IAC-22, E10,1,2, x73191

LICIACube: A Deep Space Cubsat to Witness the first Asteroid kinetic impactor test

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Abstract

Since the last few years several international space agencies are focusing their attention on small spacecraft technologies and capabilities for missions in science, exploration, and space operations. Moreover, the Near-Earth Asteroids (NEA) that could impact the Earth in the near future received increased interest. In this contest the Double Asteroid Redirection Test (DART) mission has been developed by NASA for Planetary Defence program. The DART mission is a spacecraft acting as a kinetic impactor that will change the orbit of an asteroid, by crashing itself on Dimorphos, the moonlet of the Didymos binary system, modifying its revolution period around the primary body. In order to increase the accuracy of the impact effect of the deflection measurement, the Italian Space Agency (ASI) 6U Cubesat named LICIACube (Light Italian Cubesat for Imaging of Asteroids), manufactured by the Italian aerospace company Argotec, has been designed to be carried as piggyback by the DART spacecraft. The LICIACube team includes a wide Italian scientific community, involved in the definition of all the aspects of the mission: trajectory design, mission definition and real-time orbit determination during operations, scientific simulation and modelling. The DART/LICIACube mission, launched on 24th November 2021, is presently on its way to Didymos and the arrival is foreseen on 26 September 2022. Fifteen days before the impact, LICIACube will be released and it will perform braking manoeuvres in order to increase the relative velocity with respect to the DART spacecraft and will prepare for an autonomous flyby with Dimorphos. During the scientific phase LICIACube will pursue the following mission objectives: i) testify the DART impact, ii) characterize the impact ejecta plume, its structure and evolution, iii) characterize the impact site (and possibly size and morphology of the crater) on Dimorphos' surface, and iv) image the non-impact hemisphere, thus increasing the accuracy of the shape determination. LICIACube is equipped with two imaging cameras: LEIA (LICIACube Explorer Imaging for Asteroid), a narrow camera equipped with a Panchromatic filter, and LUKE (LICIACube Unit Key Explorer) a wide-angle camera, which is the Gecko imager from SCS space, with RGB Bayer pattern filter. The images obtained by LICIACube will been downloaded directly to Earth thanks to the antennas of the NASA Deep Space Network and LICIACube Ground Segment, composed by the Argotec Mission Control Centre and the ASI Space Science Data Center for archiving and processing data. The LICIACube mission is a challenging opportunity for the implementation of a deep space mission, based on a small scale but highly technological platform.

Keywords: asteroid, NEO, planetary defense, Cubsat, kinetic impactor, 6583 Didymos Dimorphos

Acronyms/Abbreviations

CA	Close Approach
DART	Double Asteroid Redirection
DSN	Deep Space Network
FoV	Field of View
GS	Ground Station
IS	Imaging System
MATISSE	Multi-purpose Advanced Tool for the Solar System Exploration
MCC	Mission Control Center
NEA	Near Earth Asteroid
OBC&DH	On-Board Computer & Data Handling
OSW	On-Board Software
PHA	Potential Hazardous Asteroid
PL	Payload
PS	Propulsion System
RW	Reaction Wheel
SOC	Scientific Operations Center
SSDC	Space Science Data Center

1. Introduction

Near-Earth Asteroids (NEAs) are of high interest due to the fact that they can be explored with lower mission velocity, thanks to their combination of low velocity respect to the Earth (ΔV) and small gravity. So, they may present interesting scientific opportunities for both geochemical and astronomical investigation. In addition, many NEAs are considered to be Potentially Hazardous Asteroids (PHAs).

In the last decades, planetary defense has increased their relevance in national and international field, in order to detect the possibility and warn of potential asteroid or comet impacts with Earth, and then either prevent them or mitigate their possible effects.

Planetary defense involves planning and implementation of measures to deflect or disrupt an object on an impact course with Earth, or to mitigate the effects of an impact that cannot be prevented. In this contest, the LICIACube mission [1] will represent a great opportunity for the planetary defense and asteroid community, given the large opportunities science return foreseen by its observation conditions.

