Orbit Determination of LICIACube: Expected Performance and Attainable Accuracy

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Photography encouraged

1. LICIACube mission

LICIACube (Light Italian Cubesat for Imaging of Asteroid) is a 6U CubeSat project led by the Italian Space Agency (ASI) that will operate in conjunction with NASA's DART (Double Asteroid Redirection Test) mission to the Didymos binary asteroid system. LICIACube main goal is to support Planetary Defense mission objectives by taking images of the impact site and the ejecta plume after DART crash. The collected data will be processed to assess the performance of the asteroid deflection strategy and increase the knowledge of the asteroids surface [1,2]. LICIACube project will involve multiple Italian research centers and universities (INAF, UNIBO and POLIMI) working together with ARGOTEC in the role of main contractor. The launch of DART is planned for mid-2021, and the impact is expected on October, 3rd 2022.

Radiometric measurements such as ranging and Doppler will be acquired before and after the impact between the S/C and the ground antennas of NASA's Deep Space Network (DSN). Feasibility studies are still pending on the possibility of including Sardinia Deep Space Antenna (SDSA) in the available antennas network. The possibility of performing gravity investigation using radiometric and optical data, useful to constraint the physical parameters of the Didymos system, is still under investigation.

In this work a covariance analysis of the orbit determination (OD) of LICIACube is presented, obtained through numerical simulations.

2. Mission timeline

Based on latest CONcept Of OPerations (CONOPS), LICIACube will spend up to 16 months travelling stored in a dispenser on the back of DART. As soon as DART reaches the proximity of the Didymos system, LICIACube will be released from the dispenser, starting the commissioning phase. During the first 45 minutes all TT&C operations and maneuvers are inhibited due to RF clearance and safety requirements imposed by the DART team.

After the end of the commissioning phase, about 1h45m after deployment, the CubeSat will begin a series of tracking phases to accumulate as much radiometric data as possible to achieve a precise OD. Due to power constraints, after 1h55m of tracking a period of 1h45 of Sun Pointing (S/P) must be performed, as shown in Figure 1.

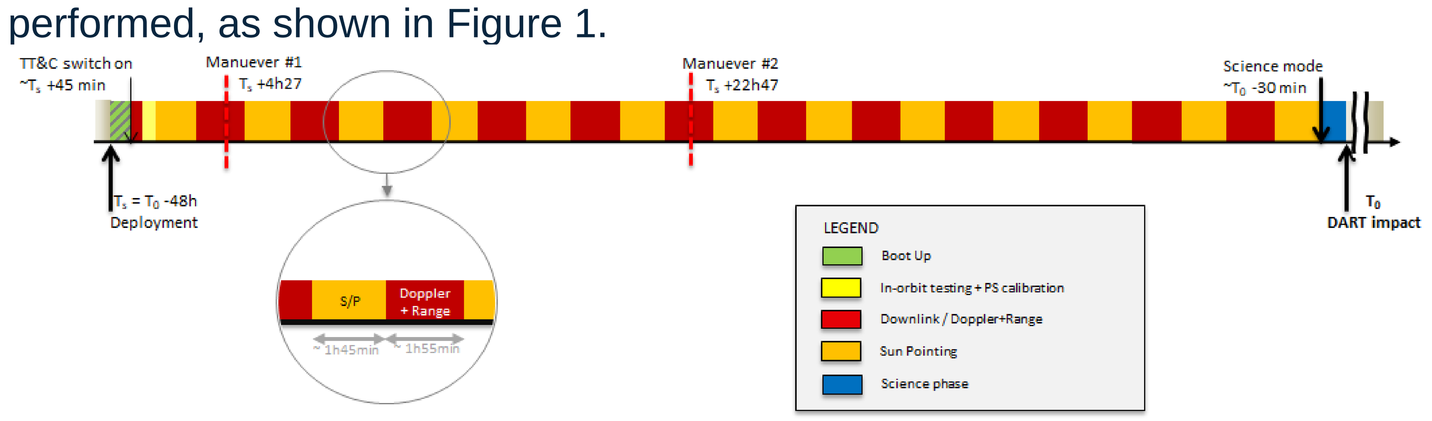

Figure 1: Mission timeline referring to baseline with relase at T_{impact}-48h.

Finally, 30 minutes before DART planned impact (T_{impact}-30m), after a battery full-charge phase, the Science mode begins and the spacecraft starts acquiring images of the Didymos system.

It is assumed that no radiometric data are available during this phase, due to the poor knowledge of the antennas capabilities in terms of datarate at non-Earth pointing.

Two Trim Control Manuevers (TCMs) are planned for the LICIACube mission before the impact [1]:

- a first braking maneuver to decrease the cubesat relative speed with respect to Didymoon and allow LICIACube reaching its Didymoon closest approach as late as possible. This would provide beneficial when observing the ejecta plume, letting the cubesat to observe a fully-developed ejecta.
- a second corrective maneuver (statistical) to be performed if the NAV highlights any undesired shift with respect to the baseline trajectory.

