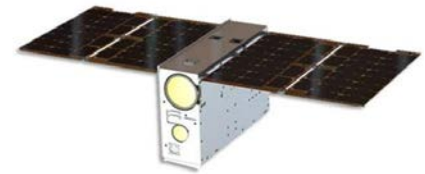

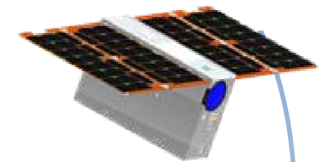

Italian first deep space missions to the Moon and beyond: ArgoMoon and LICIACube ready to be operated

S. Pirrotta[1], F. D'Amico[1], R. Mugnuolo[1], G. Mascetti[1]

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[1] Italian Space Agency, [2] Argotec srl,

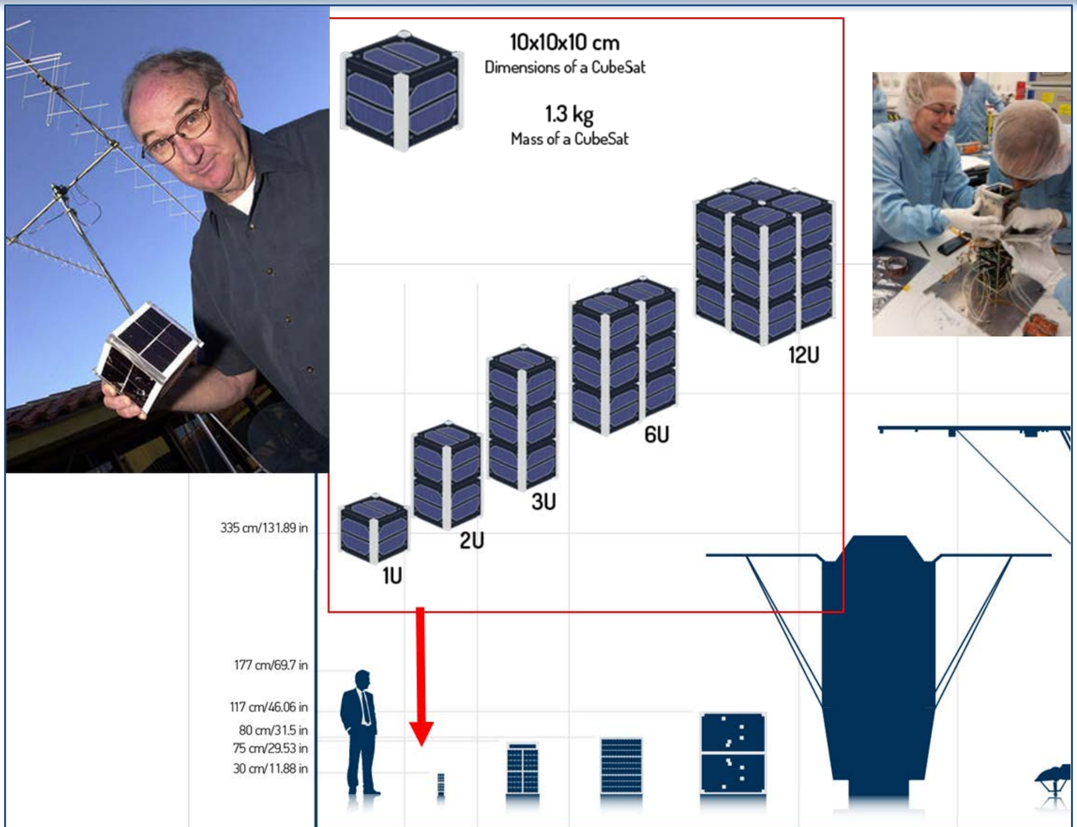
2022 SpaceOps Workshop
1–3 June 2022
NASA Ames Research Center, Mountain View, California, USA

Outlines

- Small satellites are nowadays extremely powerful, flexible and sustainable platforms that can be used to complement the missions assigned to traditional-sized satellites
- The Italian Space Agency – ASI promotes, funds and coordinates the national initiatives for smallsats (i.e. nanosats): few of them are destined to **Science** and **Exploration**, both for autonomous missions and within international cooperation frameworks.
- **ArgoMoon** 6U cubesat has been selected to take part in the Artemis-1 mission, as the only European contribution to capture significative pictures of the launcher's last stage ICPS and of the other secondary payloads deployment;
- **LICIACube** 6U cubesat is the NASA DART mission companion, with the purpose to support the redirection test verification by means of a close and timely imaging of the post-impact;

Both ASI missions are ready to enter the operative phase

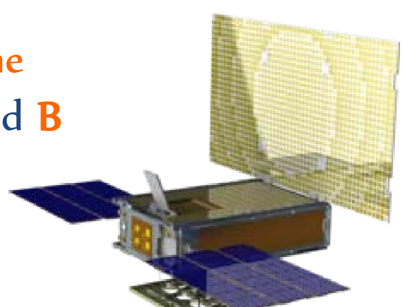
A new standard, also in Deep Space



- For the small satellites, the **design** philosophy based on large use of state-of-the art technologies with low or no flight heritage, allows to manage cheaper missions in a shorter time;
- Design is based on practice and experience: a **layered redundancy** architecture is often adopted;
- **Testing** is minimized and limited to system level, so avoiding expensive verification of single units or subsystems at lower levels.

Deep Space

Mars Cube One (MarCO)-A and B



- 26th Nov 2018: provided real-time communications link to Earth for InSight during its entry, descent and landing on Mars
- 22nd Oct. 2018: First image of Mars from a Cubesat

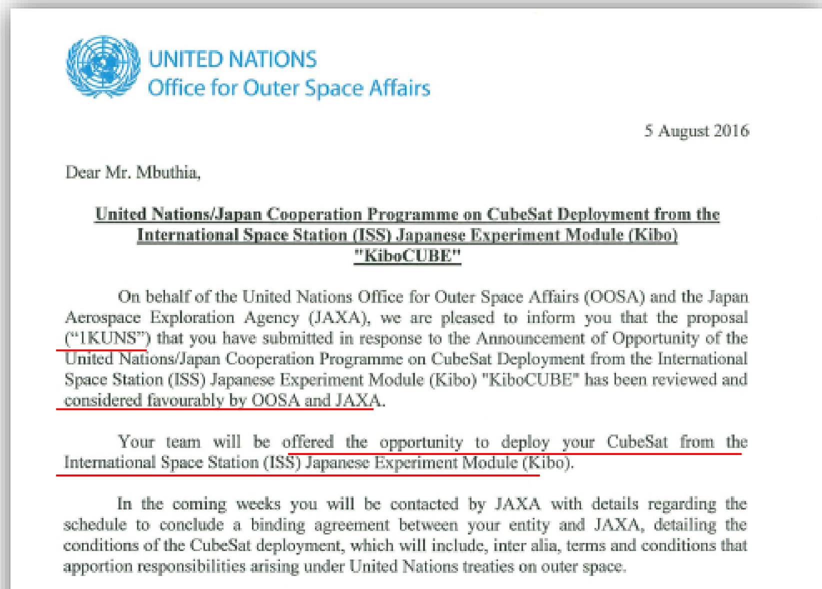
Italian cubesats

- The first national nanosats had a flight opportunity in the occasion of the European Space Agency launcher **Vega**, at its Qualification Flight, in **early 2012**.

1KUNS selected for KiboCube

In August 2016 **"1KUNS"** was selected by UNOOSA/JAXA, in the frame of «KiboCube» program, as first 1U cubesat to be carried on board of ISS by Japanese astronaut, at the end of 2017 and deployed from the Kibo JAXA module.

Launch happened on 10th May 2018



UNITED NATIONS
Office for Outer Space Affairs

5 August 2016

Dear Mr. Mbuthia,

United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo) "KiboCUBE"

On behalf of the United Nations Office for Outer Space Affairs (OOSA) and the Japan Aerospace Exploration Agency (JAXA), we are pleased to inform you that the proposal ("1KUNS") that you have submitted in response to the Announcement of Opportunity of the United Nations/Japan Cooperation Programme on CubeSat Deployment from the International Space Station (ISS) Japanese Experiment Module (Kibo) "KiboCUBE" has been reviewed and considered favourably by OOSA and JAXA.

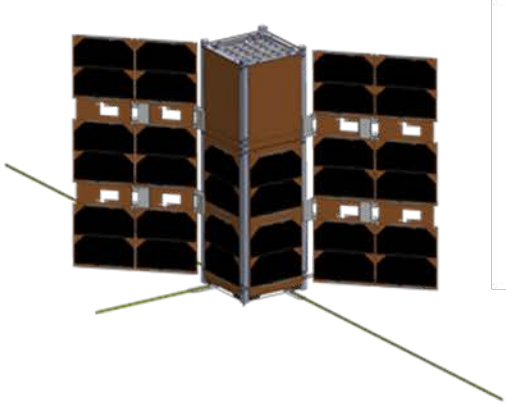
Your team will be offered the opportunity to deploy your CubeSat from the International Space Station (ISS) Japanese Experiment Module (Kibo).

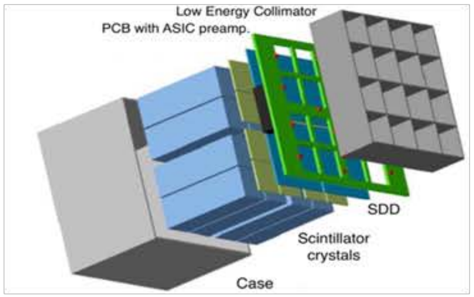
In the coming weeks you will be contacted by JAXA with details regarding the schedule to conclude a binding agreement between your entity and JAXA, detailing the conditions of the CubeSat deployment, which will include, inter alia, terms and conditions that apportion responsibilities arising under United Nations treaties on outer space.

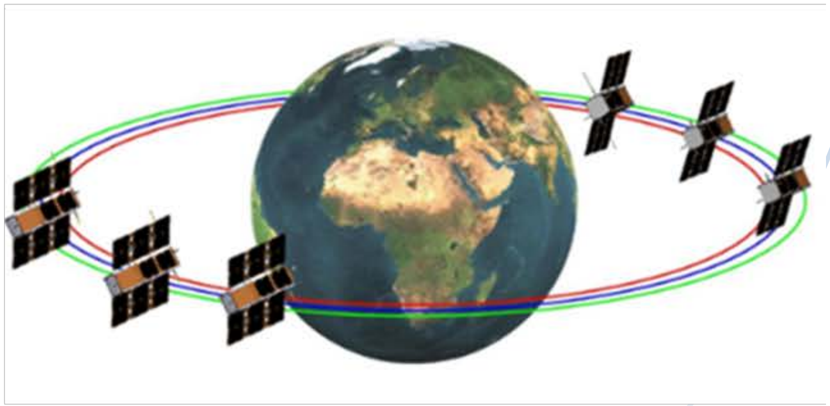
Please n
this stage. You
releases of any

ASI cubesats (work in progress)

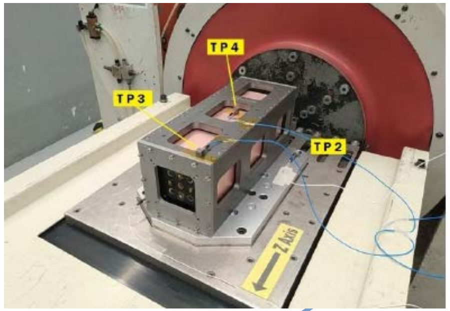
HERMES High Energy Rapid Modular Ensemble of Satellites – Pathfinder
(since 2016; launch expected in mid 2023)

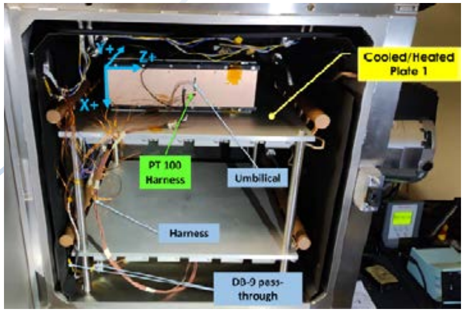






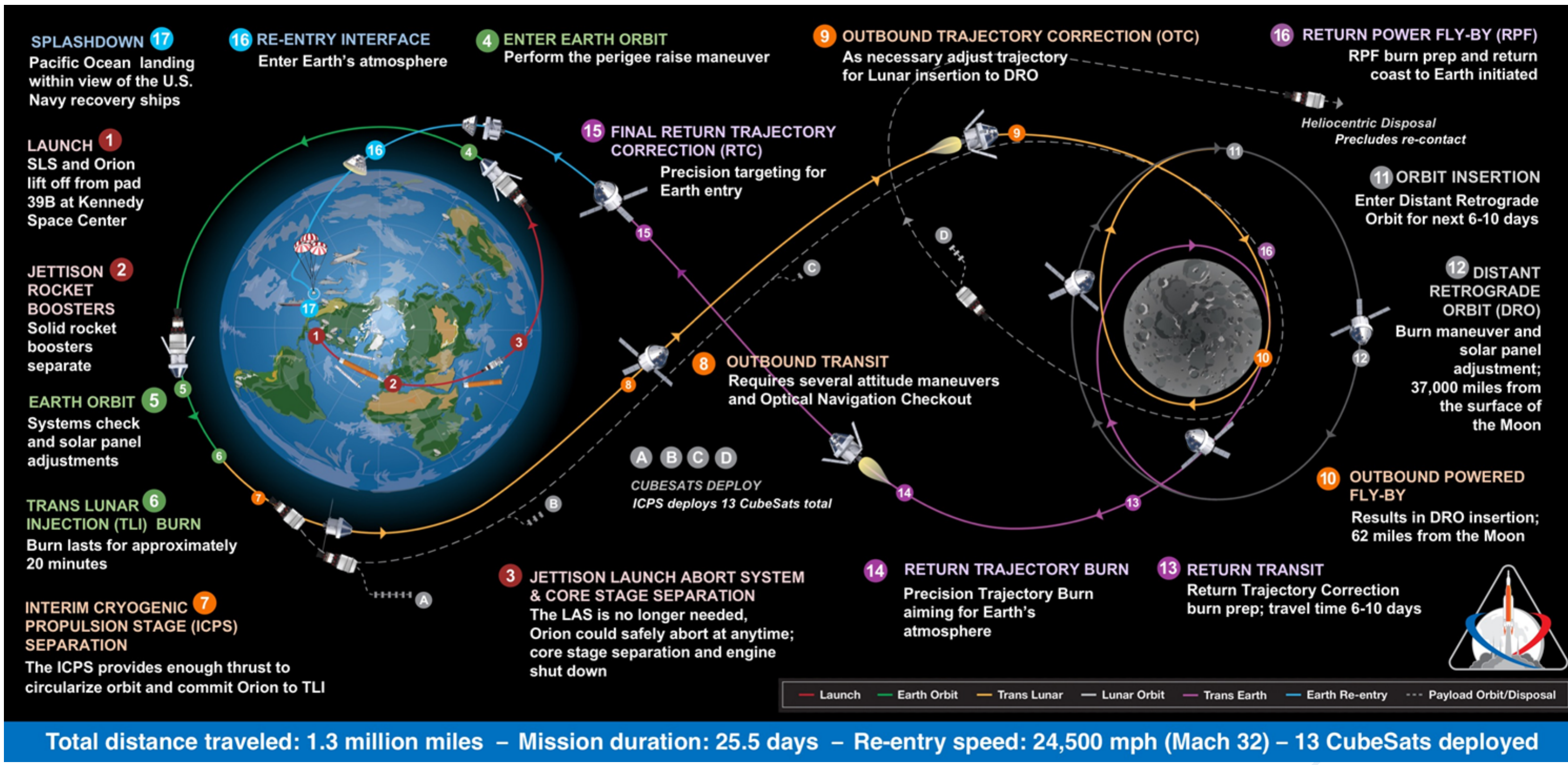
AstroBio Cubesat ABCS
(Since 2019; launch expected July 2022)





Artemis-1: Orion and its 13 companions

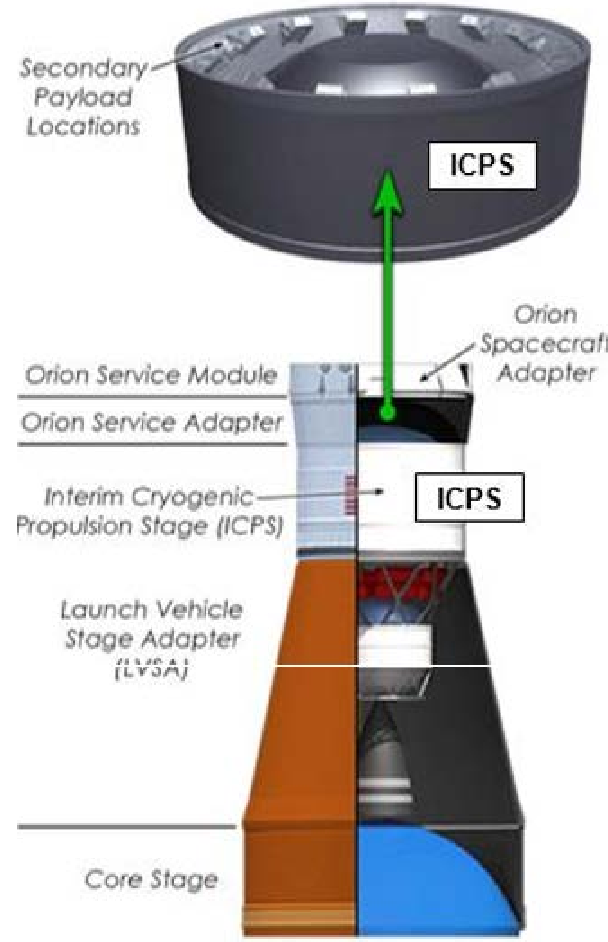
The NASA **Space Launch System - SLS** is the NASA heavy-lift launch vehicle, designed to support the next season of Exploration beyond LEO.