LICIACube is the first 6U Cubsat Italian smallsat to be operated in deep space. LICIACube platform is developed by Argotec company and managed by the Italian Space Agency (ASI), with the aim to contribute in the NASA DART Planetary Defence mission objective and to perform autonomous science at the asteroid [2]. The NASA-DART mission will be the first mission to undertake an orbital deflection experiment against a NEA. The smallest member of the binary Dydimos-Dimorphos system will be impacted by the 660 kg spacecraft at the velocity of 6.6 km/s, leading the orbital period to change in return. The expected baseline kinetic energy is 9.7 GJ [3] and <10^5 kg of mass is to be released [4].

The LICIACube has been launched with DART on 24 November 2021 to testify in-situ the impact experiment on a binary system. After 10 months of interplanetary cruise LICIACube will be released 15 days before the impact on Dimorphos. The italian cubesat will perform an autonomous fly-by of the binary system with several scientific objectives: (i) to directly witness the impact of the DART spacecraft on Dimorphos's surface; (ii) to study the ejecta plume over its evolution in time and under varied phase angles in order to estimate the properties of the plume and the evolution of its grain distribution; (iii) to study the impact site with sufficient resolution to allow measurements of the size, colour, and morphology of the artificial crater formed in the aftermath.

Such objectives will be achieved thanks to two cameras (a narrow angle and a wide-angle camera) mounted on. LICIACube:

- **LEIA** (LICIACube Explorer Imaging for Asteroid): narrow FoV camera expected to provide high-resolution images of the impact site [5] as well as contributing to a better definition of the target body shape with the acquisition of images coming from Dimorphos hemisphere not observed by the camera installed on board DART called DRACO.
- **LUKE** (LICIACube Unit Key Explorer): wide FoV imager with RGB Bayer pattern filter whose characteristics should allow for performing dedicated scientific observations such as the study of the colour variation over Dimorphos surface [6].

In order to ensure the correct orientation of the two payloads during the fly-by, a proper trajectory and attitude design shall be put in place, in order to keep the target always within the field of view of the payloads and to avoid delays and blurring effects on the images [7]. LICIACube will be deployed by DART in close proximity to the target, 15 days before impact, and will perform an autonomous overflight of Didymos.

Range and Doppler measurements between the small satellite and terrestrial antennas of NASA's Deep Space Network (DSN) will be acquired before and after the impact. The radiometric measurements, together with the optical images of the Didymos system, will be jointly processed to perform the determination of the Cubesat orbit. Furthermore, gravitational investigations performed using radiometric and optical data could also be useful to constrain the physical parameters of the Didymos system [8]. During this phase of the project, knowledge of the expected accuracy of the small-sat orbit is of primary importance for both mission and trajectory analysis, in order to optimize observation conditions and maximize the scientific return of the mission. All the data acquired by LICIACube will be received at the Argotec Mission Control Center (MCC) from Deep Space Network (DSN), and will be stored, processed and distributed by LICIACube Science Control Center (SOC), coordinated by the ASI Space Science Data Center (SSDC) [9]. LICIACube SOC, thanks to its long experience in space data management, will define the procedures to make the data ready for scientific analysis and available to the community thanks to the SSDC Multipurpose Advance Tool for Instruments for solar system Exploration (MATISSE) scientific webtool.

2. Target

The mission target is the (65803) Didymos system (provisional designation 1996 GT), discovered on 1996 April by the University of Arizona Steward Observatory's Spacewatch survey using its 0.9-m telescope at Kitt Peak Observatory, Arizona. At epoch 2459800.5 (August 09, 2022), Didymos has the orbital parameters reported in Table 1 (based on the JPL Small-Body Database Browser) and it is classified as Potentially Hazardous Asteroid (PHA). Didymos is a binary system, as estimated for about 15% of the NEA population [10]. The presence of the secondary Dimorphos was confirmed with optical lightcurve analysis and Arecibo radar imaging in 2003 [11] and the condition of low obliquity and retrograde rotator was later confirmed [12] [13] [14].