3. Navigation expected performance

The ability to meet the navigation requirements has been assessed by means of numerical simulations using MONTE (NASA/JPL).

Data selection

The radiometric observable data has been assumed using both ranging and Doppler data using spacecraft telecommunications subsystem which supports a standard two-way X/X (7.2-8.4 GHz) link. To this analysis, the following was assumed:

- Tracking coverage as from Figure 1.
- No optical observables (due to downlink datarate issues).
- Doppler noise 0.1 mm/s at 60 s integration times (constant).

Dynamical model

The dynamical model [3] used for the analysis includes:

- Gravitational accelerations of all the Solar System planets and satellites, and Didymos asteroid.
- Non-gravitational perturbations (Solar Radiation Pressure).

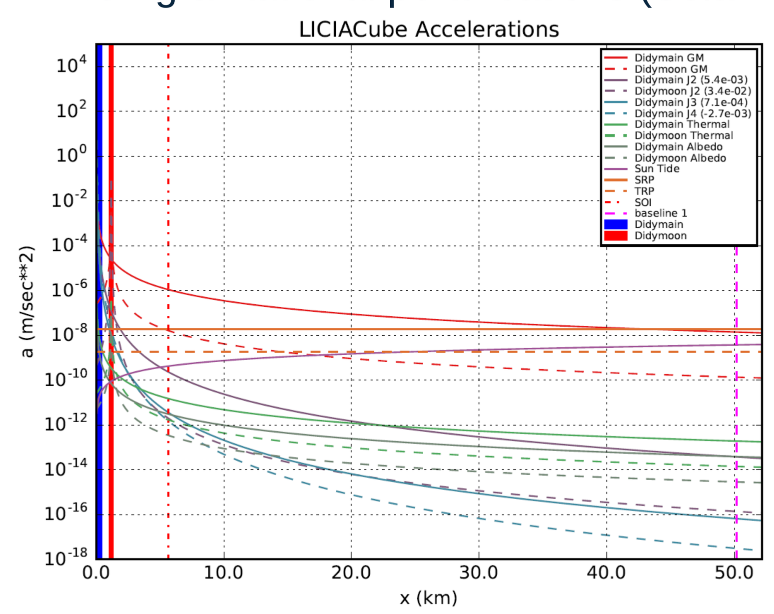

Figure 2 shows the accelerations induced by the different perturbing effects as function of the distance from Didymos, where the baseline nominal value is depicted by a magenta dashed line.

< Figure 2: Accelerations acting on LICIACube.

Filter setup

A covariance analysis was carried out using a single-arc approach from the release time to one day after DART impact. The initial covariance matrix of LICIACube wrt Didymos Barycenter is assumed from DART release state to be increasing with increasing release time due to higher distance from the system.

4. Closest approach results

The analysis of the error propagation has been provided for different LICIACube release time (48, 72, 96, 120 hours before impact), all having similar C/A distance from Didymoon. Although the distance to Didymoon should be minimized to optimize observation conditions, impact risk with plume should also be considered. The last chance for a corrective maneuver is at T_{impact}-24h considering Data Cut-Off (DCO) time 12h before (namely 02-OCT-2022 00:00) to compute the second TCM. DCO represents the last useful tracking time to provide sufficient margin of safety to avoid impact either with Didymoon or whatsoever particles of the plume.

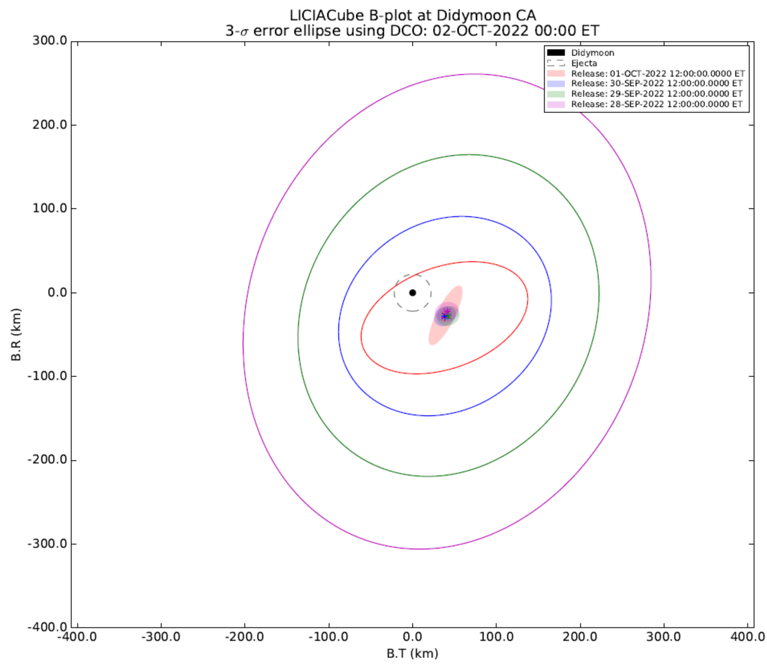

Figure 3: B-plane conditions.