NASA HQ Exploration Systems Directorate (ESD) has directed the SLS Program to accommodate **Secondary Payloads** of the Cubesat Class, to increase the scientific and exploration capabilities, allowing international community for access to much higher orbits than are currently available for small payloads

ArgoMoon for Artemis-1

In 2016, the ASI-proposed **"ArgoMoon"** mission has ben selected as European contribution to Artemis-1 mission.



This 6U nanosat aims at taking significant photographs of the Artemis-1 mission and validate new technologies in deep space.

ArgoMoon was designed, tested and integrated by the Italian SME **Argotec srl**, at its facility in Turin.

ArgoMoon will be operated by the Argotec Flight Control Team from its Mission Control Centre in Turin.

ArgoMoon mission profile 1/2

Launch (≈3 hours)

Commissioning (≈17 minutes)

Disposal (≈2 hours)

Mission's First Phase (≈ 10 hours)

SLS Artemis-1 support:

- Providing information regarding status of payloads deployment;
- Visually inspect the condition of the SLS second stage (ICPS)
- Enhance public outreach

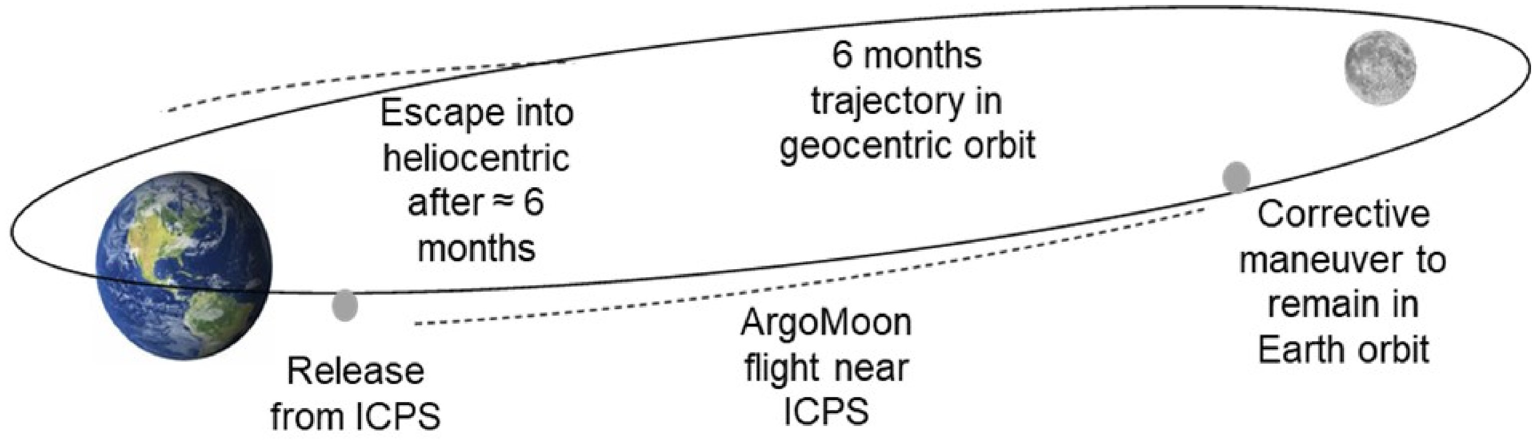
Mission's second phase (≈ 6 months)

In-orbit Operations

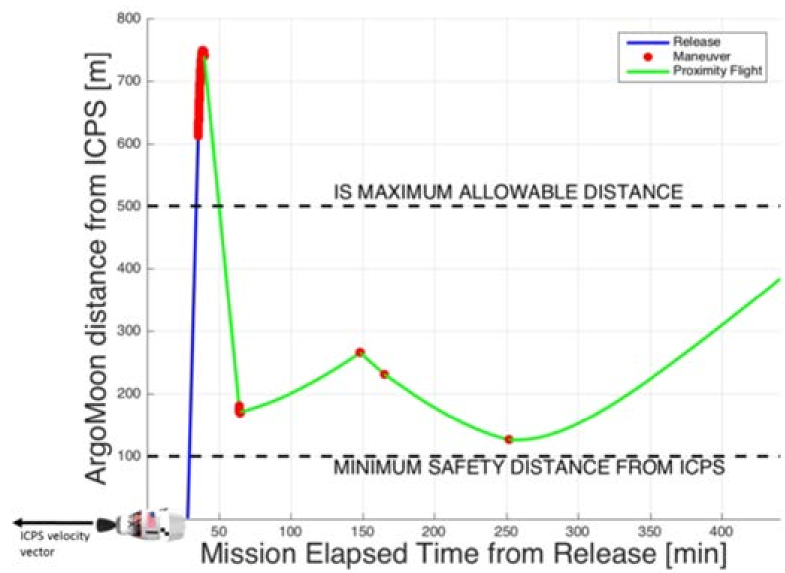
- Collect Moon's images with scientific purpose
- Validate small satellite's new technologies in deep space:
  - Targeting system based on optical recognition
  - Develop or Increase TRL of miniaturized subsystems (e.g. power distribution, data acquisition and processing)

... and objectives

ArgoMoon mission profile 2/2

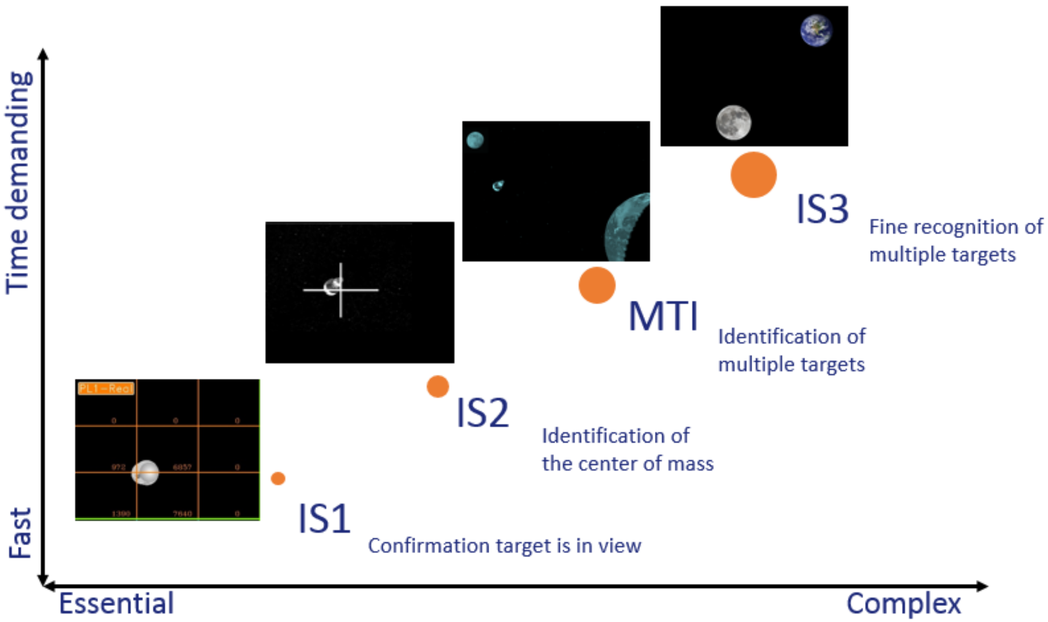


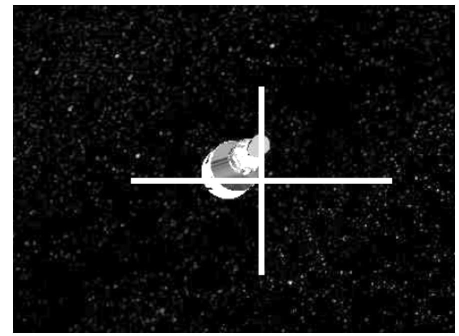
- ArgoMoon will be deployed from SLS at the Bus Stop 1
- It will reach the flight configuration and contact the DSN Ground Stations
- It will perform autonomous proximity flight at a safe distance from ICSP, for the imaging.



ArgoMoon mission First Phase

SLS ICPS targeting and imaging





Divided into 3 levels to optimize performances

Autonomous navigation algorithms was designed, developed, tested and integrated by Argotec.

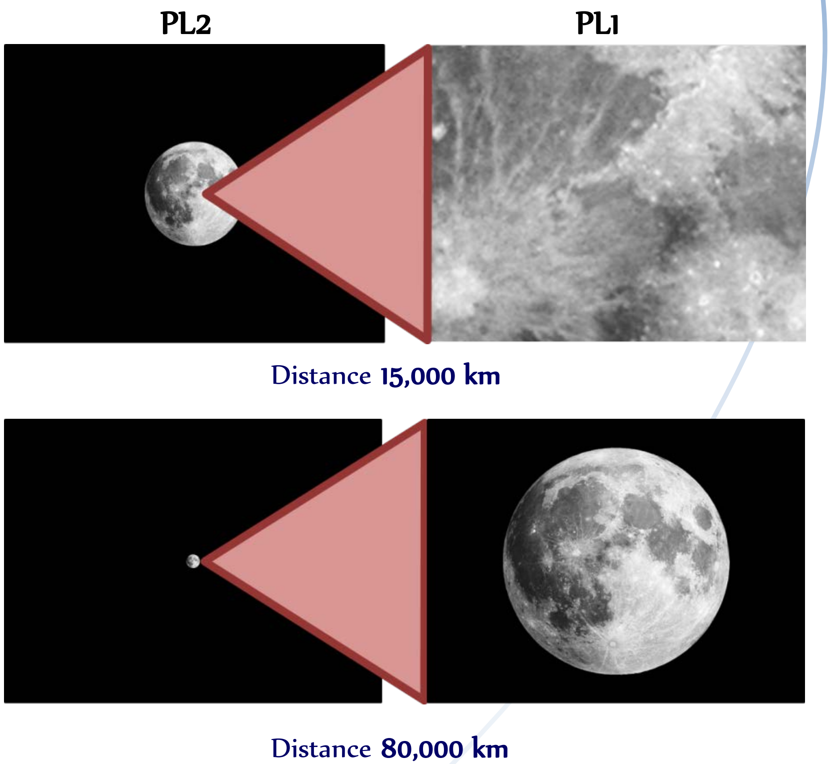
Imaging software

- **Easy to run** and operate
- Filter against Background
- **Fast identification** of the objective
- Commands interpreted by ADCS to point the target.
- **Multiple Target Identification** (MTI) capability.
- Fine tracking for photo shooting session

ArgoMoon mission Second Phase

Science opportunity and technological demonstrations

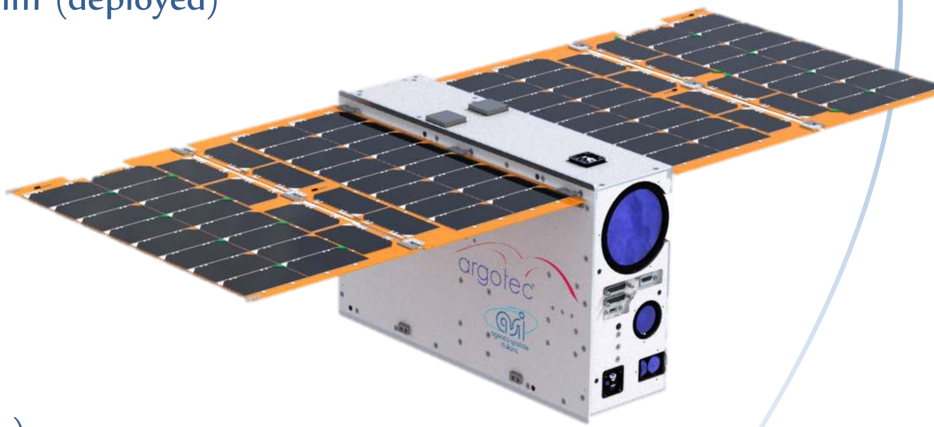
Flyby	Duration [h]	Min altitude [km]
1	49	11503
2	42	44984
3	53	34062
4	55	33240
5	41	36778
6	31	55341
7	39	38626



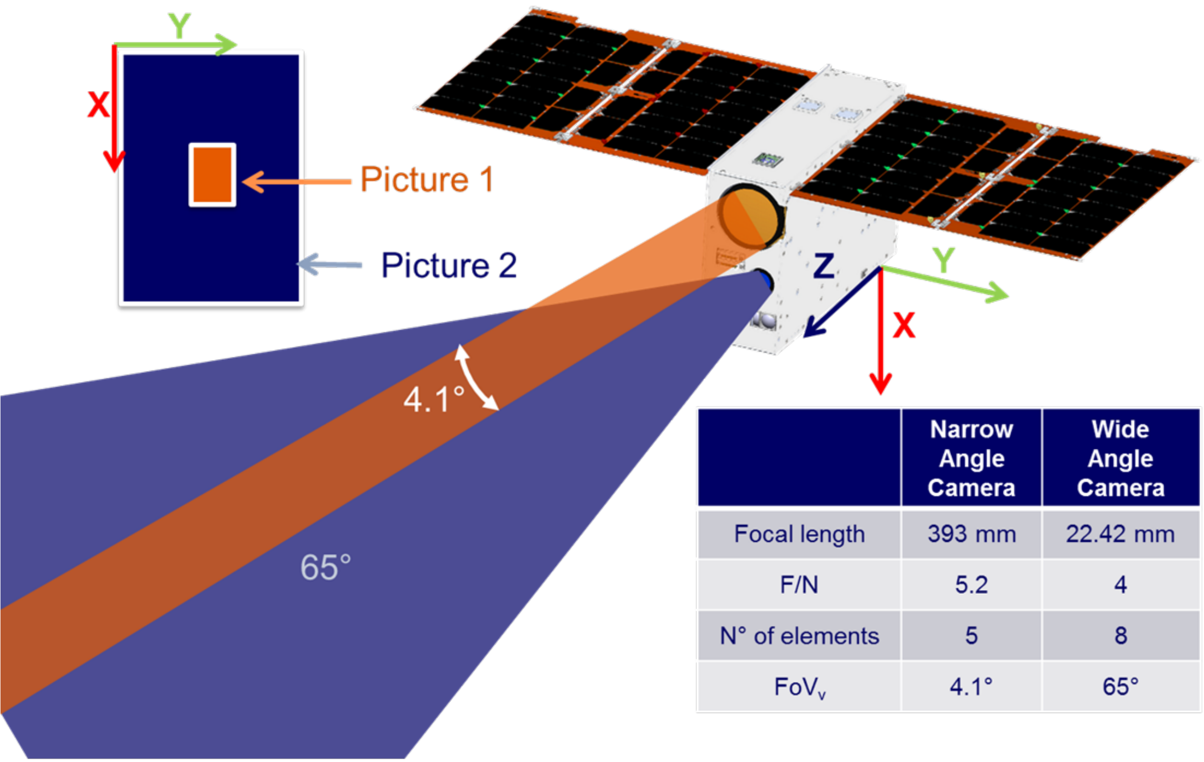
- 7 flybys during 6 months mission (min altitude below 80000 km)
- Different altitudes and different durations for each passages
- Several pictures of the Moon and of the Earth in different illumination conditions
  - Opportunity for investigations (occultation, limb obs)

