fulfill the mission objectives for the kinetic-impact demonstration mission are:

- Visual imager
- Spectrometer

- Near infrared
- Thermal infrared
- Radar
- LIDAR
- Radio signal to chaser

7 Application

To make it easy for other people interested in impact events, we are developing a Java application which will calculate the most important properties of an impact event. See figure 3 for a preliminary view of the application.

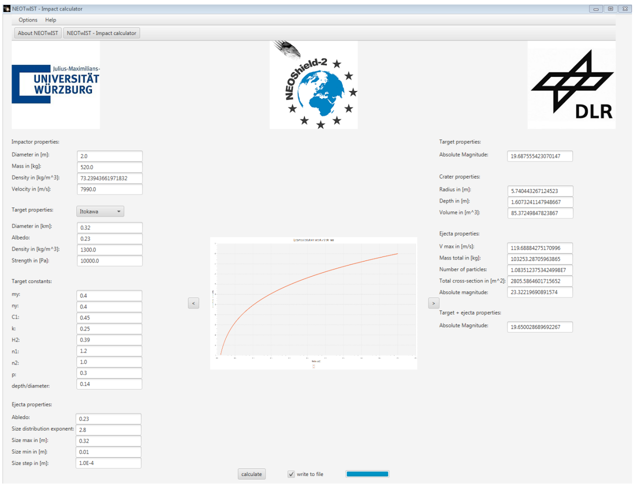

Figure 3: Tool for impact event calculations.

On the left part of the application the user can make the inputs for the impactor and the target. Possible inputs for the impactor are the mass, size, density and velocity. For the target the inputs are size, albedo, density, strength, heliocentric and geocentric distance, phase angle and constants, based on the target properties, needed for the calculation of the crater. The ejecta inputs are albedo, size distribution exponent and maximal and minimal ejecta particle size. On the right part of the application (figure 3) the outputs will be displayed. The outputs include the crater radius, depth, volume and the ejecta velocity, total mass, number of particles and the absolute and relative magnitudes of the target itself, the ejecta cloud and the combined magnitudes. In the center of the application different plots about size and mass distributions will be shown. The possibility to save the plots, write the results in files and more options are in development.

8 Conclusion

The instrumentation has to be chosen to fulfill the mission objectives. Since we don't know, if the cut-off size for the surface material is also below the surface, we need to do the observation, from the flyby subunit, with backward scattering and not forward to make sure we will get a measurement.

References

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