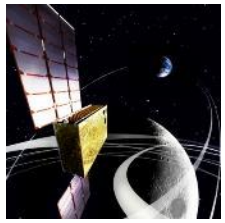


Overview of Japanese Lunar CubeSats OMOTENASHI & EQUULEUS

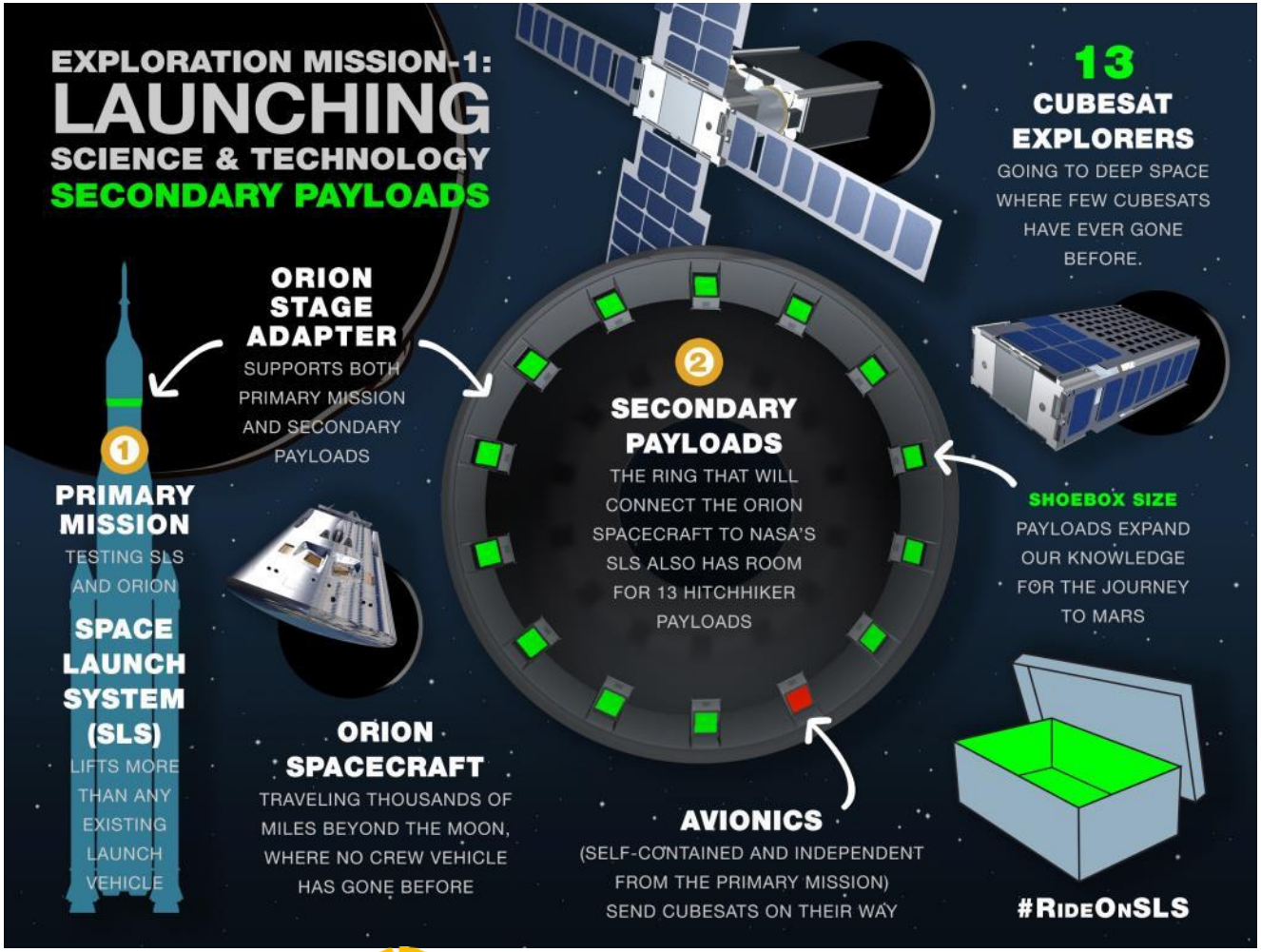
Onur Çelik[1], Tatsuaki Hashimoto[1], Ryu Funase[2], Yasuhiro Kawakatsu[1], Stefano Campagnola[1], Toshinori Ikenaga[3], OMOTENASHI[1, 2] & EQUULEUS[1, 2] team members

[1]Institute of Space and Astronautical Science (ISAS/JAXA)

[2]University of Tokyo

[3]Research and Development Directorate, JAXA

Introduction: NASA SLS EM-I



Credits: NASA

13 CubeSats were selected in Early 2016.

2 of those are EQUULEUS and OMOTENASHI from JAXA/UTokyo

"No harm" to main payload (Orion) policy.