ArgoMoon design, at a glance

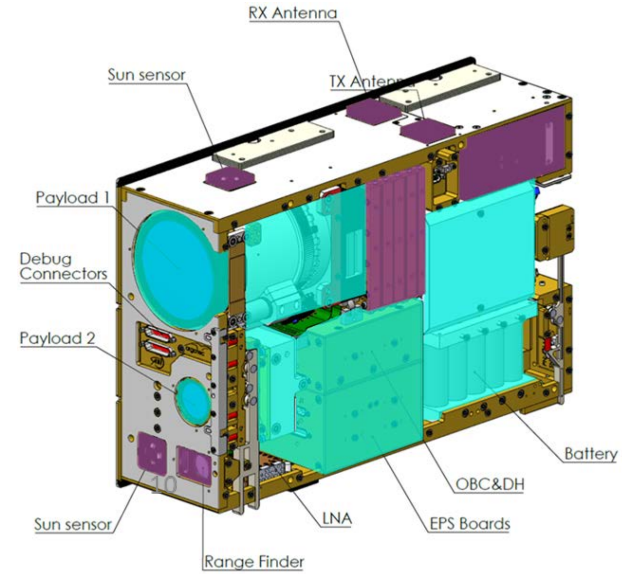
- **Mass:** 14 kg (allocated)
- **Volume:** 6U - 911.5 mm 366 mm x 239 mm (deployed)
- **Generated Power:** 80 W through solar panel
- **Storage Memory:** 16 GB
- **Downlink Band:** X-band
- **Downlink Rate:** 256 kbps
- **Propulsion:** LMP103S-LT (primary propulsion)
  R134a (secondary propulsion)
- **Payloads:** 40° field of view camera,
  2.5° field of view camera,
  Rangefinder

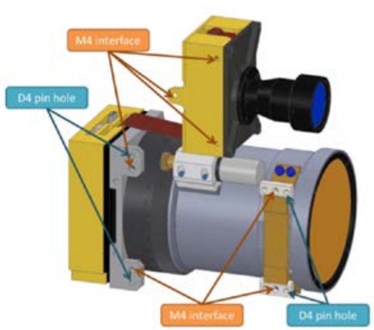


ArgoMoon configuration



	Narrow Angle Camera	Wide Angle Camera
Focal length	393 mm	22.42 mm
F/N	5.2	4
N° of elements	5	8
FoV_v	4.1°	65°

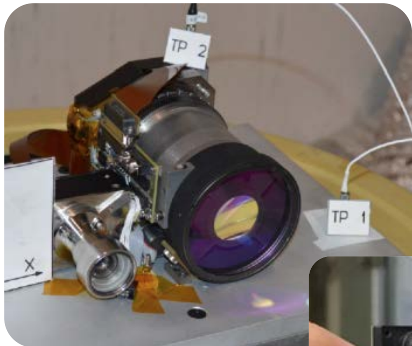




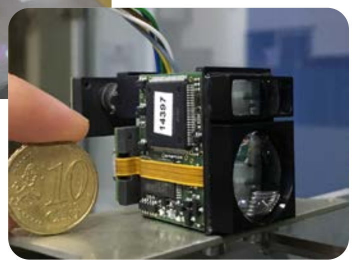
Payload:

- Optical-1+Electronic
- Optical-2+Electronic
- Range Finder

ArgoMoon integration and test

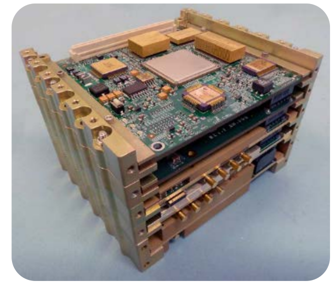


OPTICAL PAYLOADS



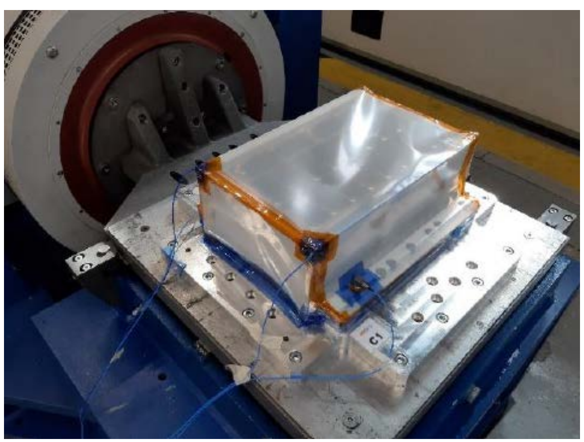
RANGEFINDER

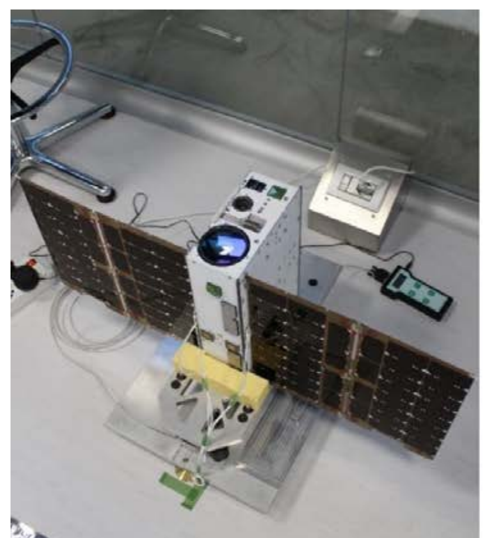
PROPULSION SYSTEM

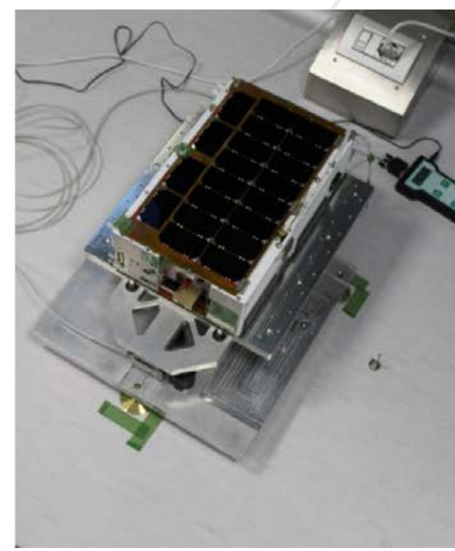


RADIO

ADCS

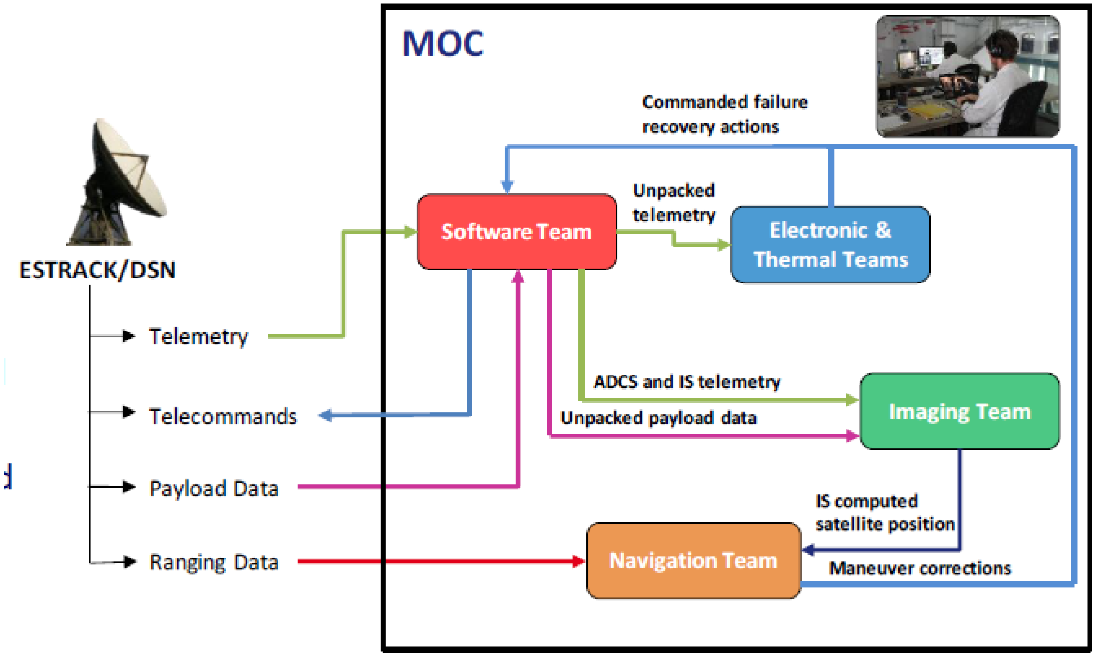






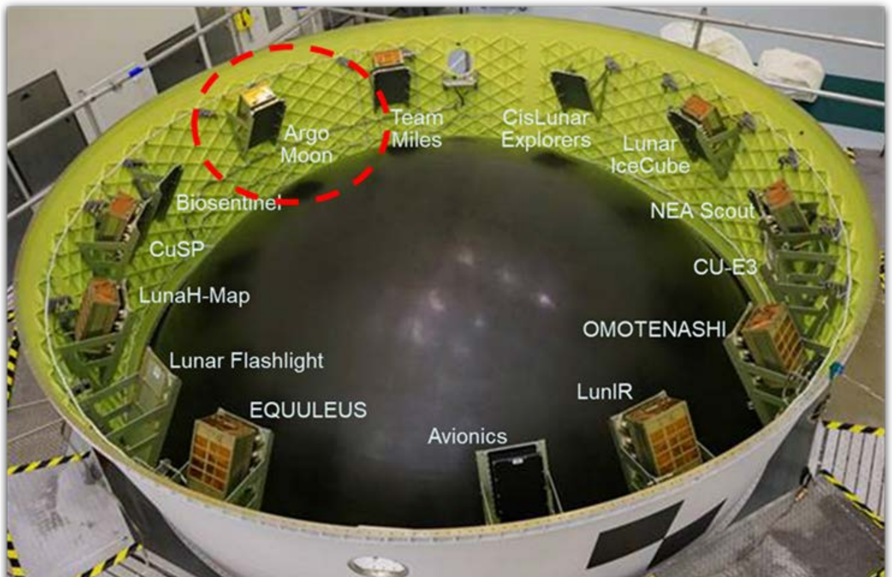
ArgoMoon current status (1/2)

- JSC and MSFC Data Connection and Voice Loop
- NASA JPL and ESTRACK as terminals, validated via Connectivity, E2E, GDS tests
- Front Room Navigation Support and Simulation
- Back Room Engineering Support and Troubleshooting
- Training of the Flight Control Team
- Mission Data Post-processing (Science and Telemetry)



ArgoMoon current status (2/2)

ArgoMoon PFM1 was integrated on the Artemis 1 Orion Stage Adapter, together with the other Secondary Payloads, during august 2021.



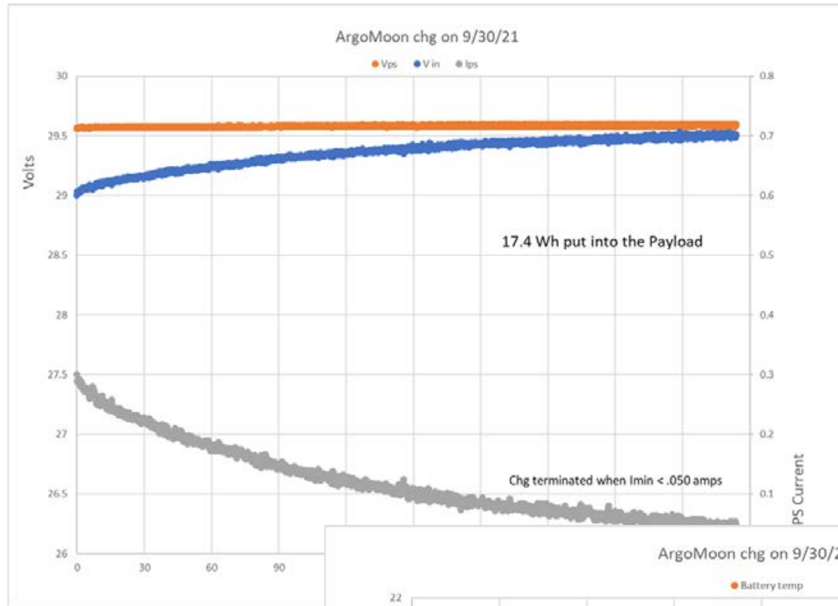
August 19th 2021 Credits: NASA – Kennedy Space Centre

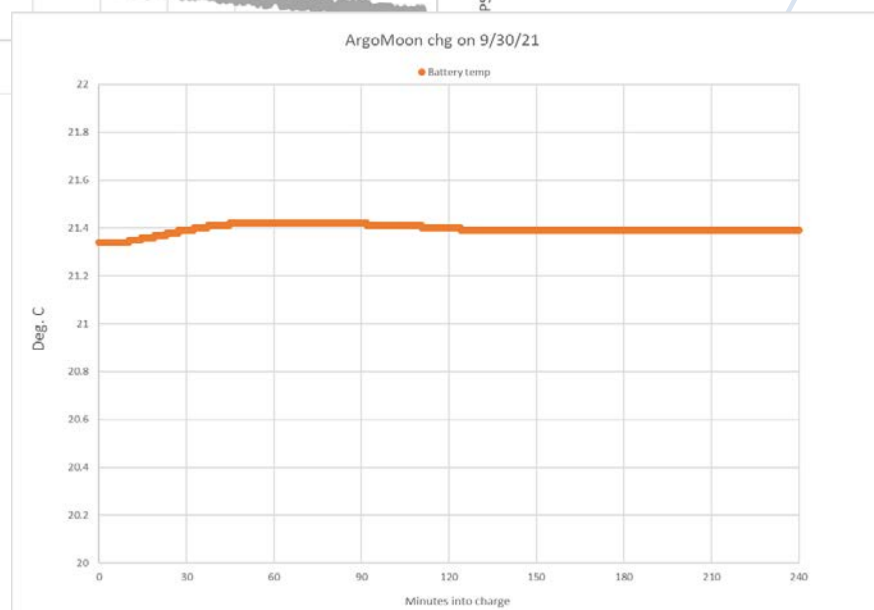
Launch of Artemis-1 is currently planned for **LP24 (26th July – 9th August)**

