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LICIACube Mission: The fastest fly-by ever done by a CubeSat

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Presenter: Valentina **MARCHESE**

Co-authors: Nicolò Roberto **BENIGNO**, Simone **SIMONETTI**, Emilio **FAZZOLETTO**, Federico **MIGLIORETTI**, Valerio **DI TANA (Argotec)**
Simone **PIRROTTA**, Marilena **AMOROSO (ASI)**
Elisabetta **DOTTO**, Vincenzo **DELLA CORTE (INAF)**

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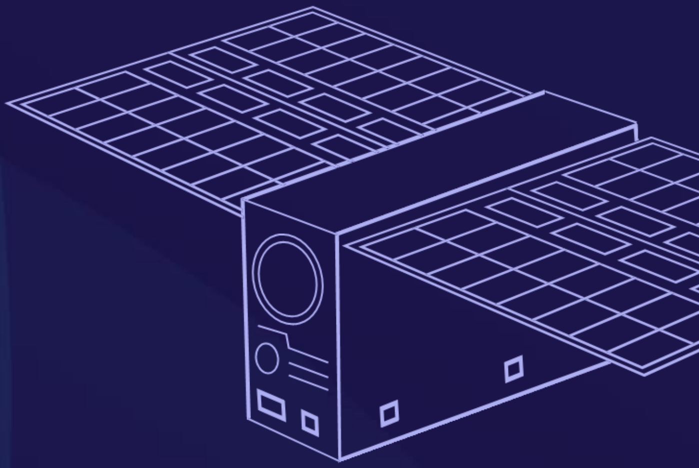
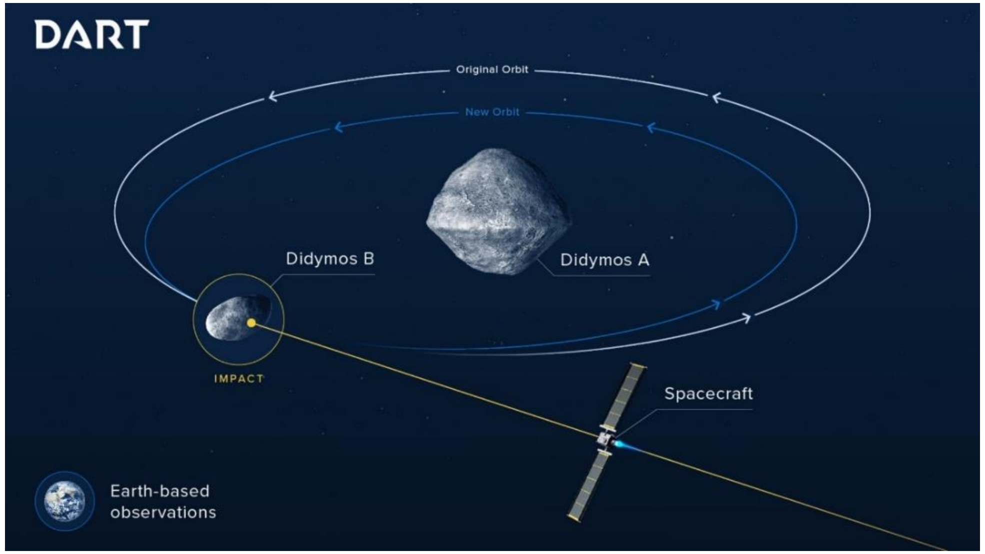
INTRODUCTION