The bulk density of the primary is compatible with known bulk density range for S-type objects (2000–2700 kg m^{-3}), and the S-type classification was recently confirmed [16] [17] showed that it is spectroscopically most consistent with ordinary chondrites, with an affinity for L/LL-type meteorites. The bulk density of the secondary is not known: models of asteroid satellite formation predict that moons should have similar or smaller densities than their primary body [18] [19] so, even if Dimorphos may be a rubble pile, it should be relatively compact and with a density close to Didymos. The rotation state of Dimorphos is not constrained by observations and may be unstable (tumbling).

Very recently, an intense observing campaign during the 2021 perihelion passage, with 37 mutual eclipse and occultation events between the binary system components detected, has been combined with 18 mutual events detected in 2003. This allowed to infer that the primary lightcurves of the binary system were complex, showing multiple extrema, on some epochs [20] They suggest a presence of complex topography on the primary's surface that is apparent in specific viewing illumination geometries; the primary shape model by [21] needs therefore to be refined.

Using recent models of the Near-Earth Objects (NEO) population [22] [23] suggested some hypothesis about the dynamical origin of Didymos. The most probable is that the asteroid reached its current orbit by exiting the inner main belt near or within the ν6 resonance between 2.1 and 2.5 au. Didymos likely originated from a high-albedo family [24] its geometric albedo matches the mean albedo of the prominent Baptistina family in that zone, but its exact origin is still not clear, as several other families can be considered as plausible parents (e.g., Flora, Nysa, Massalia, Lucienne). For what concerns physical origin of Didymos, [25] that small binary asteroids are created by the slow spinup of a 'rubble pile' asteroid by means of the thermal YORP (Yarkovsky– O'Keefe–Radzievskii–Paddack) effect, but

Didymos belongs to the special class of binary asteroids, whose primaries are at risk of rotational disruption.

A mission to Didymos has therefore an importance *per se*, allowing us to investigate nature and origin of such a weird object. Moreover, Didymos is an ideal test target for a planetary defense mission, since it poses no actual threat to Earth in the near-future, and the momentum transferred by DART is not high enough to change significantly the orbit of the binary system around the Sun; still, measuring the variation of the Dimorphos orbit about the primary body can be used as a demonstration of our capability to deflect the heliocentric orbit of a potential impactor threat, when this will be necessary.

Table 1 Orbital parameters of Didymos at epoch 2458959.5 April 20, 2020 (JPL Small-Body Database Browser).

Semimajor axis	1.64432 au
Eccentricity	0.383923
Orbital inclination	3.408°
Orbital period	2.109 yrs (770.16 days)

3. LICIACube – Scientific Objectives

Since DART will be the first test to assess the feasibility of deflecting a potentially hazardous object's trajectory through a kinetic impactor [26], both LICIACube and DART, will give us, for the first time, the unique opportunity to investigate and understand the physical properties of binary system NEA, its nature and have hints on its formation and evolution.

In particular, the images acquired by LICIACube will provide major information about crater formation and ejected particles evolution. The images will allow to study the structure and evolution of the ejecta plume produced by the impact, a fundamental task for the determination of the momentum transfer obtained by DART. LICIACube will also see both impact and non-impact sides of Dimorphos, performing observations of critical importance for modelling the outcome of the DART impact in terms of planetary defense science.

The scientific objectives of LICIACube are listed hereafter:

- Testify the DART impact;
- Obtain at least three images of the ejecta plume taken over a span of time and phase angle, in order to measure the motion of slow ejecta (i.e. slower than 5 m/s) and to allow the estimation of the density structure. The slow particles shall be over a time-span of at least 30s, with an image resolution better than 5 m/px.
- Obtain images of the ejecta plume and target asteroid to characterize both color and spectral variations during fly-by.
- Obtain multiple (at least 3) images of Dimorphos showing the nonimpact hemisphere, in order to better reconstruct the body volume and shape model. The require resolution shall be better than 2 m/px.

4. Payload overview

The 6U Cubsat platform (see Figure 1) has been designed by Argotec in the framework of the ArgoMoon mission [27] [28] for the Italian Space Agency. In order to customized LICIACube mission to achieve the primary objectives and to obtain significant pictures of the DART impact, the optical properties of the two cameras have been designed considering that DART will impact on Dimorphos at approximately 6 km/s, meanwhile LICIACube will perform a fly-by with a relative velocity of about 6 km/s and close approach (CA) distance of about 55 km after it will be release by the dispenser 15 days before impact.