ArgoMoon activities in progress

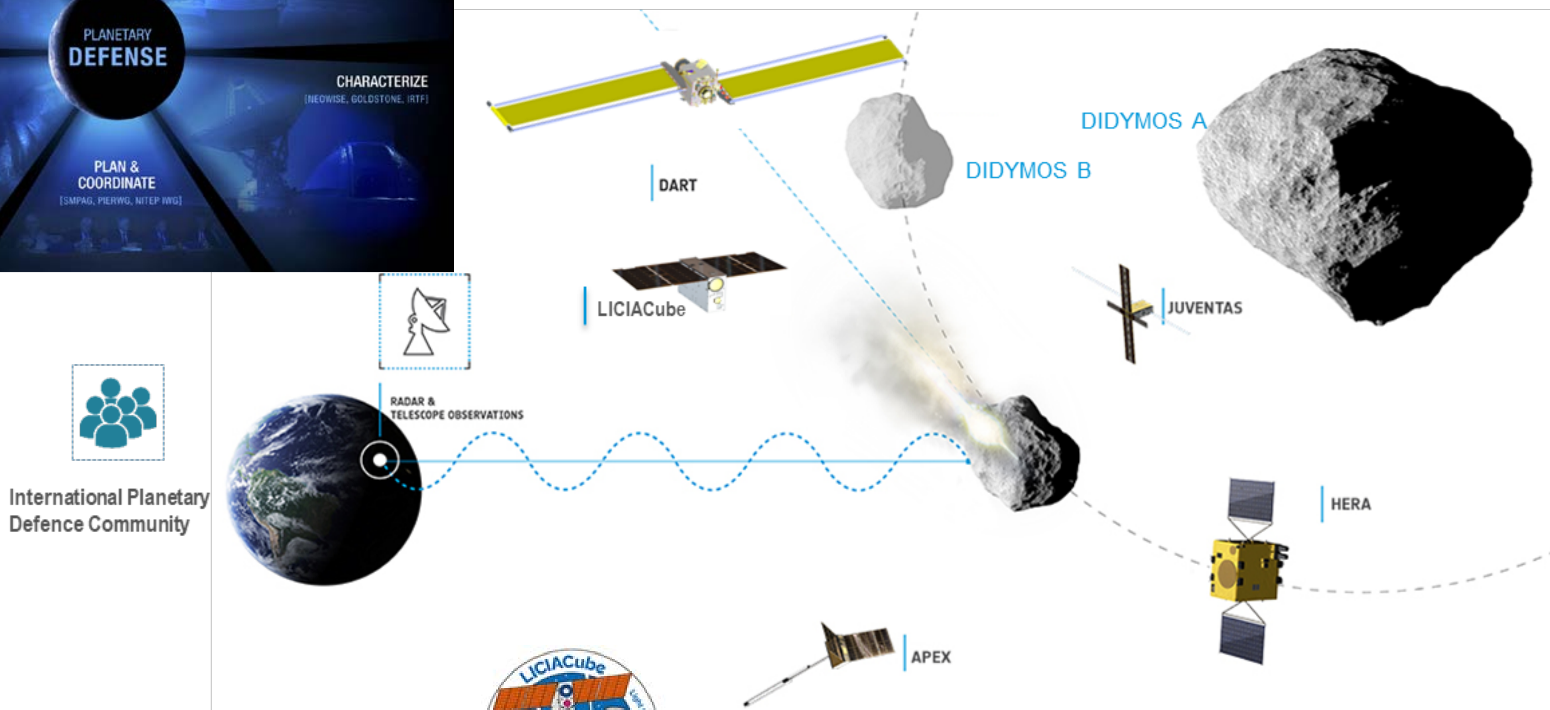
Waiting for the launch:

- Trajectories analyses;
- Periodic battery charge;
- Component/parts/units lifetime evaluation;
- Mission Control Centre final preparation and test;
- Personnel training



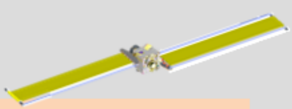


LICIACube for AIDA



AIDA

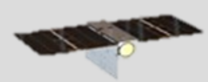
DART



First demonstration of asteroid deflection by kinetic impact on Didymos B, to change its orbit

with

LICIACube



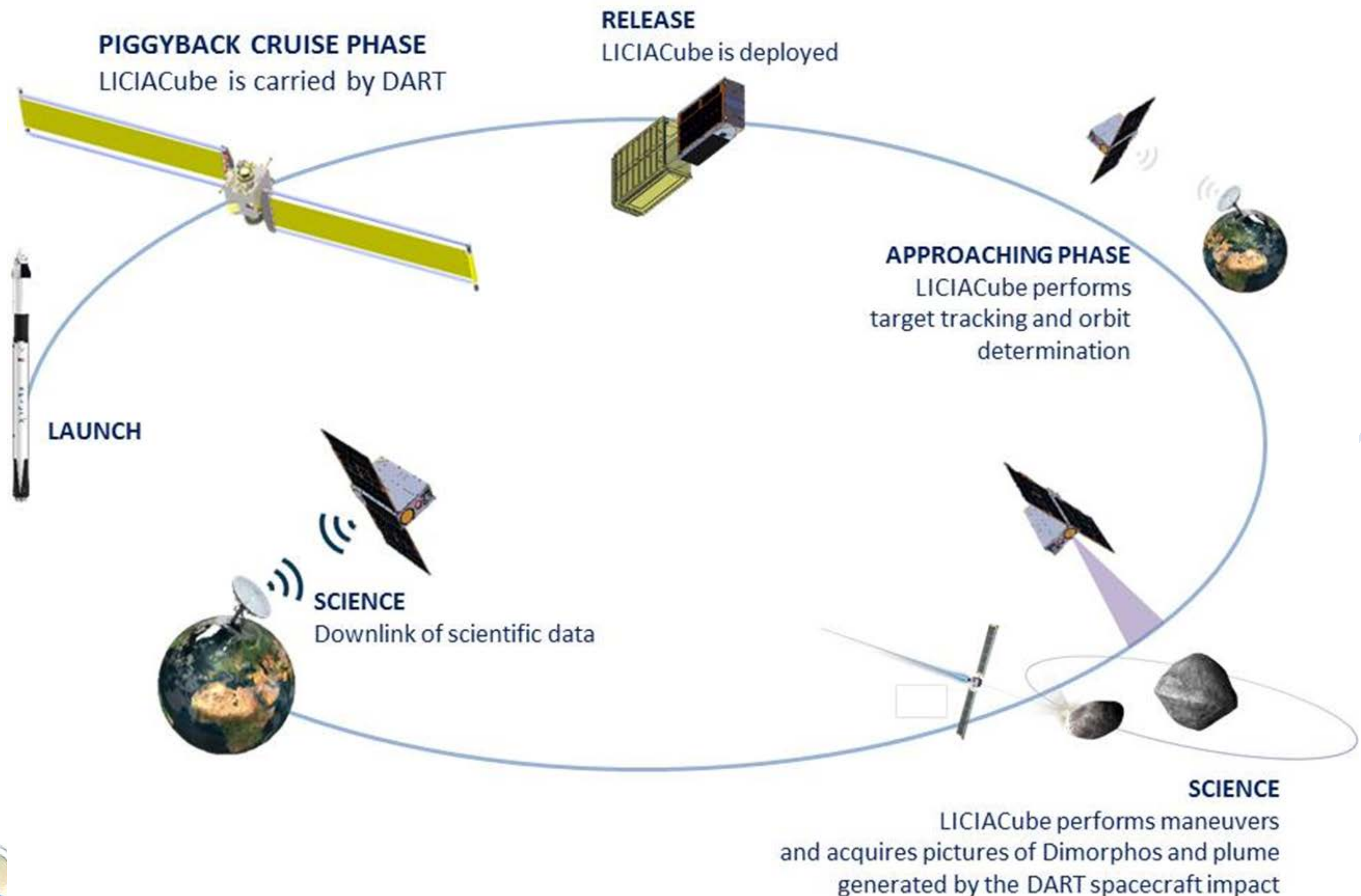
First prompt imaging of the impacted surface, ejecta plume evolution and of the non-impacted hemisphere of Didymos B

+

Hera

Mass of Didymos B
Detailed dynamical characterization, investigation of final crater, overall characterization of the asteroids

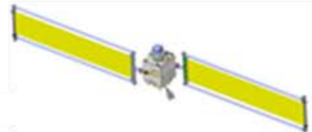
LICIACube mission profile



The cooperation frame

argotec SPACE FOR AMBITIONS

DART TEAM



NASA HQ Science Mission Directorate
Planetary Science Division –
Planetary Defense Office
- DART mission responsibility
- Leading of US team
- Technical/programmatic management
- Int. relations (LICIA) management

JHU Applied Physics Laboratory
- Mission Implementation
- Technical IF management

Jet Propulsion Laboratory – Deep Space Network
- TT&C and Navigation Services

NASA Goddard Space Flight Centre
NASA Johnson Space Centre

Implementing Arrangement

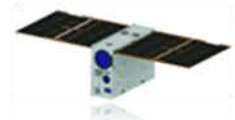
ICD

Management
Science
Engineering

Communication

Phase B/C1 contract (KickOff – Dec 2018)

LICIACube TEAM



Agenzia Spaziale Italiana:
- LICIACube mission responsible
- Leading of Italian team
- Technical/programmatic management
- Int. relations (DART) management

Argotec srl: LICIACube Contractor
- Support to programmatics
- Technical interface

INAF Istituto Nazionale di Astrofisica
- Payload performances definition
- Scientific investigation

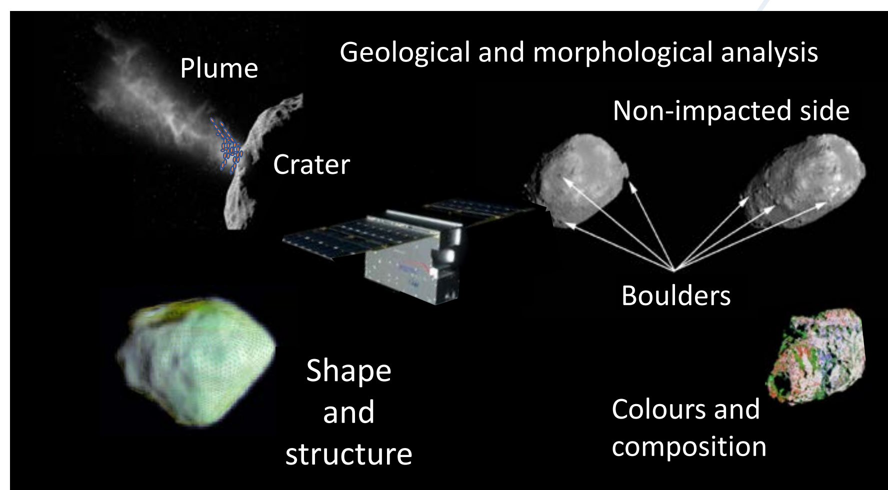
Politecnico di Milano
- Mission analysis e trajectory optimization

Università di Bologna
- Orbit Determination and Deep Space Navigation - Radioscience

SpaceOps

LICIACube scientific objectives (1/2)

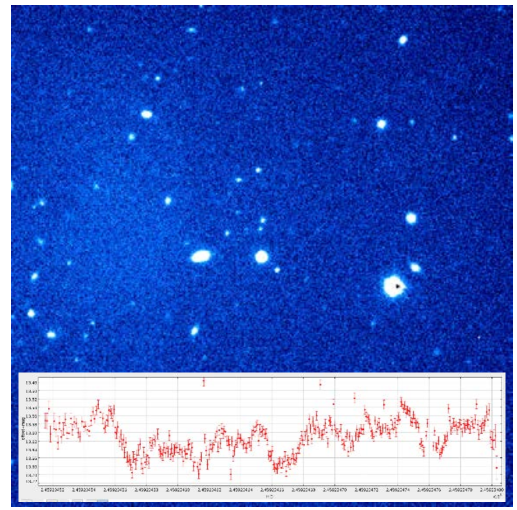
- **Testify** the DART **impact**;
- Obtain multiple images of the **ejecta plume,** over a span of time and phase angle to:
  - Allow measurement of the motion of the slow (< 5 m/s) ejecta, at spatial scale better than 5 m/pixel, with the possibility to distinguish the movements of the slowest particles;
  - Allow estimation of the plume structure, measuring the evolution of the dust distribution;
- Obtain multiple images of the **DART impact site** with a sufficient resolution to allow measurements of the size and morphology of the crater;
- Obtain multiple images of Dimorphos showing the **non-impact hemisphere**, hence increasing the accuracy of the shape and volume determination.

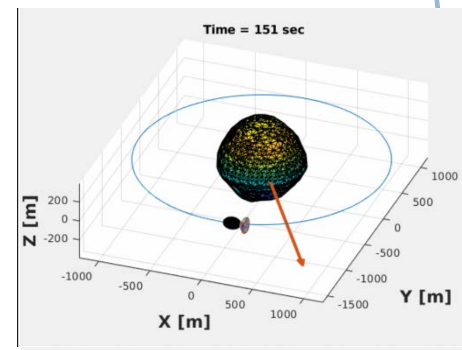


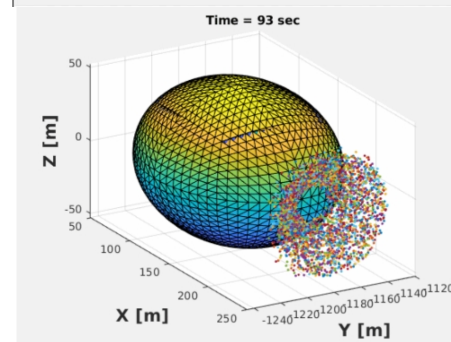
LICIACube scientific objectives (2/2)

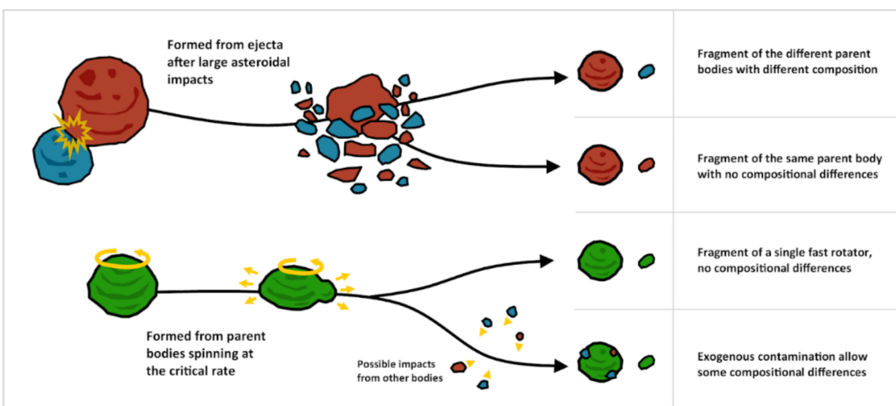
LICIACube researchers' part of the DART investigation team. Working Groups:

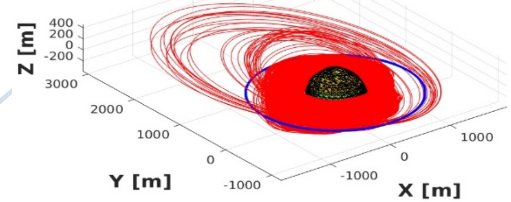
- Impact Modeling Working Group
- Observations Working Group
- Dynamics Working Group
- Ejecta Working Group
- Proximity Operations Working Group