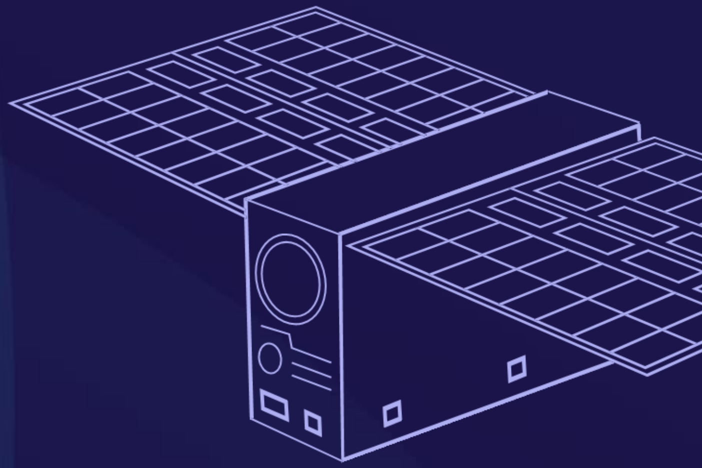
INTRODUCTION

- **LICIACube** is part of the **NASA** Double Asteroid Redirection Test (**DART**)
- **DART** is the first mission to demonstrate asteroid **kinetic impact** technique

- **LICIACube** will be embarked on DART spacecraft as piggyback
- The satellite will acquire **multiple images** of Didymos B asteroid during and after **DART impact**



LICIACUBE OVERVIEW



LICIACUBE OVERVIEW

Mission Timeline

DEPLOYMENT	The satellite will be deployed by DART 240h before the impact on Didymos B
INITIAL ORBIT	LICIACube will be deployed in a heliocentric orbit with a relative speed wrt DART of 1.14 m/s
ORBITAL MANEUVER	The satellite will perform orbital maneuver to change its orbit and avoid impact asteroid
SCIENTIFIC PART	LICIACube will start the autonomous scientific part of the mission 240s before the Closest Approach

BACKGROUND

Technical Challenges

6U CubeSat

Limited platform for a very complex mission

Deep Space

11-months cruise towards the binary asteroid Didymos

Autonomous Flyby

Fastest autonomous flyby with a body rate peak of 7°/s

Orbit Uncertainties

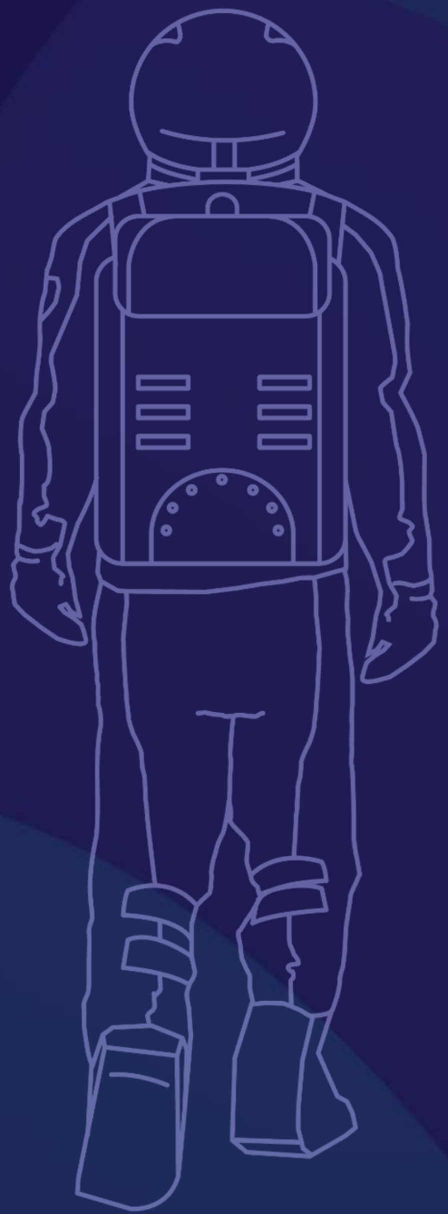
LICIACube orbit uncertainties make unfeasible maneuver planning