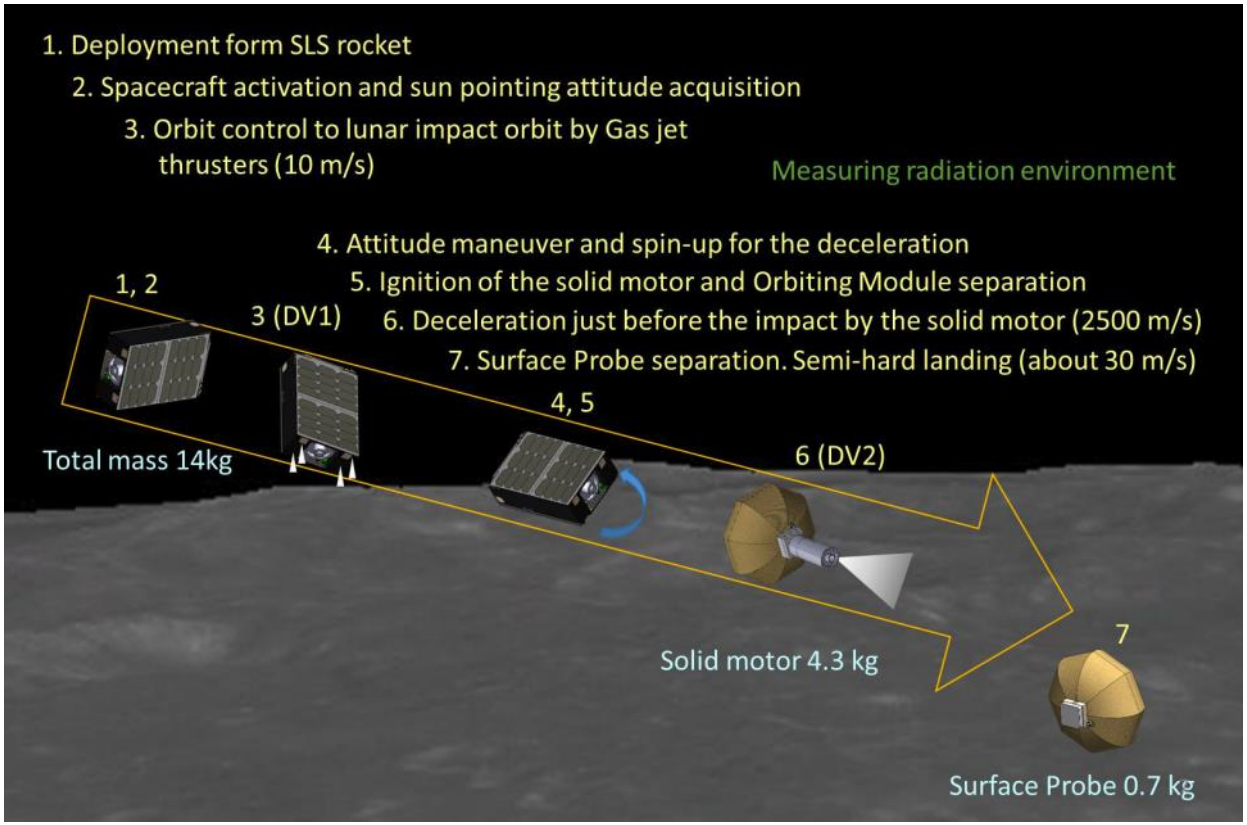
Current launch date: Late 2019

OMOTENASHI

- Outstanding MOon exploration TEchnologies demonstrated by Nano Semi-Hard Impactor
  - おもてなし (OMOTENASHI): spirit of selfless hospitality (dictionary definition)
  - Also main slogan of 2020 Tokyo Olympics
- World's smallest moon lander
  - A novel approach to landing: No initial orbit, straight to the surface after deployment.
  - 6U, Total mass = ~14 kg
- Fulfilling complimentary roles for large-scale manned and unmanned exploration missions by
  - Demonstrating necessary technologies for semi-hard landing
  - Measuring the radiation environment beyond LEO in accordance with Global Space Exploration Roadmap by International Space Exploration Coordination Group (ISECG).