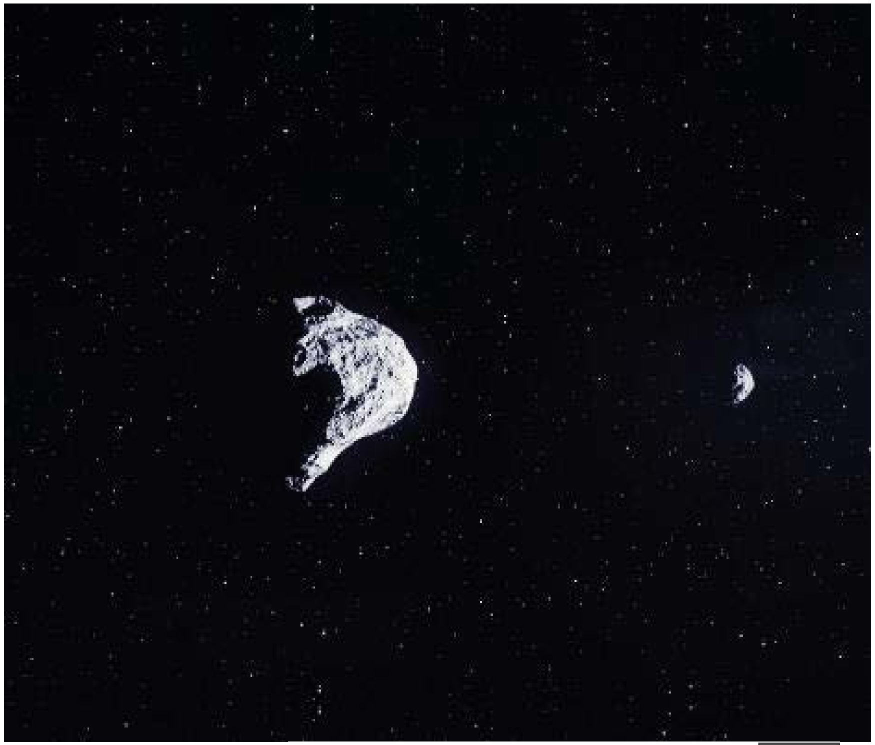


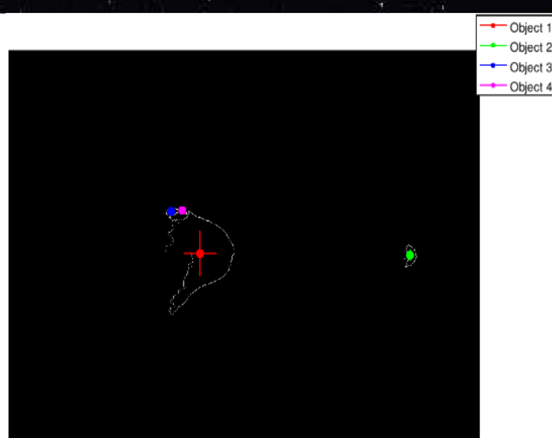




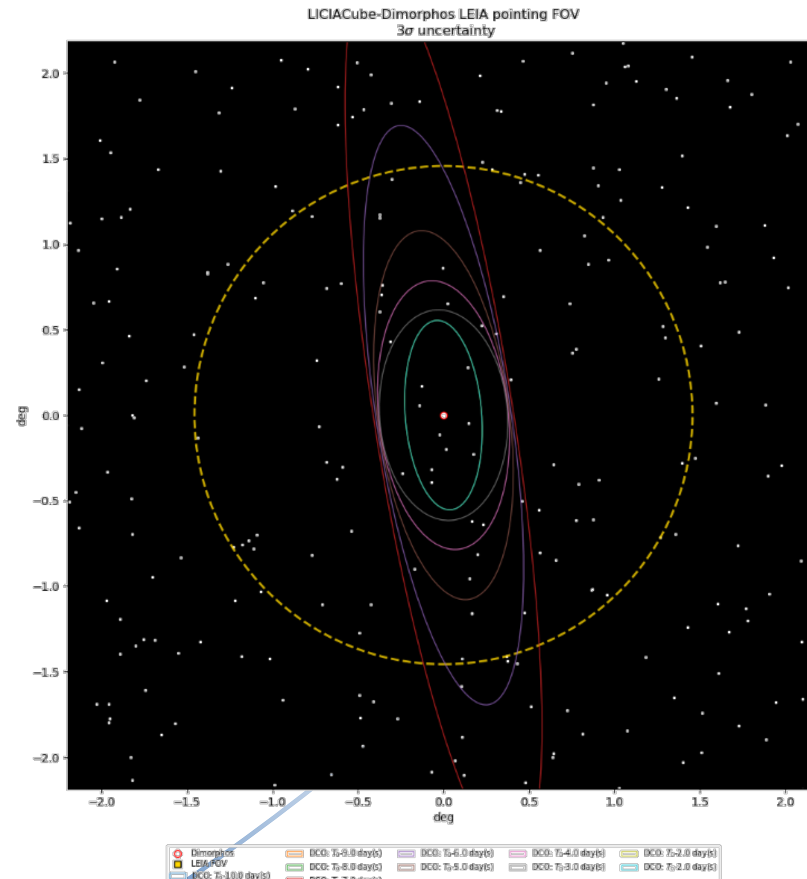


LICIACube mission design (1/2)





Trajectories were optimized, and maneuvers designed, considering uncertainties predicted by **Orbit Determination** (radio and optical)



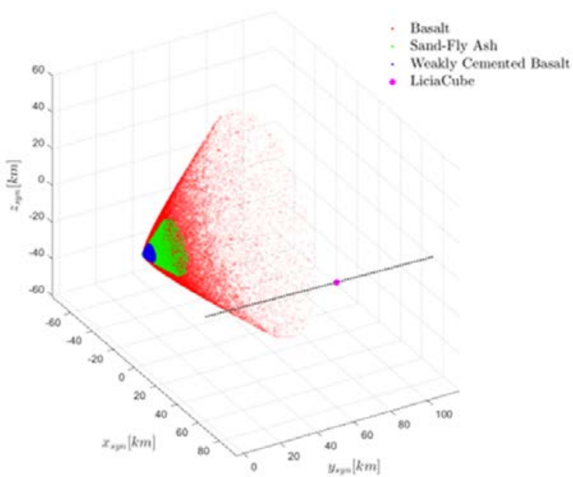
LICIACube mission design (2/2)

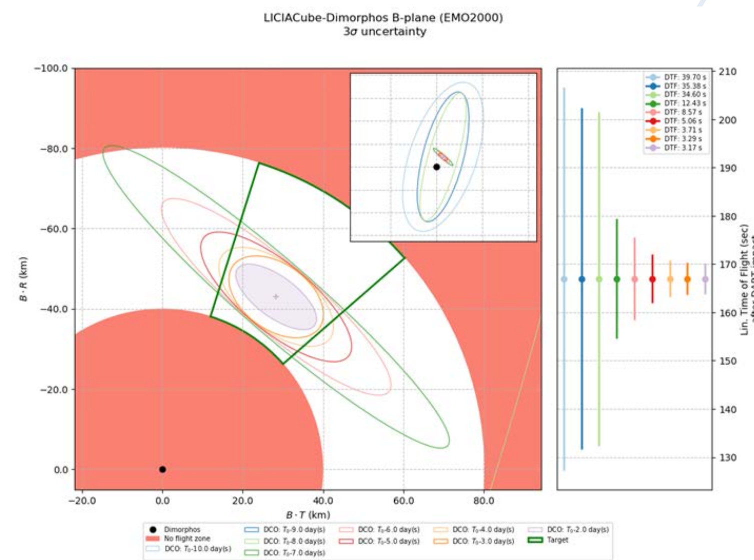
High-Level requirements
- Low Speed Particles Observation (< 5m/s)
- Dimorphos “Back side” Observation
- Crater Observation

Low-Level requirements
- $\Delta t_{5m/px}$ (i.e. d<200 km) > 30 s
- Nadir Pointing for the whole mission

Camera
- Focal Length = 222.5 mm
- Diagonal FoV = $\pm$ 2.06°
- Resolution= 2048 x 2048 px
- Exposure time range= 0.1 ms → 30 s
- Lens: Diameter = 79 mm, (Material: Corning HPSF-7980)

Propulsion System:
- Thrust = 50 mN
- Isp = 40 s

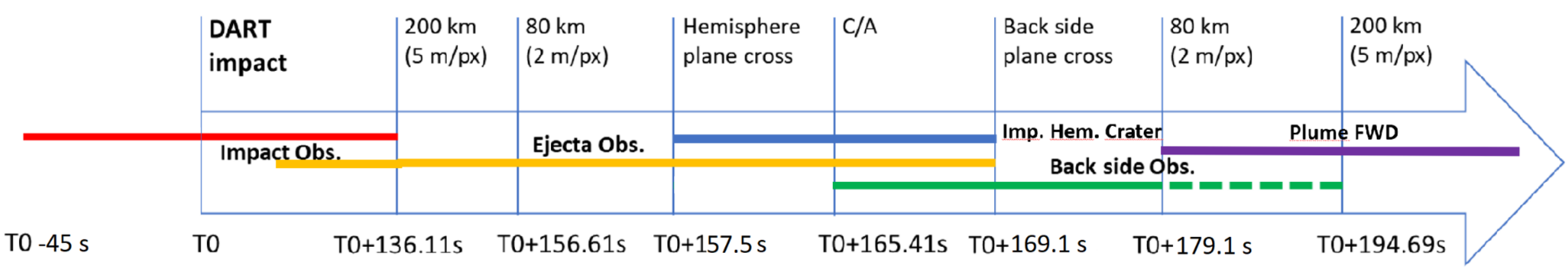




Close Approch (**CA**) distance $\mathbf{d_{C/A}}$ and delay time $\mathbf{t_{delay}}$.

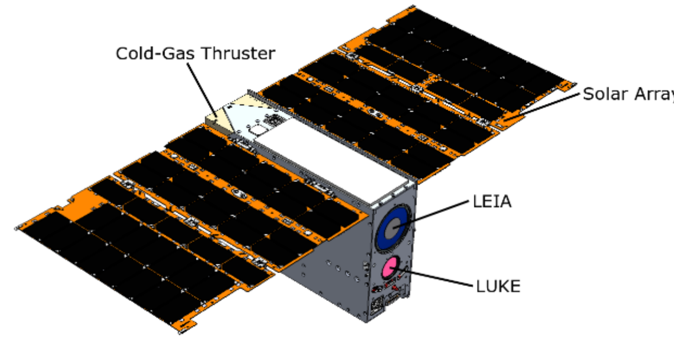
LICIACube Timeline

Phase	Start	End	LEIA	LUKE
1 – DART Impact	-45 s to T0	T0+136.11 s	yes	Not operative
2 - Ejecta Observation	-25 s to T0	T0 + 169.1 s	yes	yes
3 - High resolution (surface properties/crater) observation	T0 + 157.5 s	T0 + 169.1 s	yes	yes
4 – Non-impact hemisphere observation	T0 + 165.41s	T0 + 179.1 s	yes	yes
5 – Plume evolution in forward scattering	T0 + 179.1 s	T0 + 600 s	yes	yes



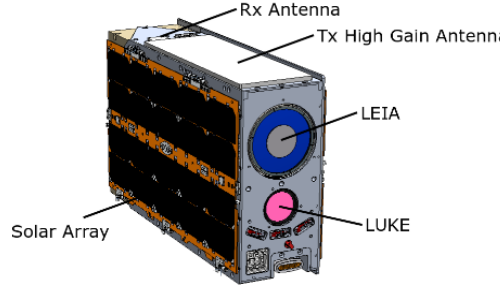
LICIACube design, at a glance

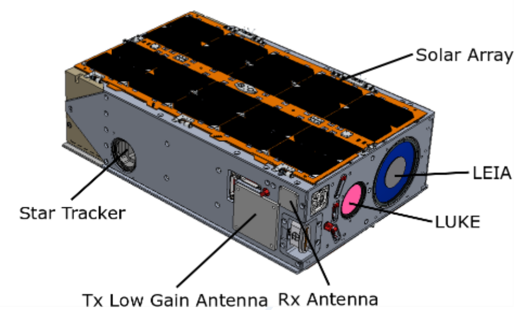
Orbit: Heliocentric (~10M km from the Earth)
Mass: 14 kg
Volume: 6U+
366 mm x 239 mm x 116.2 mm (stowed)
911.5 mm x 366 mm x 239 mm (deployed)

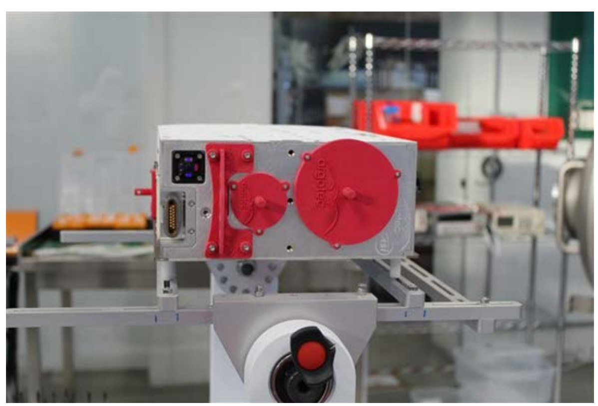


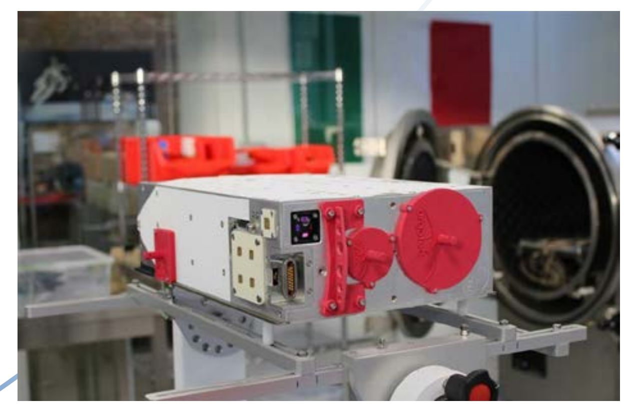
<u>LEIA:</u> a catadioptric camera with spatial scale at C/A (~55km) 1.38 m/px