Communication

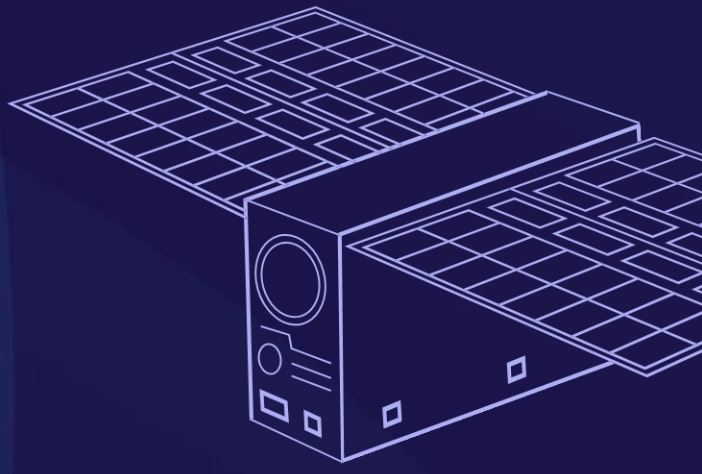
Communication flow-down 12 hours before the flyby

Dust Plume

Not-well-known dust plume produced by the high-speed DART impact



AUTONOMOUS NAVIGATION



AUTONOMOUS NAVIGATION

System Overview

IMAGING SUBSYSTEM

It processes the acquired images to recognize the asteroids and compute their centroids as an input to the trajectory recognition module

TRAJECTORY RECOGNITION

Based on the optical feedback, it estimates the trajectory on which LICIACube is traveling and compensates the uncertainties of o/board time and ephemeris

TRACKING LOOP MODULE

Based on the reconstructed trajectory and on the optical feedback, it computed the desired attitude to track Didymos B during the flyby

ATTITUDE CONTROL

Based on the desired and the actual attitude, it controls the angular velocities of the Reaction Wheels via a PD controller

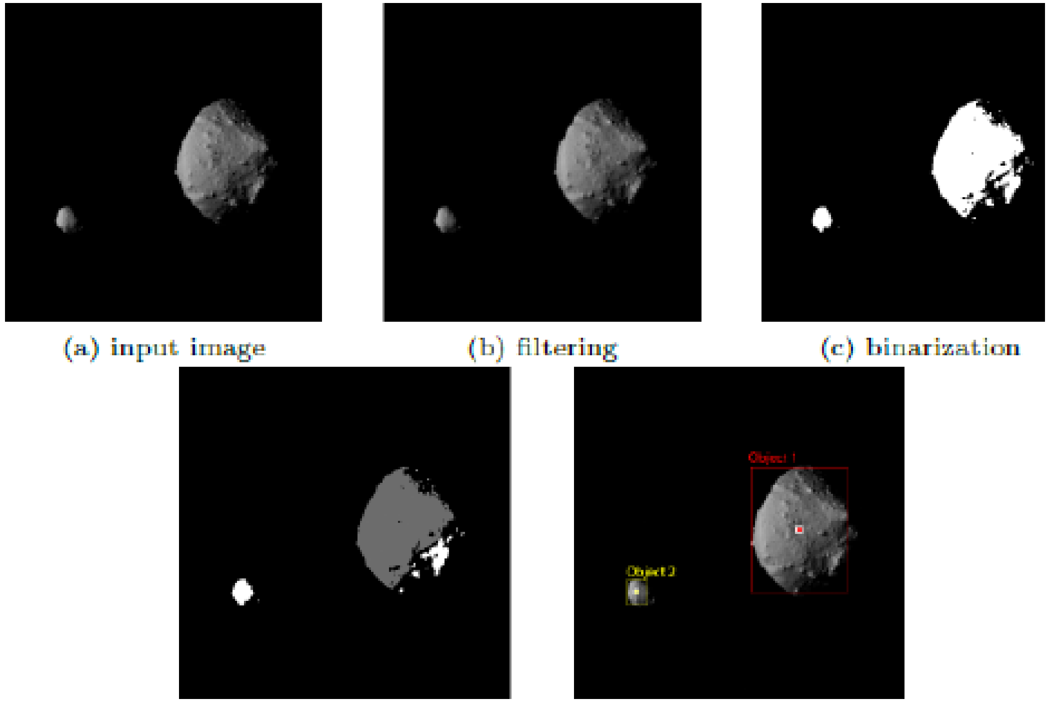
AUTONOMOUS NAVIGATION

Imaging Subsystem (IS)

The IS is in charge of receiving images from the **primary payload** and to **recognize** multiple **objects** in the picture.