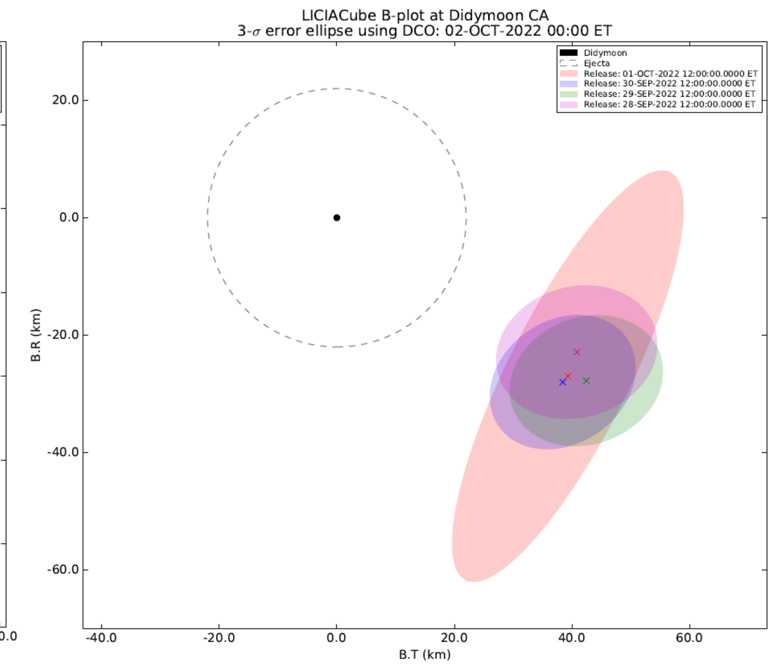

Figure 4: B-plane conditions after OD.

In Figure 3, B-plane conditions are shown for each release time, mapping the expected error at 3-σ both with a priori knowledge (without using tracking data, non filled ellipses) and with OD using all data until DCO (filled ellipses, zoomed in Figure 4). From the plots is clear that, for any release time, the collected tracking data are sufficient to provide enough margin of safety to avoid the collision with plume particles. In fact, even though earlier release time are associated to a larger a priori error on the B-plane, it also provides more tracking time available until DCO. Thus release time is not strongly affecting the uncertainty at CA. It is also interesting to notice that the error ellipse associated to the most delayed solution is much larger compared to the other release times.

5. Future work

The mission analysis is continuously evolving due to updates both of DART release conditions and of payloads definition and related requirements. Further analyses will be performed to assess the minimum amount of observables (measurements) needed to achieve the required uncertainty. A critical step could be the implementation of optical observables to increase the navigation performances, but this is still under investigation. Other future works may concern a variation of out-of-plane release angle to achieve possible fly-bys after leaving the Didymos system.

References

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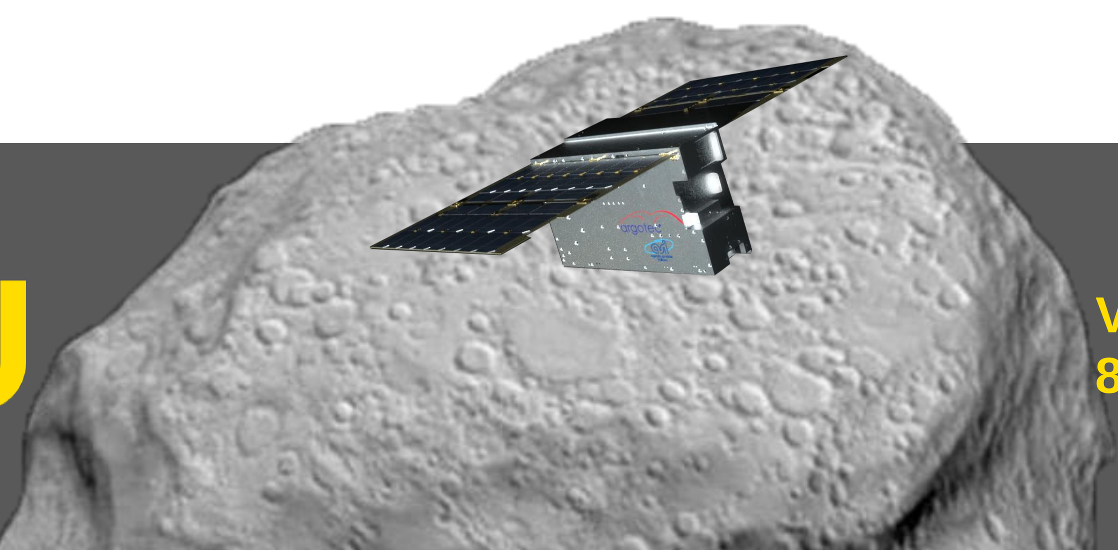

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