<u>LUKE</u>: a camera with a RGB Bayer pattern filter

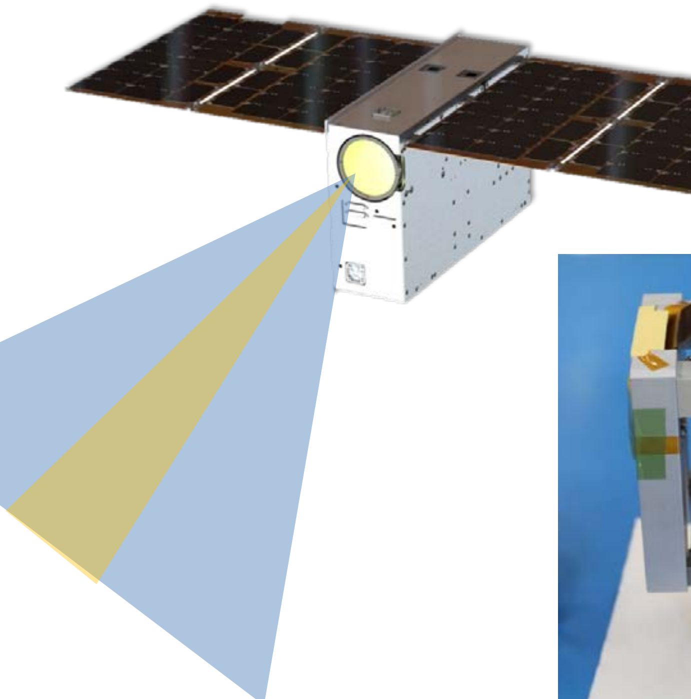




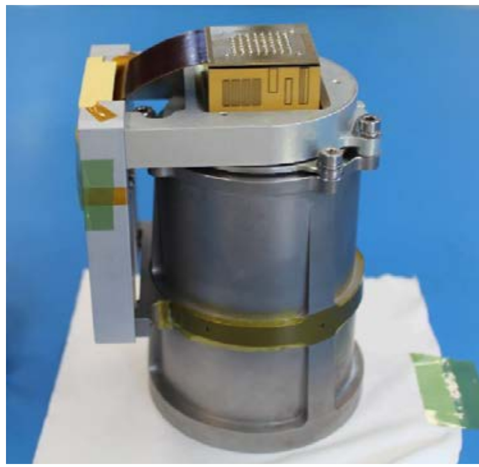




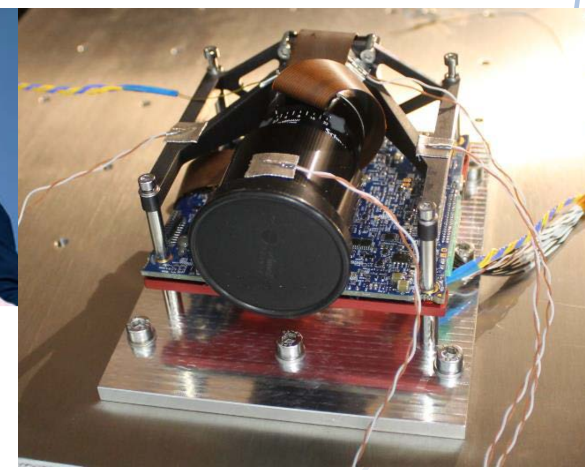
LICIACube Payloads



LEIA



LUKE

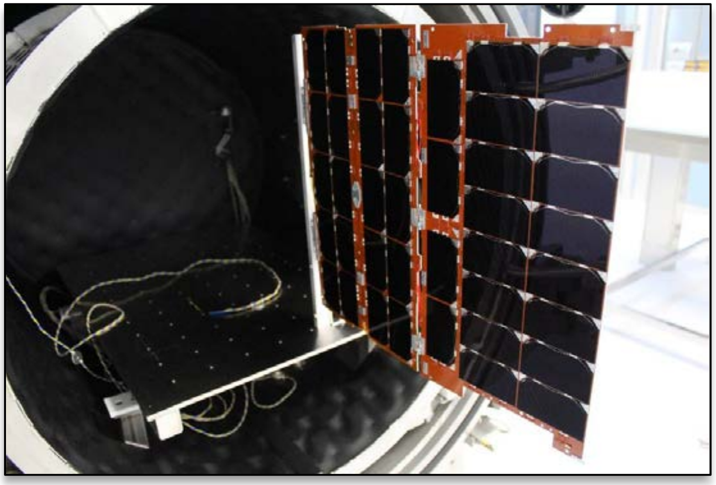


Liciacube Explorer Imaging for Asteroid

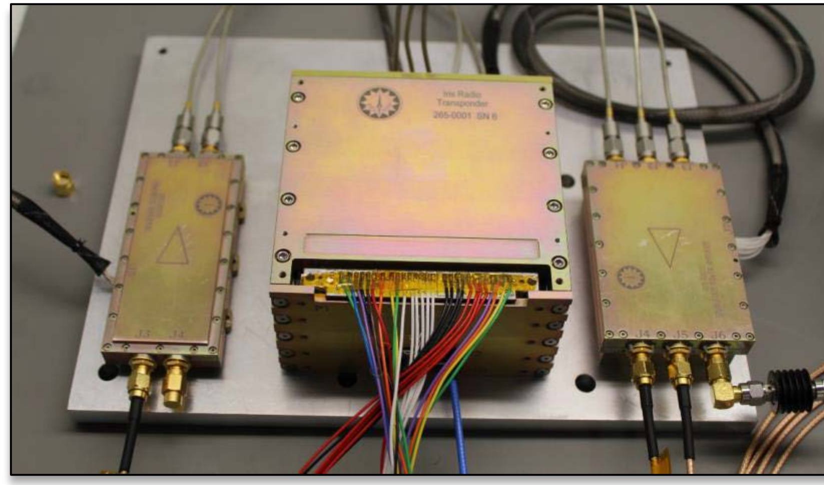
Liciacube Unit Key Explorer

	Focal length (mm)	FoV (°)	IFoV (μrad/px)	Spat. scale at 55.2km (m/px)
LEIA	222.55	± 2.06	24.71	1.38
LUKE	70.5	±5	78	4.31

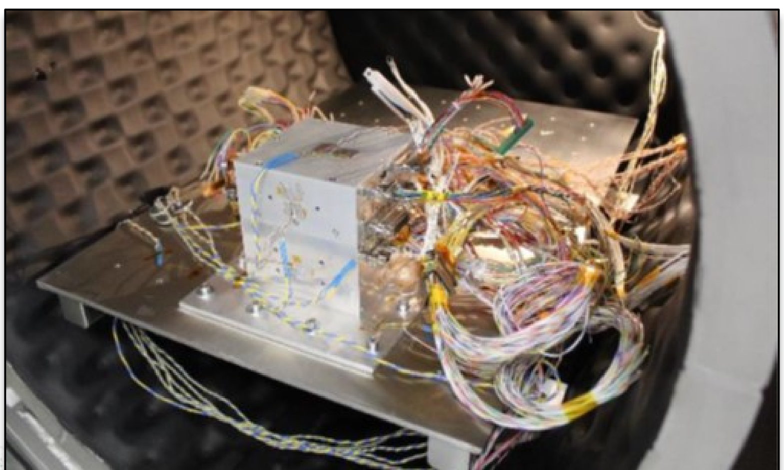
LICIACube testing 1/4



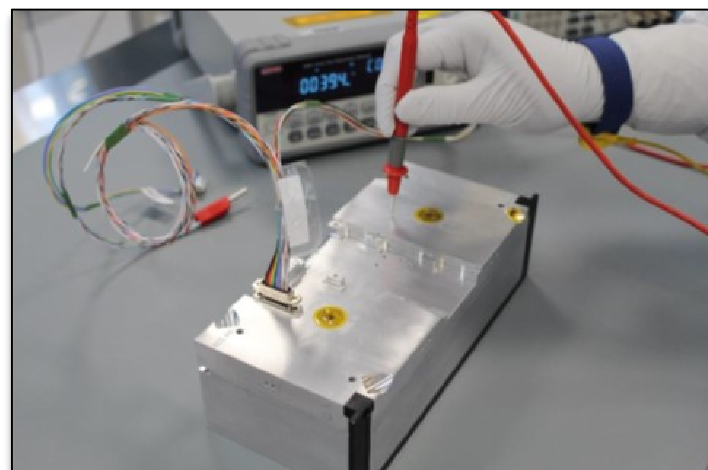
Solar Panels in Argotec TVAC



TT&C Subsystem

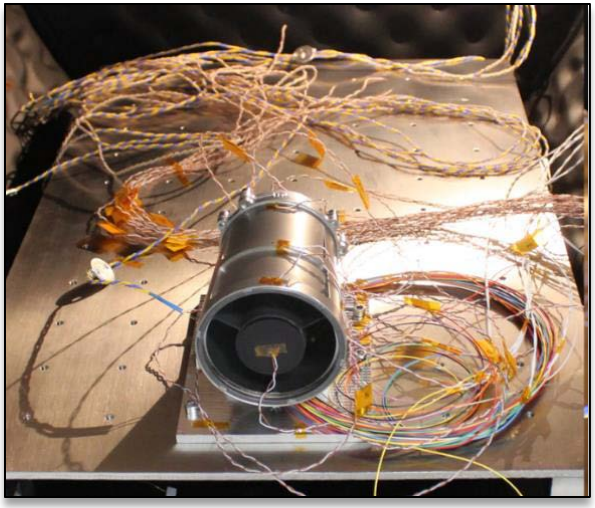


OBC in Argotec TVAC

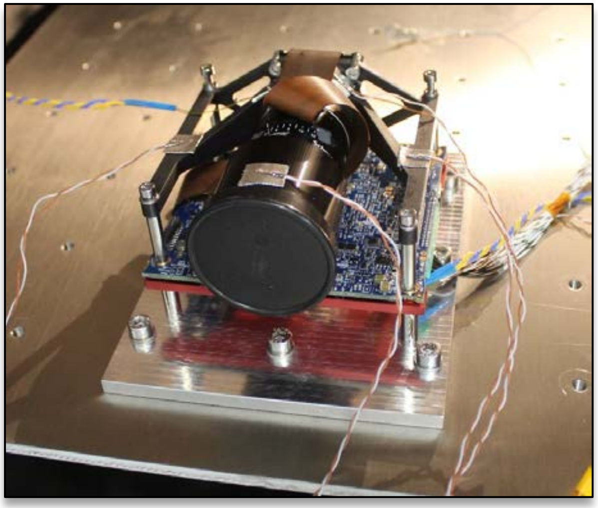


PS in Argotec Clean Room

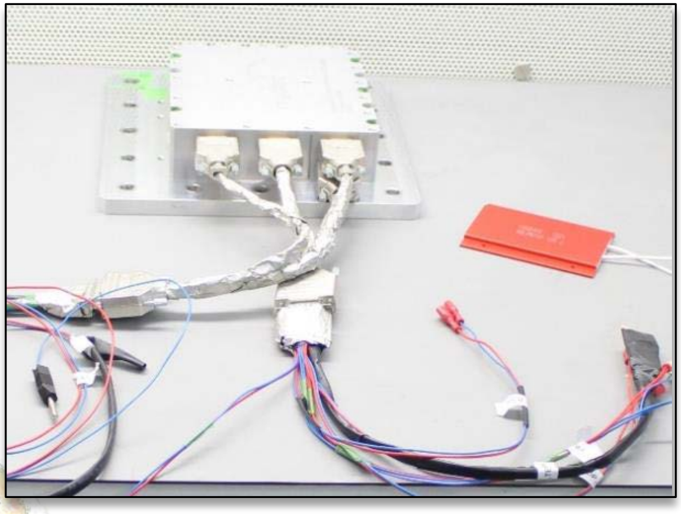
LICIACube testing 2/4



LEIA in Argotec TVAC



LUKE in Argotec TVAC

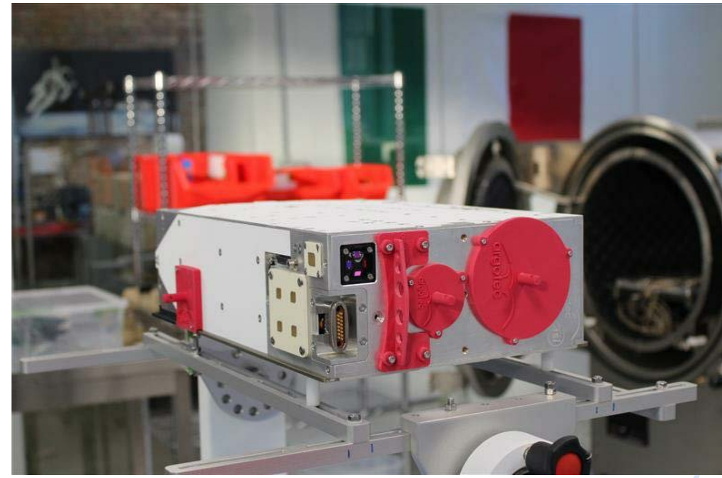


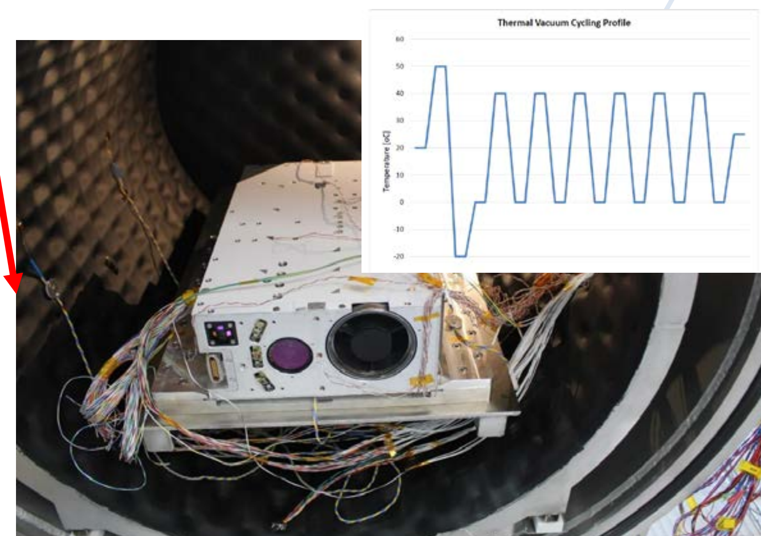
EBC

DISPENSER

LICIACube testing 3/4

ID	Test	Date	Status
1	Full functional test	12/03/2021	Done
2	Thermal Vacuum test	22/03/2021	Done
3	Reduced functional test	01/04/2021	Done
4	Thruster filling	22/04/201	Done
5	Solar panel installation	07/04/2021	Done
6	Solar panel deployment	07/04/2021	Done
7	Optical alignment	29/04/2021	Done
8	Full functional test	14/04/2021	Done
9	Physical Properties	23/04/2021	Done
10	Software and Nav. Verification	26/04/2021	Done
11	Integration with the dispenser	12/05/2021	Done



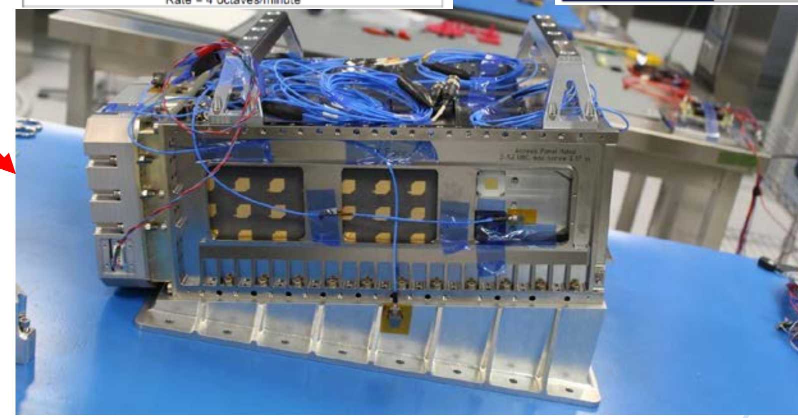


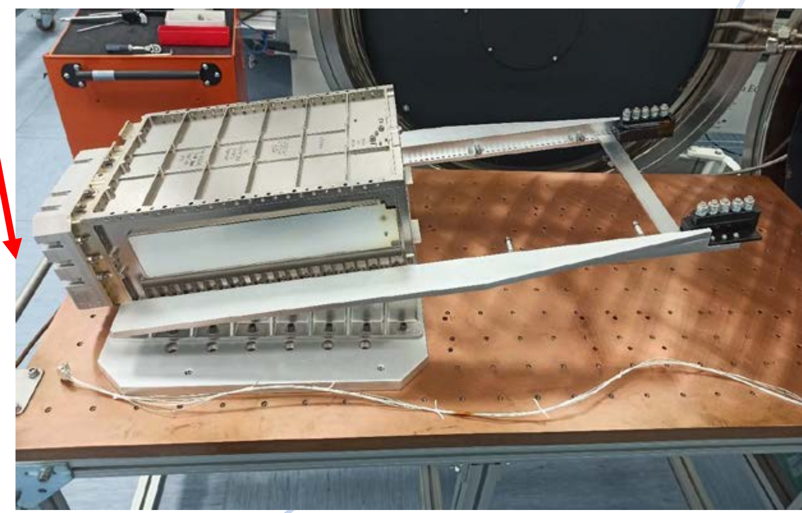
LICIACube testing 4/4

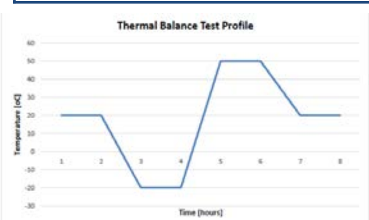
ID	Test	Date	Status
1	Aliveness test	13/05/2021	Done
2	Vibration test (sine and random)	18/05/2021	Done
3	Aliveness test	20/05/2021	Done
4	Deployment test (at -20°C and + 50°C)	21/05/2021	Done
5	Functional Test (Ambient, Hot and Cold Temp.)	25/05/2021	Done
6	MLI Integration	25/05/2021	Done
7	Thermal Balance test	03/06/2021	Done
8	Aliveness check	09/06/2021	Done