The **algorithm** is composed of:

- **FILTERING**
- **BINARIZATION**
- **OBJECT DETECTION**
- **FEATURES EXTRACTION**



(a) input image (b) filtering (c) binarization

(d) object detection (e) merging

AUTONOMOUS NAVIGATION

Trajectory Recognition

The Trajectory Recognition in in charge to understand the satellite **relative motion** wrt the target asteroid.

The strategy is based on two **uncertainties**:

1. **DISTANCE** from the asteroid at Close Approach
2. **TIME INSTANT** at which the Close Approach will happen

The **algorithm** is based on:

- Up to 30s before the Close Approach, the "**best estimated trajectory**" sent by Earth is used
- 30s before the Close Approach, it selects the "**best fitting trajectory**" among a pre-computed dataset, based on a minimum **mean square error** computation

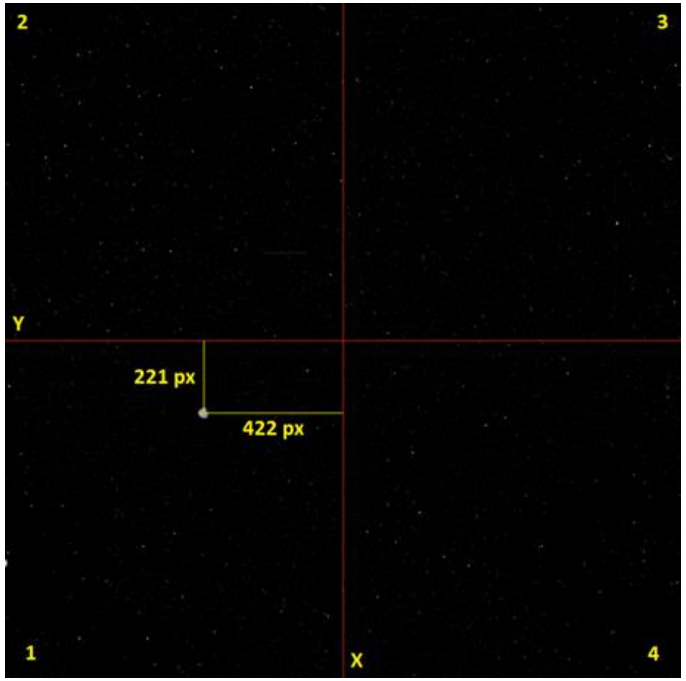
AUTONOMOUS NAVIGATION

Tracking Loop Module

The Tracking Loop is based on a **second order** control loop **minimizing** asteroid pointing **error**.

The module is capable to:

1. **Correct** initial pointing error, based on asteroid **centroids** and satellite **orientation**
2. **Compute** the satellite **desired** attitude based on optical **feedback**



AUTONOMOUS NAVIGATION

Attitude Control

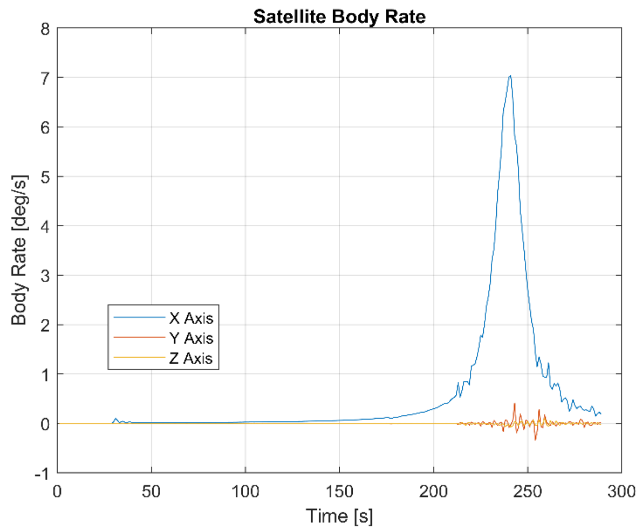
The Attitude Control has the aim to **control** the satellite **attitude** to perform the **fly-by** with **reaction wheels** only.