LEIA, the principal payload is catadioptric camera composed of 2 reflective elements and 3 refractive elements with a FoV of ±2.06° on the sensor diagonal, IFoV 25 µrad/px (see Table 2). The optic is designed to work in focus between 25 km and infinity and the detector is a CMOS sensor (CMV4000) with 2048 x 2048 pixel. It is a highly miniaturized, compact and high-performance camera. It is a monochromatic sensor and it is able to operate in the NIR and visible spectral range between the 400 nm and 900 nm. The detector is connected with On-Board Computer & Data Handling (OBC&DH) via Spacewire interface, in order to reach an adequate transfer rate for shot pictures. The same SpW interface shall be used for payload commanding and telemetry as well.

LUKE is the secondary instrument, it is the Gecko imager from SCS space, is a catoptric camera composed by 4 refractive element and 2 reflective elements. The detector is a CIMOS sensor (CMV2000) with 2048 x 1088 pixel. It is interfaced with the NanoCU, the data elaboration unit of the camera, through a flexible PCB, to minimize any mechanical stress. The detector is able to operate in the NIR and visible spectral range from 400 nm to 900 nm. The NanoCU is connected with On-Board Computer & Data Handling (OBC&DH) via SPI interface. The same interface is used for payload commanding and telemetry. LUKE is an RGB camera with a Bayer pattern filter and its focal length (70.55 mm) is designed to work in focus between 400 nm to infinity (see Table 2). The FoV is ±5° and IFoV 78 µrad/px with a spatial scale about 4 m/px at 51 km. Moreover, the hardware is capable of directly integrating the image data to the integrated mass storage.

The suite of the payload will obtain images of the Didymos system with both LUKA e LEIA cameras during the flyby.

The primary camera will acquire pictures from a high distance providing high level of details of the frame field, meanwhile, the second one will take pictures to the CA by pointing at the ejecta cone and possibly the target surface if not obscured by ejecta.

Both LEIA e LUKE cameras will get about 240 images of the impact and non-impact target sides with a variable rate up to 1 picture per second at CA, as well as of the ejecta plume produced by the DART impact.

The current imaging plan [1] is to collect a set of three images at maximum frame rate possible and with differing integration times for each programmed snapshot, in order to maximize the dynamics of the acquired imaging data (pictures) of the impact plume and surface.

The proximity operation and image acquisition at the asteroid have been scheduled on the basis of the trajectory design and Orbit Determination (OD) constraints, to accomplish the different mission objectives.

Table 2
Design parameters of LEIA and LUKE.

	Focal length (mm)	FoV (°)	IFoV (µrad/ px)	Spatial scale at 55.3 km (m/px)
LEIA	220	± 2.06	25	1.38
LUKE	70.55	± 5	78	4.31

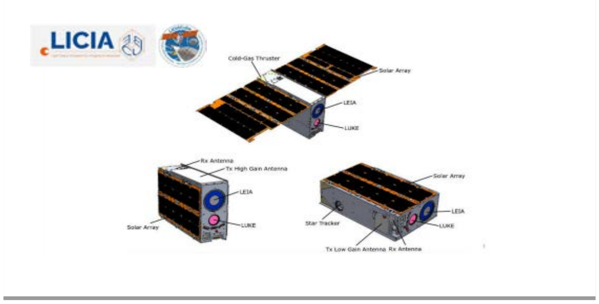

Fig. 1 3D view of LICIACube spacecraft with deployed Solar Array on top with the two payloads LEIA and LUKE onboard

5. Asteroid proximity operations

In order to meet the mission objectives, the LICIACube trajectory must be design considering all constrains come from environmental and platform limitations in addition to science purposes. LICIACube will be deployed from DART 15 days before the impact and will exploit a small cold gas thruster to deviate its trajectory and avoid asteroid. The low thrust magnitude does not allow a capture into the asteroid system therefore a flyby is the only viable option.