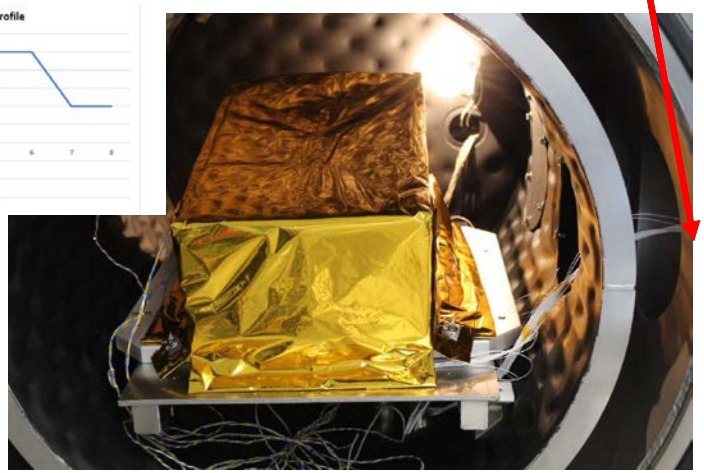
DART S/c Thrust Axes (Z_{SC})		DART S/c Lateral Axes (X_{SC}, Y_{SC})	
Frequency [Hz]	Acceleration [g]	Frequency [Hz]	Acceleration [g]
5	0.63	5	0.63
25	15	20	10
29	15	24	10
36	1.25	31	1.25
100	1.25	100	1.25
Rate = 4 octaves/minute			

Frequency [Hz]	ASD [g^2/Hz]
20	0.0063
80	0.10
300	0.10
2000	0.0023
Overall Acceleration	7.09 gRMS
Duration	60 s









LICIACube integration and launch!

argotec
SPACE FOR AMBITIONS

ASI

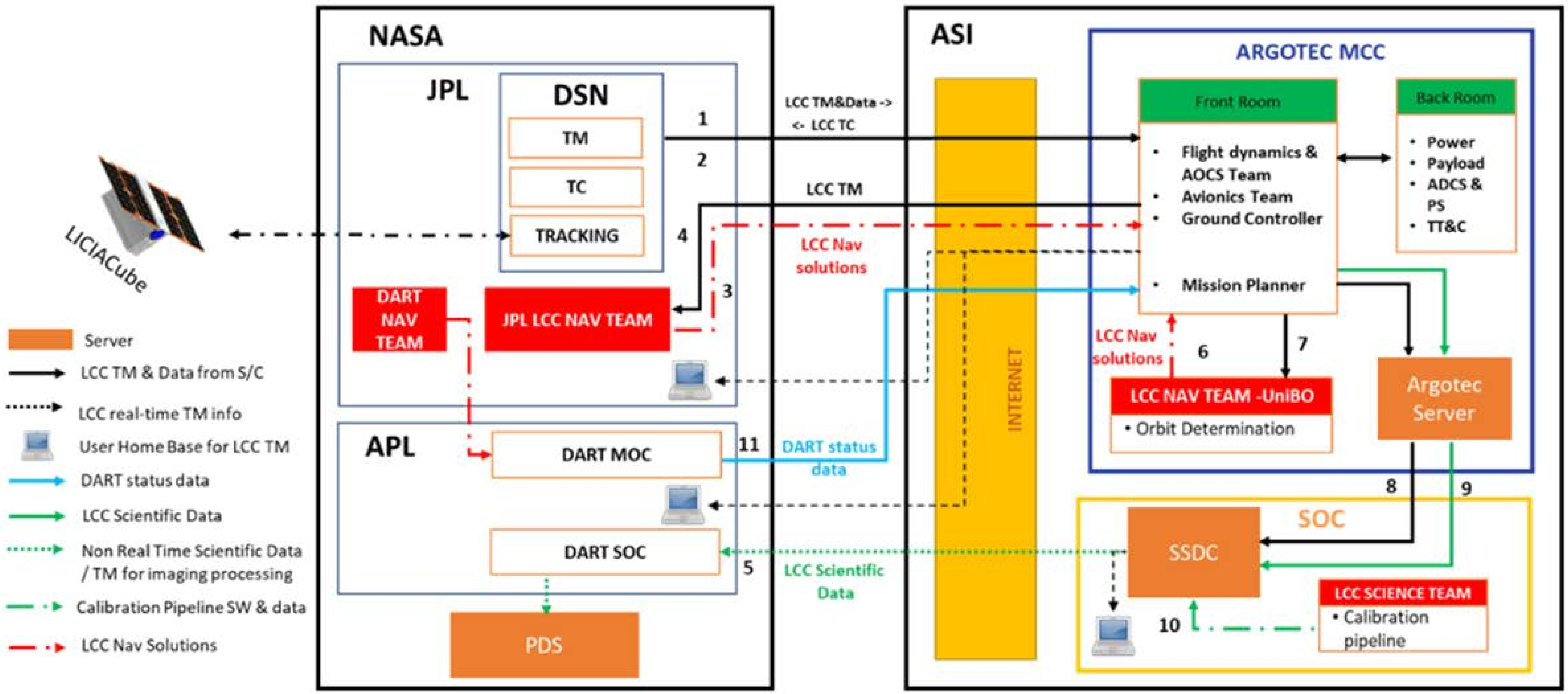
August 2021: Integration on DART at JHU – APL, Baltimore, MD

24th November 2021: DART and LICIA Launch – Vandenberg Air Force Base, CA

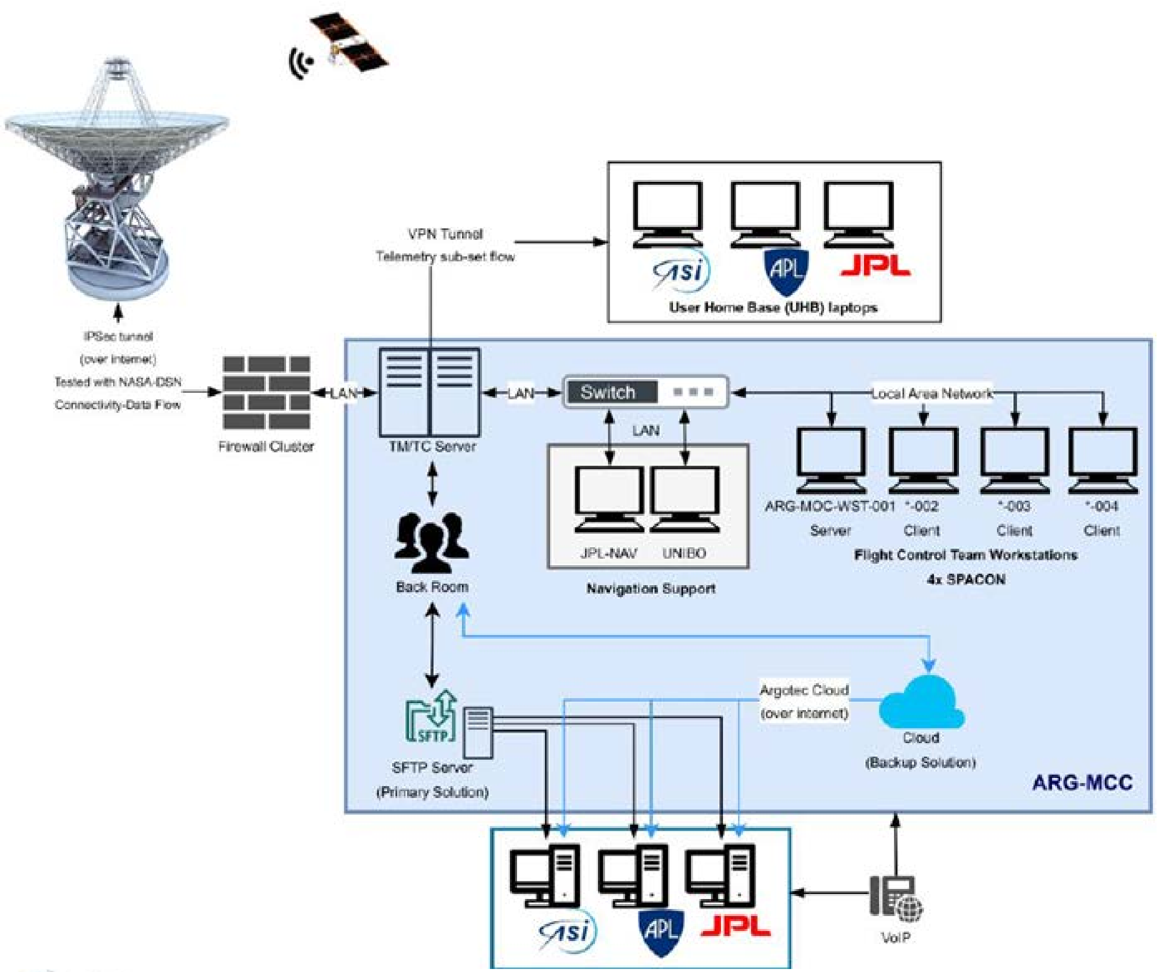
SpaceOps

LICIACube GS architecture

A quite articulated **Ground Segment architecture** was implemented: Antennas terminals are part of the DSN, while the **Mission Control Centre** is located in Turin (Argotec) and the **Science Operation Centre** in Rome (ASI)



LICIACube Ground Segment layout



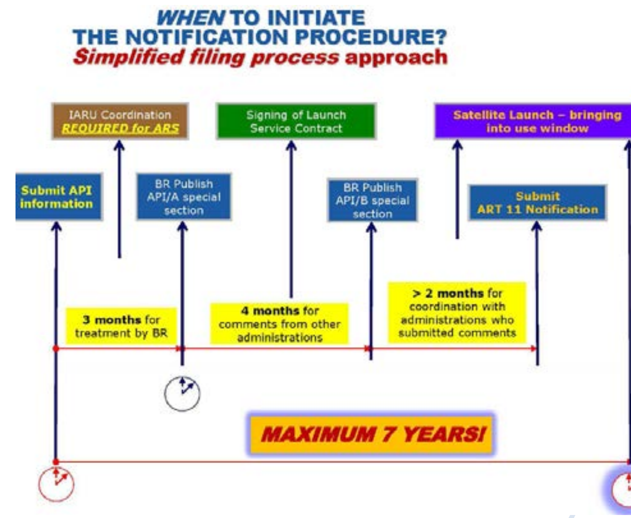
- Encrypted and secured communication tunnel between NASA DSN and LICIACube **Mission Control Centre**
- User Home Base (UHB) laptop to share real-time satellite telemetries with mission nodes
- Data exchange via secure way between MCC and network nodes (APL, JPL, ASI)
- TM/TC **server** redundant
- **Back Room** comprises engineering support to real-time operations

Frequency licensing (at ITU)

According to **Radio Regulations**, the relevant procedures involve:

- Advance Publication Information (API) (Section I, Article 9);
- Coordination (Section II of Article 9);
- Notification and recording in the MIFR (Article 11)

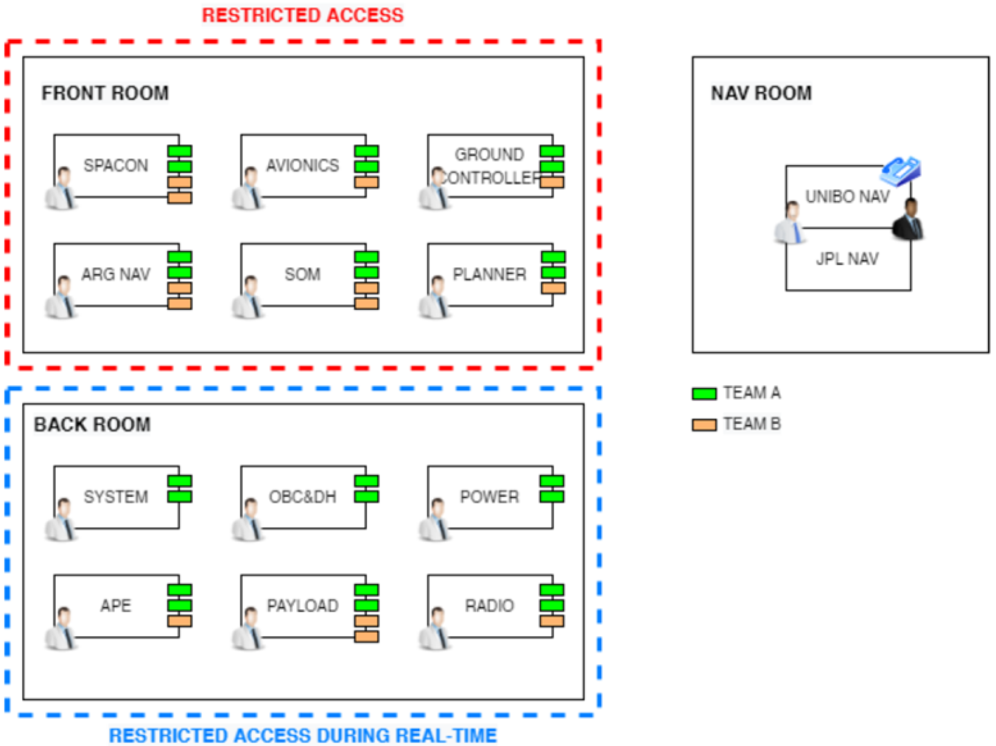
[NB: there is no regulatory definition for small satellites in the ITU RR. The RR is recognizing only geostationary (GSO) and non-GSO satellites or systems]



ArgoMoon coordination anticipated at **SFCG** and agreed with four countries
LICIACube coordination anticipated at **SFCG** and led by JPL (fully Deep Space)

ID number (SNS)	adm	ORG or Geo.area	Satellite name	Earth station	long_nom	Date of receipt	ssn_ref	ssn_no	ssn rev/ Sup	ssn rev no	removal	Part/ Art.	WIC/IFIC (ific.mdb)	WIC/IFIC date
up down	up down	up down	up down	up down	up down	up down	up down	up down					up down	
118545132	I		ARGOMOON		N-GSO	03.08.2018	API/A	12246					2885	11.12.2018
118545132	I		ARGOMOON		N-GSO	03.08.2018	API/B	1067					2896	28.05.2019
120500269	I		ARGOMOON		N-GSO	23.12.2020	PART I-S						2944	20.04.2021
120500269	I		ARGOMOON		N-GSO	23.12.2020	PART II-S						2947	01.06.2021

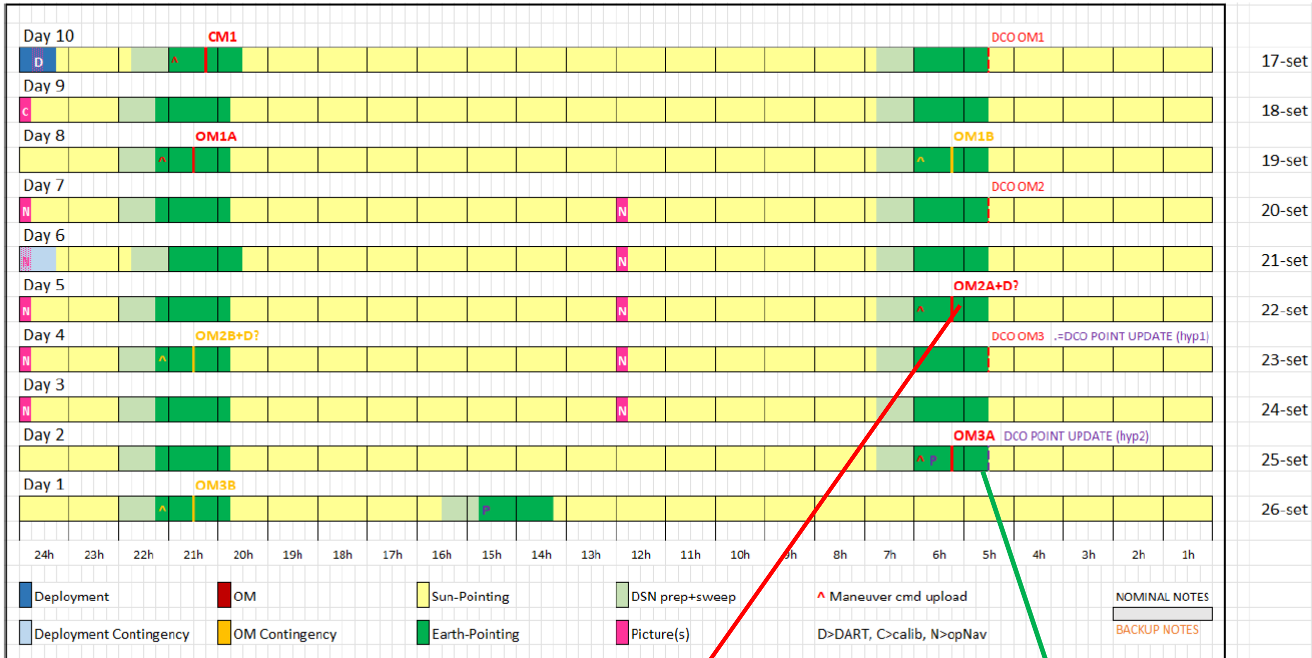
GS and Operations readiness



- **MCS** based on commercial software
- **Custom software** (MARGOT) for data processing and visualization developed by ARGOTEC.
- Flight Operations Procedures (**FOP**) validated by the FCT during SVT.