OMOTENASHI: Mission Sequence

Credits: JAXA



Total mission duration: ~5 days

Total of 2 orbital maneuvers, dV1, dV2

Attitude spin maneuver before deceleration

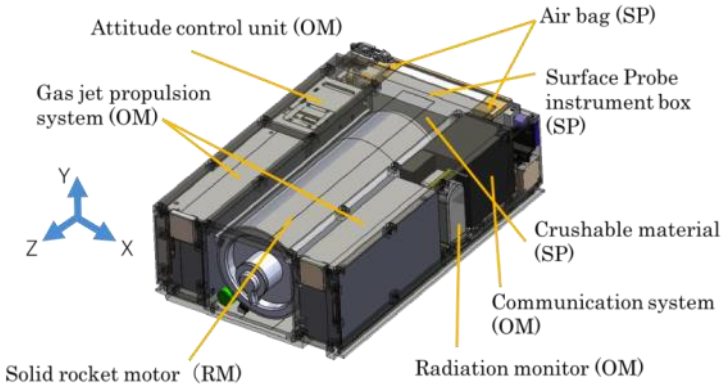
Deceleration until "some" (~100-200 m) altitude above the surface

Free fall to the surface with low vertical speed.

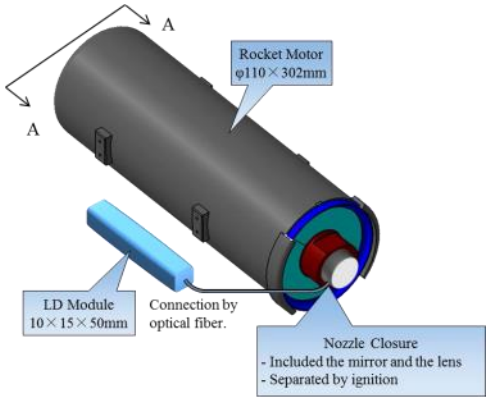
OMOTENASHI: Spacecraft configuration

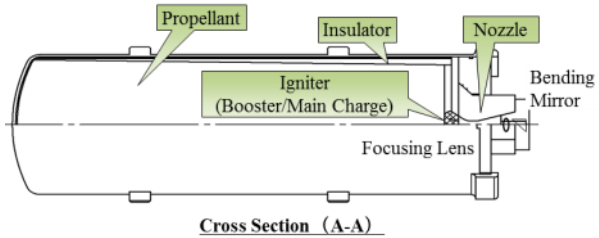
Total mass = 14 kg

Orbit Module: 8.5 kg (excl. RM and SP)
OM carries all spacecraft bus and payloads



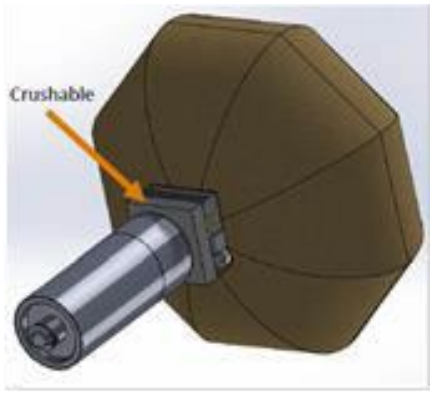
Retro Motor: 4.3 kg (excl. OM and SP)
RM is the solid motor that decelerates the CubeSat to the Lunar surface.