5.*1 Trajectory design*

The trajectory design has been driven by many different aspects that acted as constraints, which have scientific, environmental and platform-related natures.

The two main performance parameters that characterise the trajectory of the CubeSat are the close-approach distance $d_{C/A}$, defined as the minimum distance from Dimorphos and the delay time, t_{delay},, which identifies the time gap between DART impact and LICIACube closest approach.

The value of $d_{C/A}$ directly defines the resolution obtainable with the on-board payload, thus the satisfaction or not of the scientific imaging requirements. Smaller values of this distance will provide higher resolutions and more accurate imaging, penalising however the burden required by the ADCS to keep the asteroid pointing, which will require faster and faster slewing capabilities.

Given the scientific requirements provided in Section 3 and the Payload capabilities of Section 4, it is possible to define upper boundaries of the close approach distance for the different objectives, i.e.:

- 200 km for low speed particle imaging
- 40 km for crater imaging
- 80 km for Dimorphos non-impacted side imaging.

The variation of the delay time is instead connected directly to the state of evolution and expansion of the ejecta plume. The best scenario in this case would be to have enough clearance of particles to leave the crater un-obstructed. However, too dispersed particles due to a higher delay time may be complex to be observed and detected on the images. To address the evaluation of such limiting time, a proper modellisation of the ejecta behaviour has been done, exploiting the scaling laws proposed by [29] and applied as in [30]. This analysis led to the contrasting values of minimum delay time of 340s for crater imaging and a maximum delay time of 200s for ejecta imaging. This unsolvable conflict required giving the priority to just one of the two objectives, which is the ejecta imaging.

An additional platform related constraint is associated with the possibility of some particles impacting the CubeSat. Indeed, the higher the delay time, the larger the dispersion of ejecta in the surrounding space, thus higher likelihood of particles reaching distances comparable to that of LICIACube. This poses a lower boundary to the close approach distance that is delay time dependent. At the maximum allowable delay time of 200s e.g. the minimum distance is ~48.3 km. In addition, as mentioned above, to ensure a target pointing with the maximum obtainable spin-rate of 18 deg/s a minimum distance of 21 km is also imposed.

The finally allowed boundaries are:

- Delay time between 0 and 200 s
- Close approach distance between 21/48.3 and 80 km

To get such features the Concept of Operations is defined by a single nominal orbital maneuver (OM1) few days after the release from DART and two trajectory correction maneuvers (OM2 and OM3), used to ensure the correct execution of the flyby, minimising the effects of perturbations and propulsion execution errors.

The baseline flyby performances selected after different iterations keeping the orbit determination performances in the loop are presented in Table 3.

Table 3
Nominal fly by performances

$d_{C/A}$	t_{delay}	Time for Science Ops	Max resolution	Max slew rate	OM1 DV
55.2 km	165.4 sec	38.1 sec	1.38 m/px	6.8 deg/sec	1.6 m/sec

To see full details of the optimisation process that let to this baseline trajectory, a detailed analysis is presented in [31].

5.2 Orbit Determination

During the entire period of the mission, LICIACube navigation activities are performed in four principal mission phases.

- *pre-launch phase*: several simulations were performed to support Mission Analysis and Platform Design, such as link budget definition, tracking schedule and maneuver execution plan. The expected performances of trajectory reconstruction and prediction are assessed through numerical simulations and a realistic model for observables generation (Zannoni et al., 2018).

- *operation phase*: a quasi-real-time Orbit Determination (OD) of LICIACube with respect to Didymos will be accomplished. This also involves the propagation of the estimated trajectory, along with associated uncertainty, and the assessment of possible Orbit Trim Maneuvers (OTM).

- *post-impact phase*, OD will be limited to the heliocentric trajectory reconstruction to ensure the DSN pointing capability to the spacecraft and allow data downlink

- *post-mission phase*: a complete a-posteriori OD of LICIACube will be elaborated.

The activities are carried out using JPL's orbit determination program MONTE [32], currently used for the operations of several NASA deep space missions and for past radio science data analysis [33] [34].