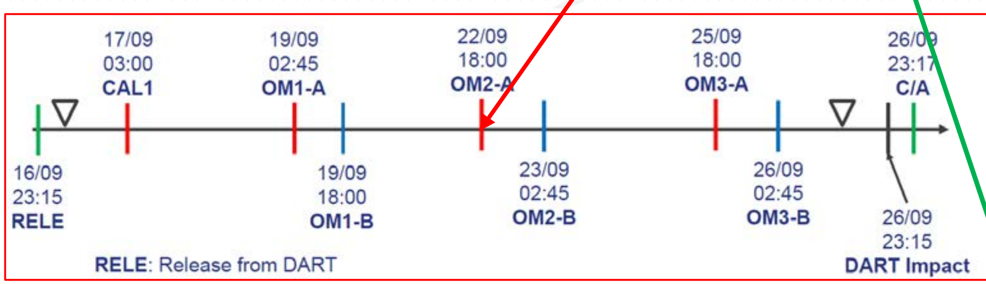
- **Operational features** under finalization (timeline, connectivity and data sharing); End-to-end dry run simulation of the Ops phase planned in June
  - The same GS-MCC will be used also for ArgoMoon mission, with the additional **Encryption** functionality (due to the sensitiveness of the data)

LCC Operational Timeline



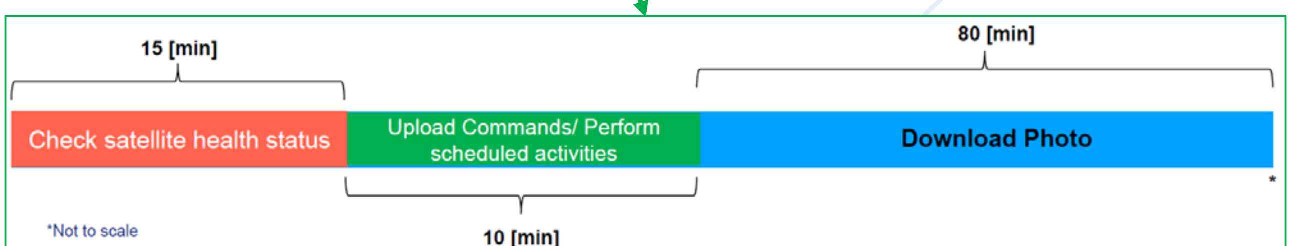
LICIACube mission timeline has been optimized to operate the **correction maneuvers**, the payloads calibration and navigation **imaging**, as well as the periodic **communication windows**

MENEUVERS SEQUENCE



RELE: Release from DART
CAL: Calibration Maneuver
OM: Orbital Maneuver
A: Nominal
B: Backup
C/A: Close Approach
▽ Possible Desaturation

TYPICAL COMM WINDOW TIMELINE



LCC data budget

PAYLOAD	SIZE	TOT. MEMORY [MB]
LEIA	2048 x 2048 [Full]	8.192
	1024 x 1024 [Binned]	2.048
LUKE	2048 x 1088 [Full]	2.176

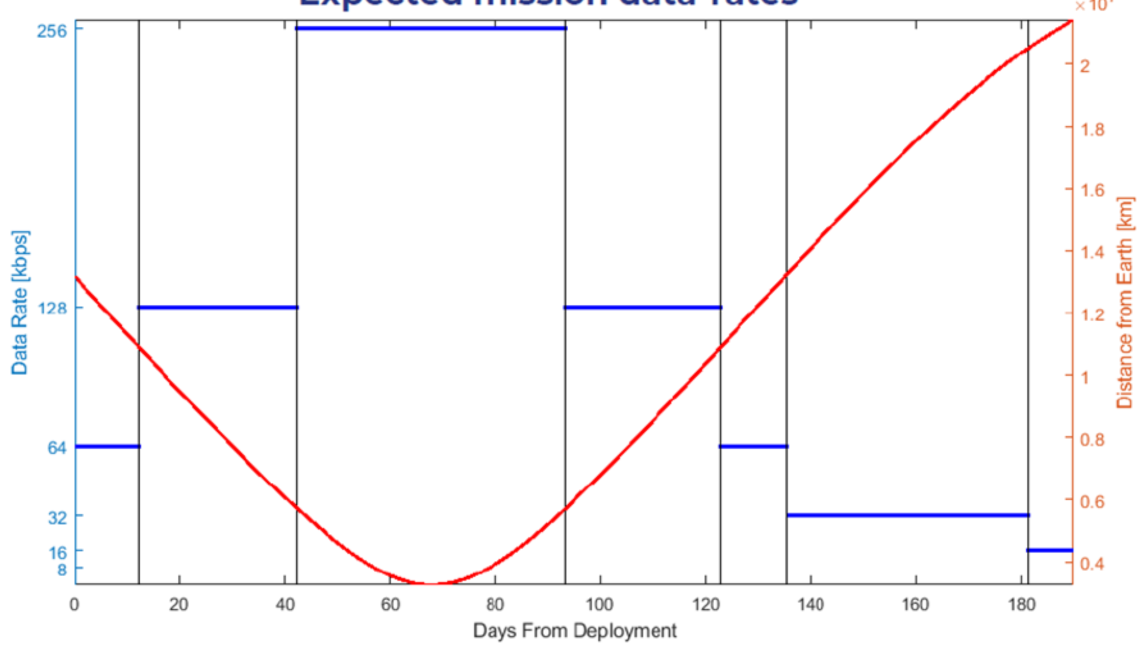
	DATA-RATE				
Data	16 kbps	32 kbps	64 kbps	128 kbps	256 kbps
LEIA [Full]	77	39	32	10	5
LEIA [Binned]	21	11	9	3	2
LUKE [Full]	19	10	9	3	2

Time to download 1 photo [min]

		Total number of photo during 1 COMM window		
Data-Rate [kbps]	Net Time for download [min]	LEIA [Full]	LEIA [binned]	LUKE [Full]
16	80	1.03	4.1	3.9
32	80	2.7	8.3	7.8
64	80	2.4	9.8	9.2
128	80	8.6	34.4	32.4
256	80	17.6	70.69	66

The data budget analyses lead to the estimation of the possible **number of pictures** expected during the comms windows

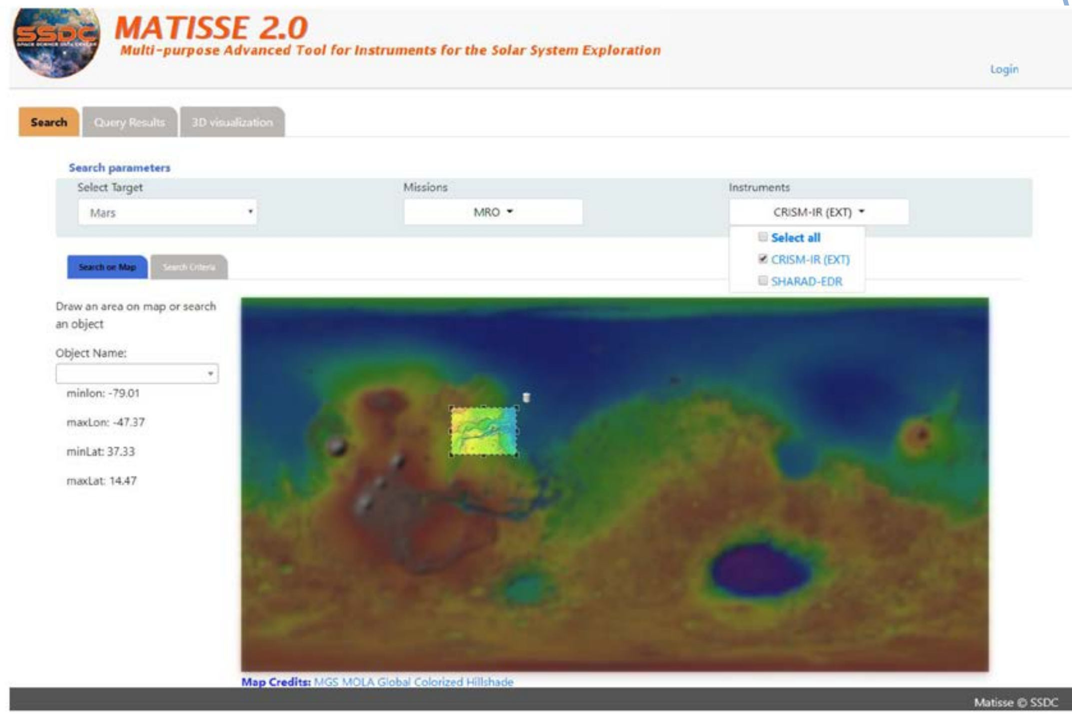
Expected mission data-rates



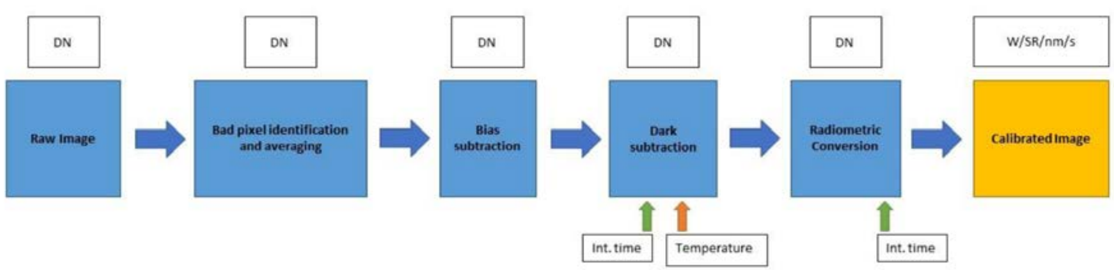
LCC data processing

- MATISSE is the ASI SSDC scientific webtool expressly dedicated to the search, visualization and analysis of data coming from planetary exploration missions

https://tools.ssdc.asi.it/Matisse



- Plan to use MATISSE, to manage LEIA and LUKE observations in an optimal way, by using both its data search and 3D data projection capabilities



- Robust image processing prepared for the **calibration procedure**

LICIACube activities in progress

Flight Segment

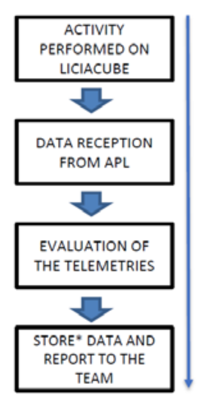
- Satellite in Cruise Phase (piggyback of DART) and in "off" status
- Temperature telemetries are nominal; periodic battery charging through DART successfully performed;
- Calibration of payloads (on ground) and data analysis are in progress

Ground Segment

- Connectivity test between the GS nodes periodically performed (second run) with success. Simulation of representative data set flow expected soon
- Ground Data System - GDS testing between LCC-MCC and DSN antennas completed
- The whole LICIACube GS chain process is ready to be testing adding the data download from raw to telemetry between LCC-MCC to LCC-SOC

Operations

- Data Products definition completed;
- Tools Software to process Data Product completed
- Operational Plan, Schedule, Timeline, Procedures prepared in first Issue.



N°	DATE	EVENT	STATUS
1	06/12/2021 (DOY 340)	BATTERY CHARGING	COMPLETED

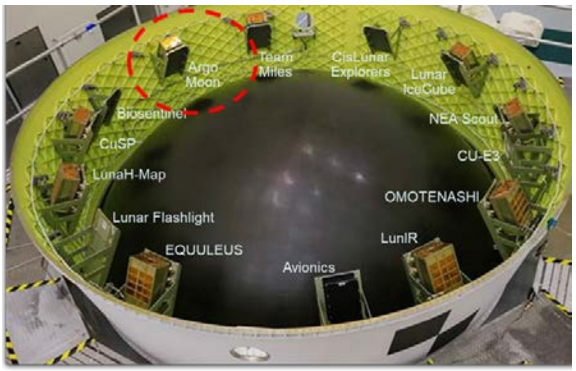
N°	DATE	EVENT	STATUS
2	29/12/2021 (DOY 363)	BATTERY CHARGING	COMPLETED

N°	DATE	EVENT	STATUS
3	17/02/2022 (DOY 47)	BATTERY CHARGING	COMPLETED

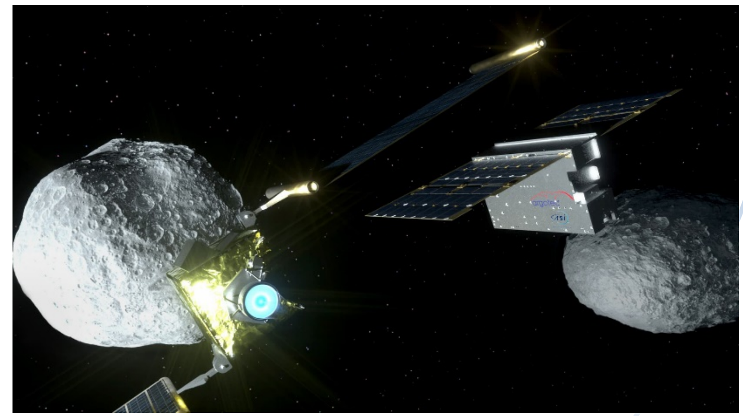
**NOTE : The data received are stored in a specific logbook maintained by the Argotec flight control team*

Conclusions

- Italian first cubesats in Quasi- and Deep Space, namely **ArgoMoon** and **LICIACube**, have been completely developed and they are now going to enter in Operational phase



August 19th 2021 Credits: NASA – Kennedy Space Centr



- The projects implementation and mission preparation allowed the building and training of a **large and skilled national team**, well prepared for similar future challenges
- **Small satellites**, as short-time, low-cost but highly-specialized elements, confirmed their potentialities as **powerful tool** to complement traditional missions.

  Considering the specific framework of these initiatives, they also benefit and promote **international cooperation** with partner Agencies.