All Credits: JAXA

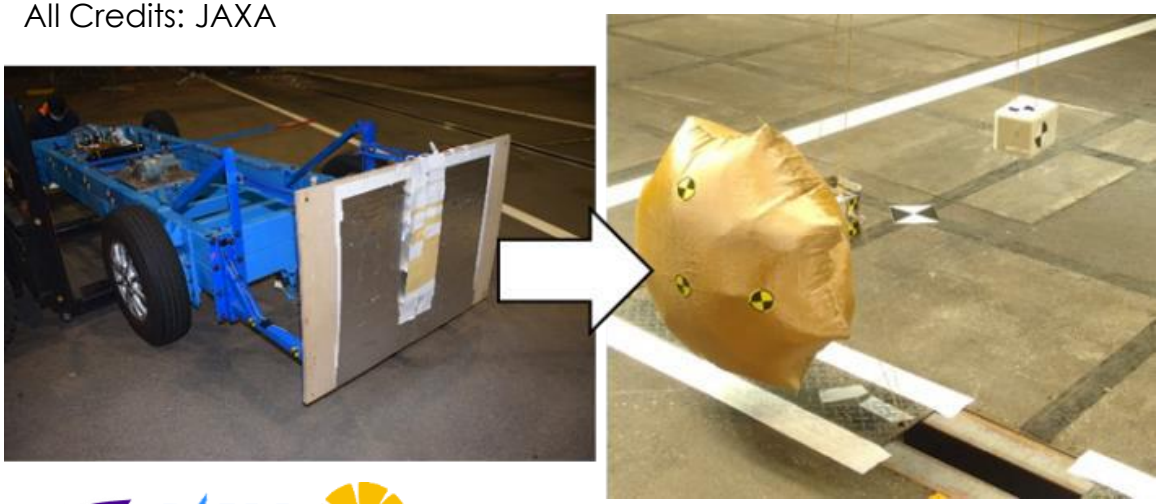
OMOTENASHI: Spacecraft configuration



Surface Probe: 0.7 kg

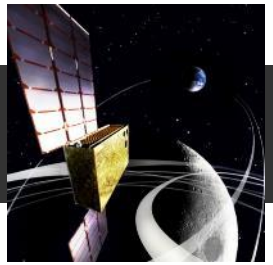
SP carries the landing structure and the transponder for communication (P-band), along with OBC and Power system (Li – 18Wh)

All Credits: JAXA



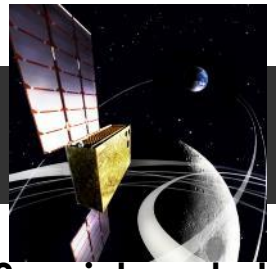
Crash tests in Japan Automobile Research Institute.

EQUULEUS



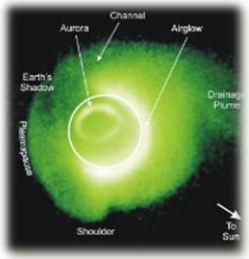
- EQUlibriUm Lunar-Earth point 6U Spacecraft
  - Also, means small horse (in Latin), one of the star constellations listed by Ptolemy
- World's smallest spacecraft to reach Earth-Moon L2 point
  - 6U, Total mass = ~14 kg
- Primary mission: Demonstration of the trajectory control techniques within the Sun-Earth-Moon region by a nano-spacecraft through the flight to the Earth-Moon Lagrange point L2 (EML2)
- Science missions:
  - Imaging observation of the Earth's plasmasphere
  - Measurement of dust environment in cis-lunar region
  - Lunar impact flash observation (optional)

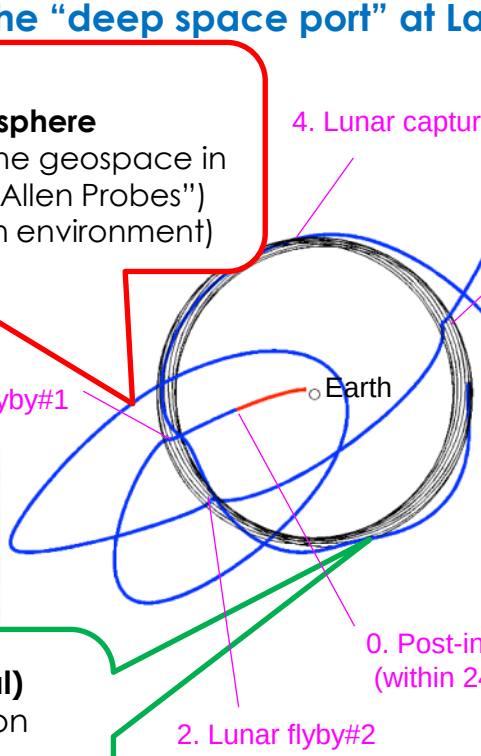
EQUULEUS: Mission overview



The spacecraft will **fly to a libration orbit around the Earth-Moon L2 point and demonstrate trajectory guidance, navigation and control techniques within the Sun-Earth-Moon region** for the first time by a nano-spacecraft. The mission will also **contribute to the future human exploration scenario** by **understanding the radiation environment in the geospace and characterizing the flux of impacting meteors at the far side of the moon**, and **demonstrating the future deep space exploration scenario using the "deep space port" at Lagrange points**.