In order to ensure the safety of the LICIACube and the capability of achieving the mission objectives, some requirements have been set on the attainable OD accuracy. Most of them are set at the C/A of the encounter with Dimorphos, which represents the most critical event. For the LICIACube mission, the following OD requirements were identified:

*Req 1***.** The $d_{C/A}$ from Dimorphos shall be between 41.4 km (ejecta impact risk area at selected C/A delay) and 80 km (loss of ground resolution), with a confidence of 3-sigma or higher.

Req 2. The Dimorphos pointing accuracy due to only LICIACube position uncertainty shall ensure the capability of having Dimorphos inside LEIA FoV at LEIA target locking (about 200s before the impact) with a confidence of 3-sigma or higher.

Req 3. The pointing accuracy to DSN Ground Station (G/S) due to only LICIACube position uncertainty shall always ensure the capability of establish a radio link. In particular, the antenna pointing uncertainty shall be lower than 0.017 deg with a confidence of 3- sigma[1].

Req 4. The LICIACube Closest Approach to Dimorphos shall occur not later than 200s after DART impact.

Req 5. The Sun Phase Angle relative to Dimorphos at the Closest Approach shall be between 45 and 70 deg, to ensure a suitable illumination of the target.

The OD of the LICIACube spacecraft relies on the radiometric observables of ranging and Doppler acquired using the spacecraft telecommunication system, employing a standard two-way X/X (7.2-8.4 GHz) link. The DSN ground support guarantees two daily passes for a total of 3h of radiometric data per day. No tracking is assumed during the science phase - from 20min before, to few minutes after the DART impact - to allow the camera pointing to Dimorphos. In addition, the communication to ground is inhibited in the last 12h before the flyby to allow DART for the complete downlink of data. For the post-flyby phase, the ground support is relaxed, and a single 1.5h pass is scheduled each day. The capability of optical observables of Didymos to enhance the solution has been assessed, but is not included in the baseline, as may dramatically change during the operations depending on the available data rate and need for additional calibration activities.

Three different maneuvers are planned to control the trajectory by targeting the flyby state, plus a beginning

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[1] DSN Telecommunications Link Design Handbook, 101 70-m Subnet Telecommunication Interfaces, 810-005 Rev. G

small-thrust maneuver to check the state of the thrusters after the year of cruise to the Didymos system.

The expected navigation performance was assessed through numerical simulations. The dynamical model used in the simulations includes: the gravitational accelerations induced by the Sun, the planets, the Moon, and the Didymos asteroid, the maneuvers as instantaneous velocity and mass variation, and the Solar Radiation Pressure (SRP). Others non-gravitational forces are expected to be at least 1 order of magnitude lower than the SRP and were accounted for using time-varying stochastic accelerations.

The expected uncertainties at flyby are presented in Figure 2, in the Didymos-relative B-plane [35] at different Data Cut-Off (DCO) times. The delivery DCO is set about 72h before the flyby (coincident to OM3 DCO).

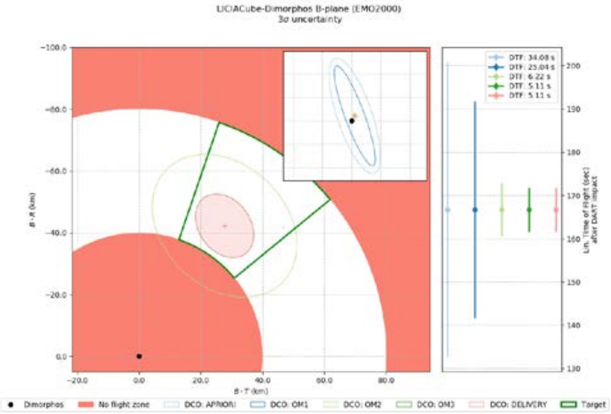

Figure 2: LICIACube-Dimorphos B-plane uncertainty (3-sigma). The representation of the relative uncertainty is provided by in-plane the ellipse centered in the probe's nominal position. The out-of-plane contribution is given as Differential Time of Flight (DTF), representing the time uncertainty of the flyby event. The in-plane target area is derived from the navigation requirements.