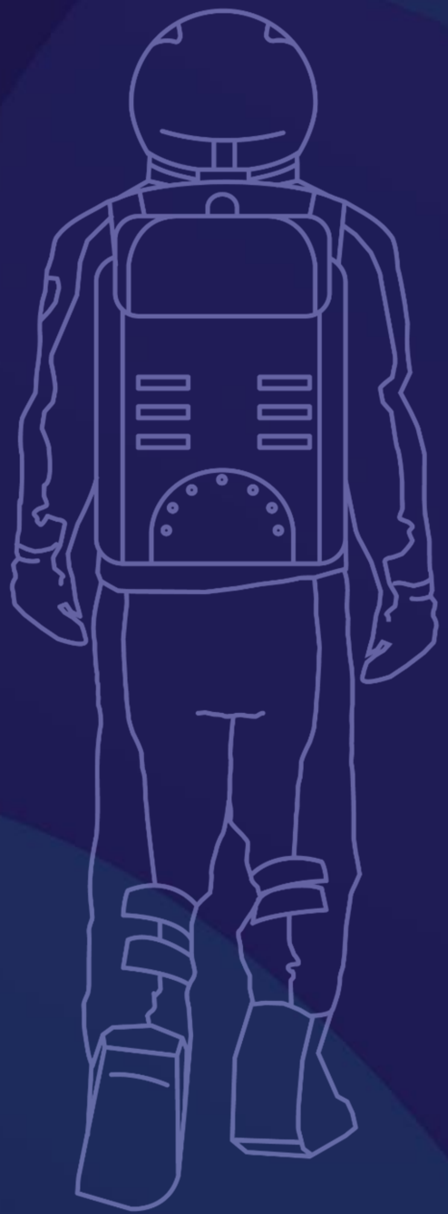
The main characteristics are:

- A nominal distance of ~55 km
- A body rate peak of 7°/s
- A payload FOV of 2.9°

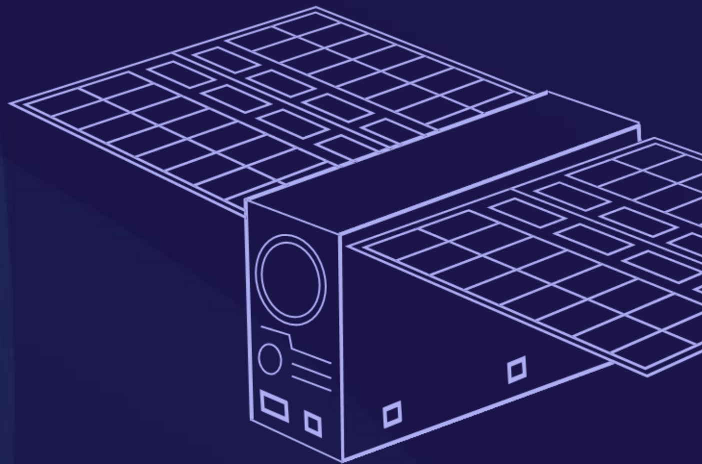
Main Controller Highlights:

- PD Controller
- Quaternion and velocity errors
- One gains set for all trajectories





SYSTEM VALIDATION AND RESULTS



SYSTEM VALIDATION AND RESULTS

Validation Approach

The System **Validation** was based on:

1. Validation at **Unit Level**
   - **Imaging Subsystem** with a software Test Bench
   - **Trajectory** Recognition and **Tracking** Loop with MonteCarlo Simulation and a Simulink™ Model
   - Attitude **Control** with a Simulink™ Model and Hardware Test