Mission objective #1
Imaging the Earth's plasmasphere
(Comprehensive understanding of the geospace in cooperation with "ERG" and "Van Allen Probes")
(Understanding the Earth's radiation environment)





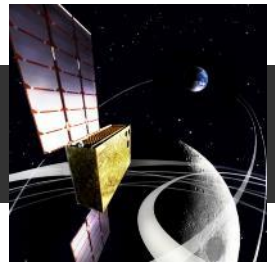
Mission objective #2
Trajectory control within Sun-Earth-Moon region
(Orbit insertion into a libration orbit around the Earth-Moon L2 point using Sun-Earth weak stability regions, for the demonstration of the future exploration mission scenario using the "deep space port")

Mission objective #3 (optional)
- Lunar impact flash observation
- Dust detection at EML2
- Flyby exploration of an asteroid or comet starting from EML2

* The spacecraft will be disposed to heliocentric orbit after mission completion.

All Credits: UTokyo/JAXA

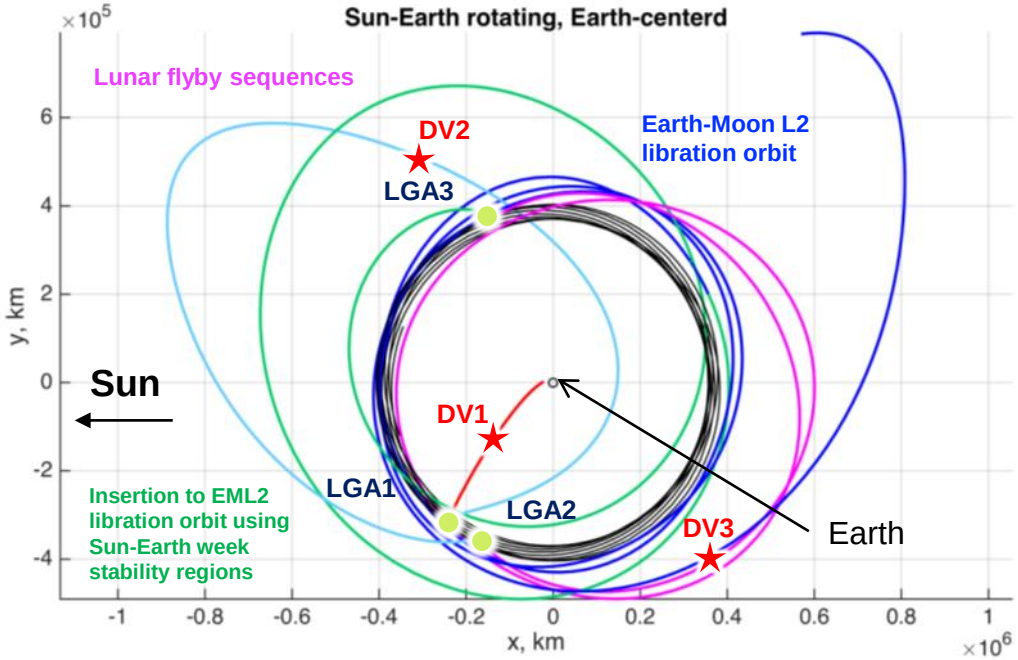
EQUULEUS: Trajectory

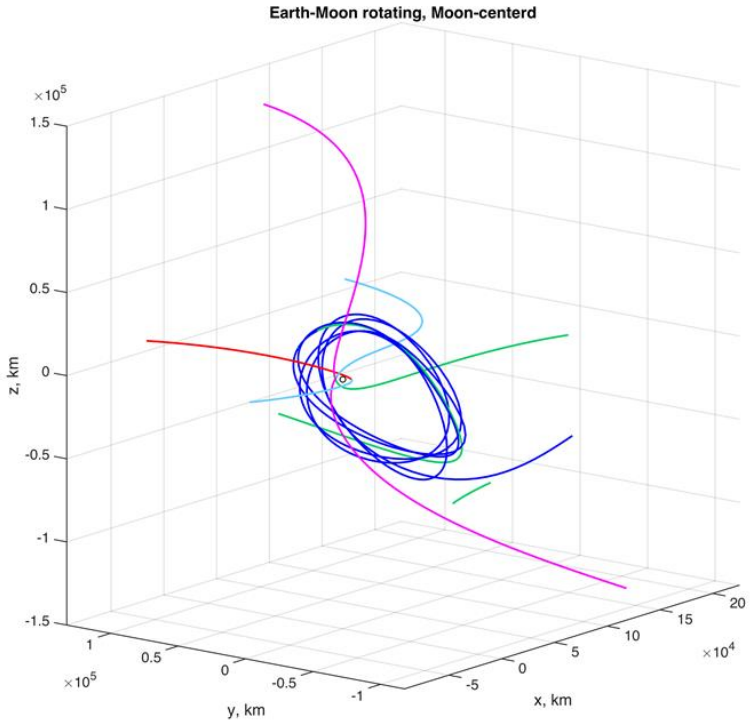


1. Launch and Early Orbit Phase (LEOP) : ~1 week
2. Lunar flyby sequence phase : 1~3 months (full success)
3. Insertion to EML2 libration orbit phase : 5 months
4. Observation (from EML2) phase : > 1 month
5. Departure from EML2 (End of mission)

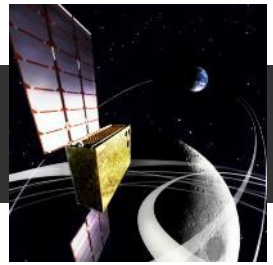
Simulations are performed for Launch Date: July 2018

EQUULEUS will perform **~6-8 months flight to EML2** with DV of **as low as ~10m/s.**



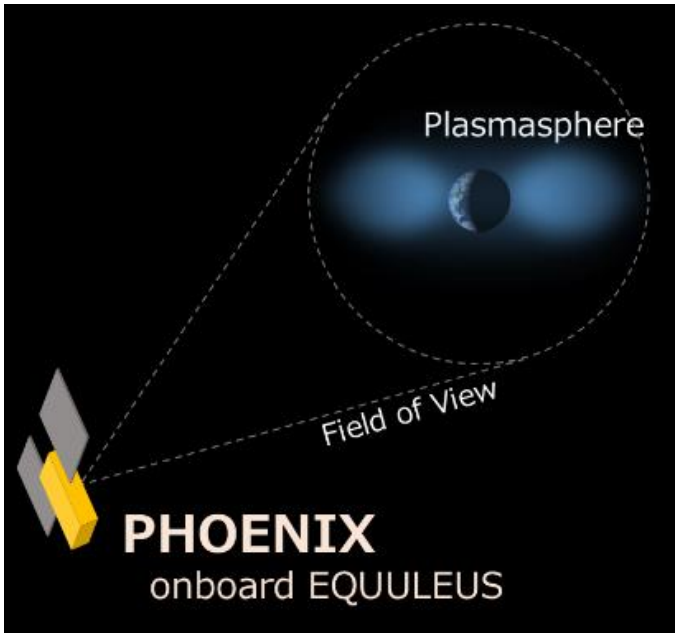


All Credits: UTokyo/JAXA



EQUULEUS: Science Goal #1

Imaging observation of the Earth's plasmasphere in UV band, enhancing results of ERG and other magnetospheric probes.



Detector (MCP)