The obtained uncertainty on the B-plane at the delivery DCO is almost circular with a 10km of radius, and 5.1 sec of time uncertainty. The SPA is the only non-compliant requirement, being out of bounds (about 5 deg) of the allowed range, at 3-sigma level. Nonetheless, the project agreed to deal with possible slightly out-of-requirement SPA instead of the decreasing the ground resolution which would be caused by the redesign of the trajectory

5.3. Images Acquisition

The LICIACube observation strategy has been designed considering the payload operations and the science objectives to be met. Since the science objectives are very challenging, they constrain the operations of the payloads in order to obtain data redundancy acquisition, to cover the possible uncertainty on the real brightness of the objects in the field of view of the cameras and to increase the dynamic range of the detectors on board the payloads; The imaging acquisition phases (Fig. 3) are hereafter detailed:

DART impact observation

LEIA: will presumably witness the impact as an increase of the target luminosity by comparing images of Dimorphos taken before and after the impact. Approximately 5 «images » before and about 5 «images» after the impact have been planned to get.

Given the relatively limited dynamics of the sensor (FW 13000 e-) each « image » will be composed, as said above, by different images acquired at different integration times.

The expected impact time has to be known with a precision of at least 30 s, in order to be sure that at least 1 image will be acquired before the impact (with 3 different integration times).

LUKE: will be not operative.

Ejecta observation

In this phase LEIA and LUKE shall work simultaneously.

LEIA will observe the plume developed after the DART impact. It will acquire several images (each composed by different images acquired at different integration time).

LUKE, due to its larger FoV, will have a better view of the plume global expansion. Likely, LUKE could start observations even before the start of LEIA plume observation, and could continue into the following phases.

High resolution (surface properties, crater) observation

In this phase LEIA and LUKE shall work simultaneously.

LEIA will reach the best spatial resolution. It shall work at highest frame rate.

LUKE will continue to operate and acquire « images» (each composed by different images with different integration times) of the plume and possibly of the Dimorphos surface.

Non-impact hemisphere observation

Also, in this phase LEIA and LUKE should work simultaneously.

LEIA could reach the goal to observe the non-impact hemisphere (part of the images taken after the C/A passage).

LUKE due to the use of an RGB detector, will add some physical information on the surface properties of

Dimorphos. In addition, due to its wider FoV, under good illumination conditions, it could provide further observations of the plume.

Plume evolution in forward scattering

In this phase LEIA and LUKE will work simultaneously.

LEIA could reach the goal to observe the plume evolution in a different observation condition.

LUKE by using the RGB detector, will add some physical information on the plume.

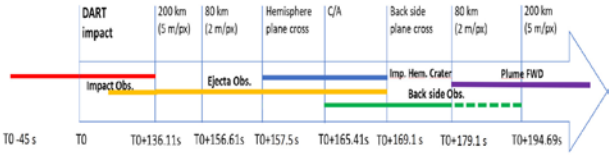

Fig.3 Scientific observation phases timeline: T0 is the nominal DART impact time, the red bar is the time interval dedicated to testify the DART impact; the yellow bar identifies the time interval focused on the expanding plume observation; the blue bar is the time period dedicated to the surface High resolution imaging of the Didymos system; the green bar is the observation phase dedicated to the non-impact hemisphere; the violet bar is the observation time dedicated to the Plume observation at high phase angle.

6. Scientific return

6.1 Plume and Ejecta Analysis

In the effort of fully characterizing the impact event, it is important to be able to properly simulate the evolution of the ejecta from the crater over different time scales. The LICIACube science team developed two specific models for this purpose. The details of these models, dubbed **LICEI** (LICIACube Ejecta Integrator) and **LIMARDE** (LICIACube Model for Aspherical Rotating Dust Ejecta), can be found in [36] [37] [38].

The simulations of the ejecta evolution over the first few hundreds of second were used to produce a model of the plume geometry needed to compute the expected radiance of the whole plume. This value is of paramount importance for the determination of the proper exposure times of the LICIACube images. (Figure 4) ALEFIG1 shows an example of a simulated plume [39]. The case shown in the figure refers to a set of ejecta initial conditions, derived by means of "scaling laws", from an impact against a Weakly Cemented Basalt (WCB) target. Note that stronger (more cohesive) or weaker (e.g., Sand Fly Ash) targets produce significantly different time evolutions that we expect to be able to discern in the LICIACube images.