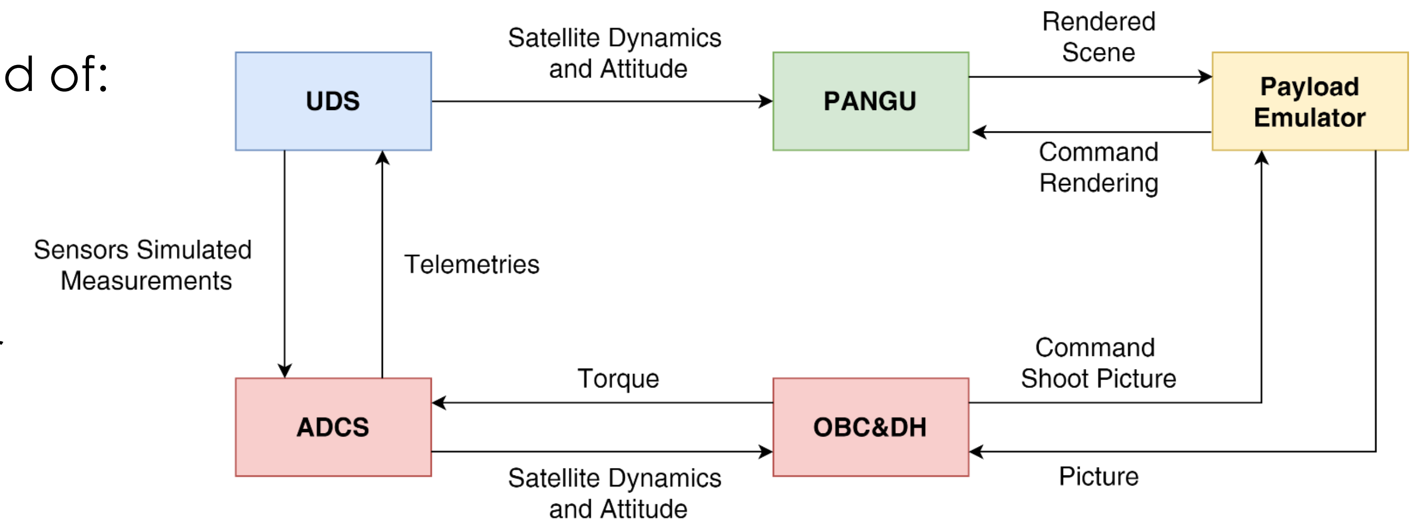
2. Validation at **System Level**
   - System **Integration**
   - High Resolution **Images** with PANGU™
   - Hardware In the Loop **(HIL)** Setup

SYSTEM VALIDATION AND RESULTS

System Validation Results

HIL **Test Setup** composed of:

- ADCS
- OBC&DH
- Payload Emulator
- PANGU™



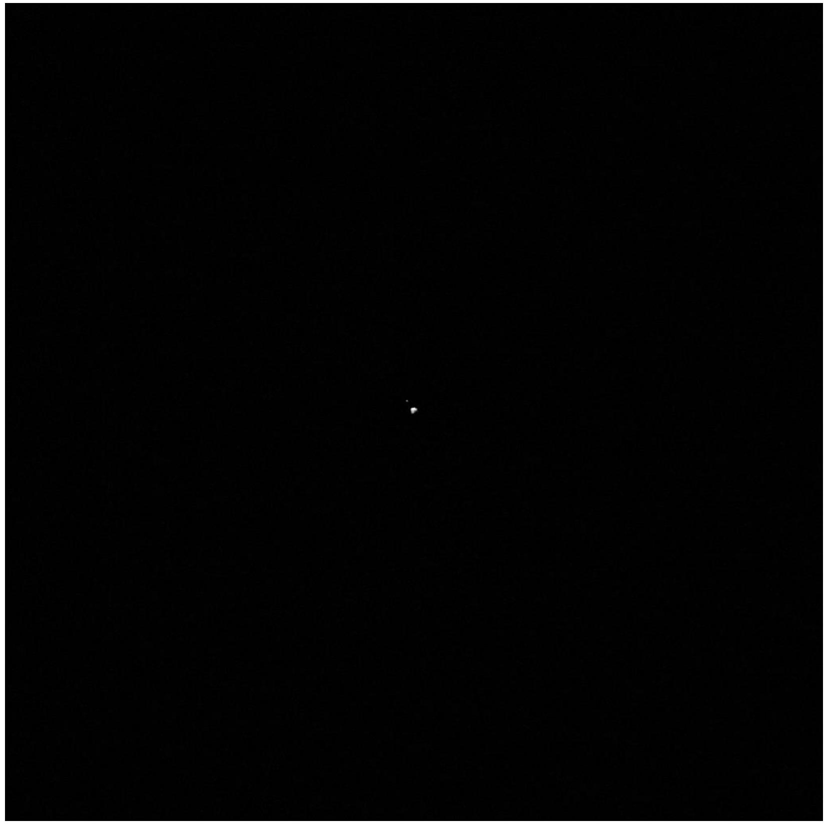
SYSTEM VALIDATION AND RESULTS

System Validation Results

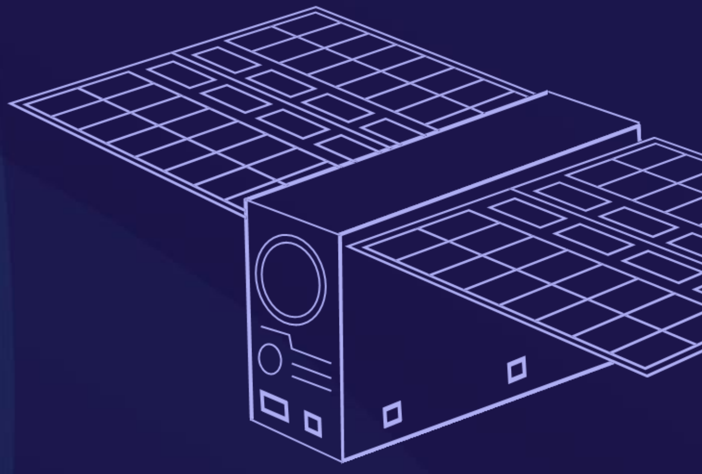
HIL **Test Cases**:

- **Nominal** Case Trajectory
- **Worst** Case Trajectories

The asteroid is in the FOV for **98%** of time, as requested to fulfil the **mission objectives**

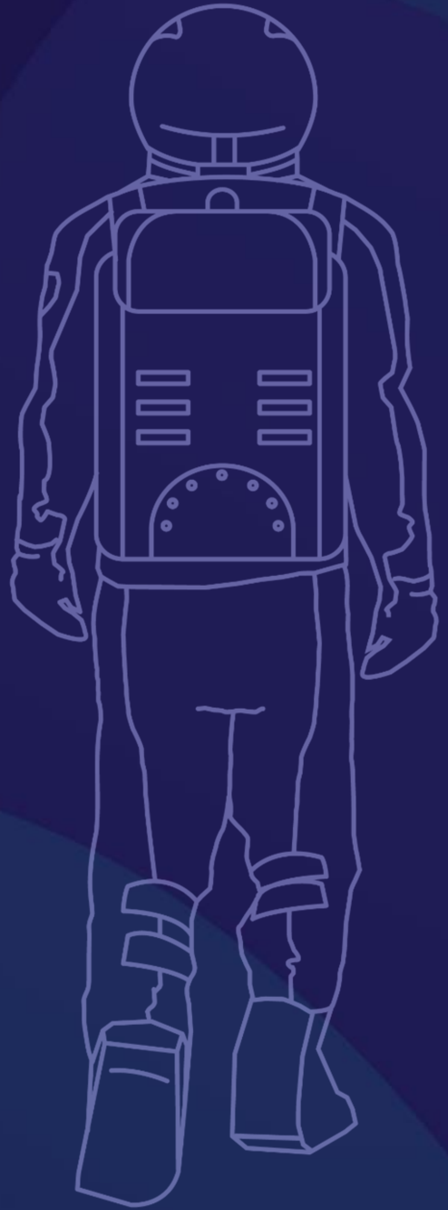


CONCLUSION



CONCLUSION

- The paper presented the Autonomous Navigation **Strategy** for LICIACube satellite
- The mission **scenario** and the technical **challenges** were highlighted
- The Autonomous Navigation System **components** were technically detailed
- The **validation approach** was based first on unit level testing and then on system level testing
- The **HIL setup** allowed to **validate** the system and **verify** the **fulfilment** of the mission objectives



Thank You!