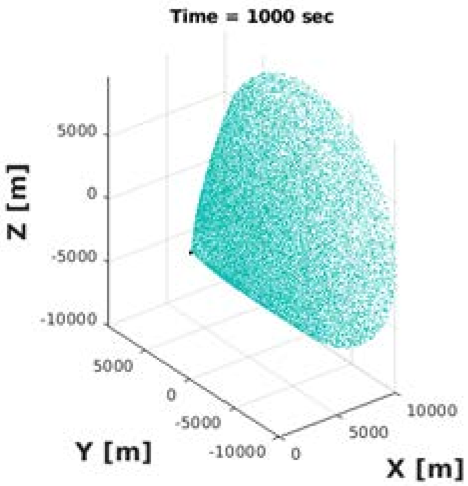

Fig. 4 ALEFIG1: evolution over 1000 sec of 100,000 ejecta particles for a simulated DART impact against a WCB target. The small black dot at the vertex of the cone represents Dimorphos in scale.

In fact, post-impact, the models will be immediately used to interpret the LICIACube images. The observed geometry of the plume will be compared with the plumes obtained by simulating different target compositions in order to derive the best possible estimation of the Dimorphos physical properties. This estimation will be extremely important in the effort to derive the value of the momentum transfer enhancement parameter referred to as "Beta" (β) (see, e.g., [40]).

7. Data Management and MATISSE tool

The LICIACube Scientific Operations Center (SOC), hosted and maintained by ASI-SSDC, is responsible for entire data management, starting from the conversion into FITS format of the raw-from-telemetry image files and ending with the availability of the calibrated images to the public by means of scientific tools, such as MATISSE (https://tools.ssdc.asi.it/Matisse).

The data-flow starts with the MCC sharing the raw-from-telemetry files, downloaded from the S/C making use of the DSN antennas.

These files are automatically converted to raw FITS format, as soon as MCC share them, by adding a header with a series of keywords useful for the interpretation of the image, according to what specified [9].

Afterwards, using the calibration pipeline developed by the scientific team led by INAF, the raw FITS are converted to radiometrically calibrated FITS: for LUKE a debayering process is also required in order to have the RGB final image.

The images thus generated, together with the calibration files, are automatically shared on the LICIACube SOC, in a restricted access web page, where it is also possible to search for specific images using a textual search.

The dataset is already designed to be compliant to the PDS4 specification, for a two-fold purpose: in this way the dataset is both born ready to be shared to the public using the PDS website and protocols and can be easily integrated in MATISSE, the SSDC scientific webtool able to search, visualize and analyse planetary exploration data, also projecting them on the 3D shape model of the target object, thus improving the scientific capabilities of the mission.

8.Conclusion

The paper presented the ASI-LICIACube, the first Italian Cubsat to be operated in deep space. It has been developed by Italian LICIACube team composed by scientists and engineering, in order to achieve the primary objective of the DART Planetary Defense mission. For that reason, the suite cameras on board of LICIACube have been thought and suitable to accomplish science investigation of nature of binary NEA, for the first time.

Indeed, he study of the nature and the evolution of the produced dust plume, will allow to deeply investigate the composition and the structure of the material composing a small NEA. Moreover, the analysis of comparison between the impact and non-impact regions will lead to deeply understand the result of the first kinetic impact test operated by NASA DART mission.

Acknowledgements

The LICIACube team acknowledges financial support from Agenzia Spaziale Italiana (ASI, contract No. 2019-31-HH.0 CUP F84I190012600). MZ, IG, DM, PT wish to acknowledge Caltech and the Jet Propulsion Laboratory for granting the University of Bologna a license to an executable version of MONTE Project Edition S/W. MZ, IG, DM, PT wish to acknowledge also Julie Bellerose, Justin Atchison and Dan Lubey for providing the a-priori uncertainties of DART and Didymos system.

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