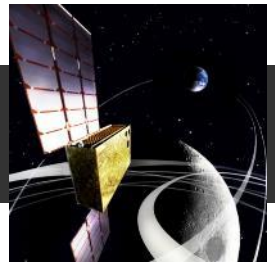
Metal thin film filter

Mechanical shutter

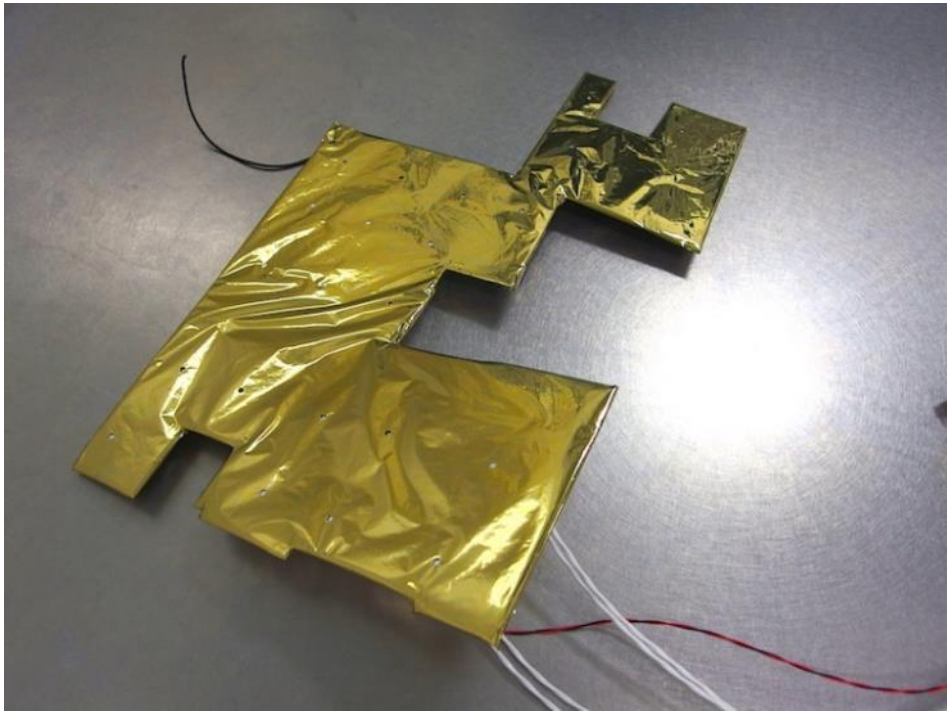
Primary mirror (multilayer film optimized for He+(30.4nm)

All Credits: UTokyo/JAXA

EQUULEUS: Science Goal #2

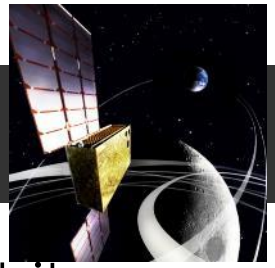


Measurement of dust environment in cis-lunar region along the trajectory



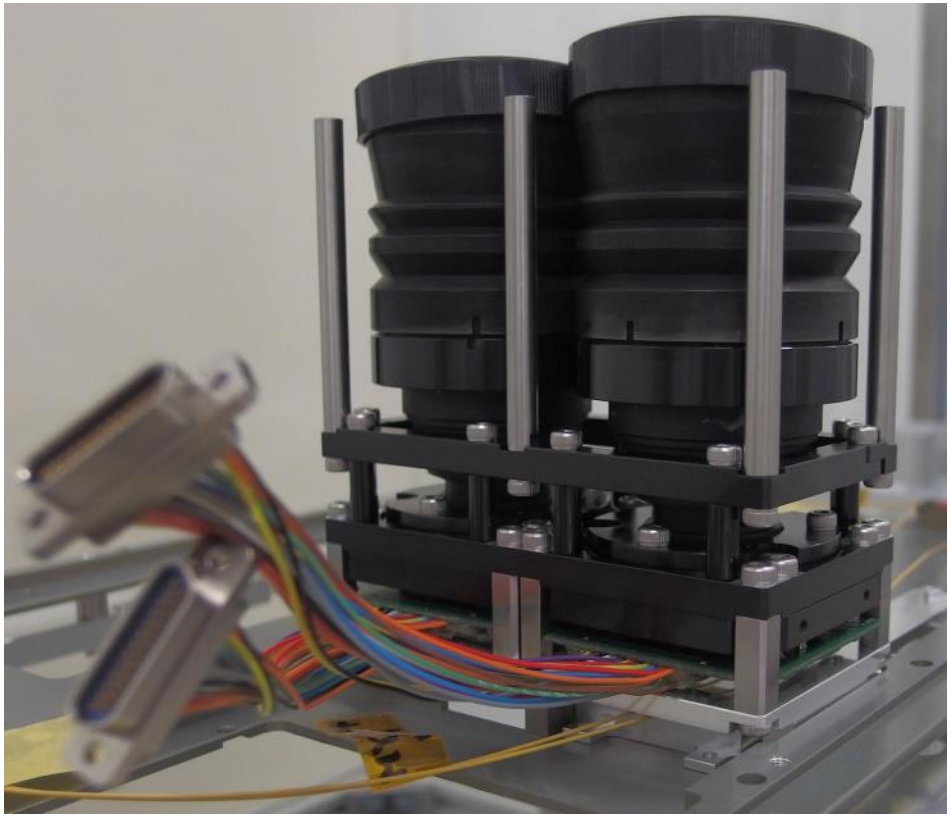
Dust impact sensors installed within spacecraft thermal blanket (MLI)

Credits: UTokyo/JAXA



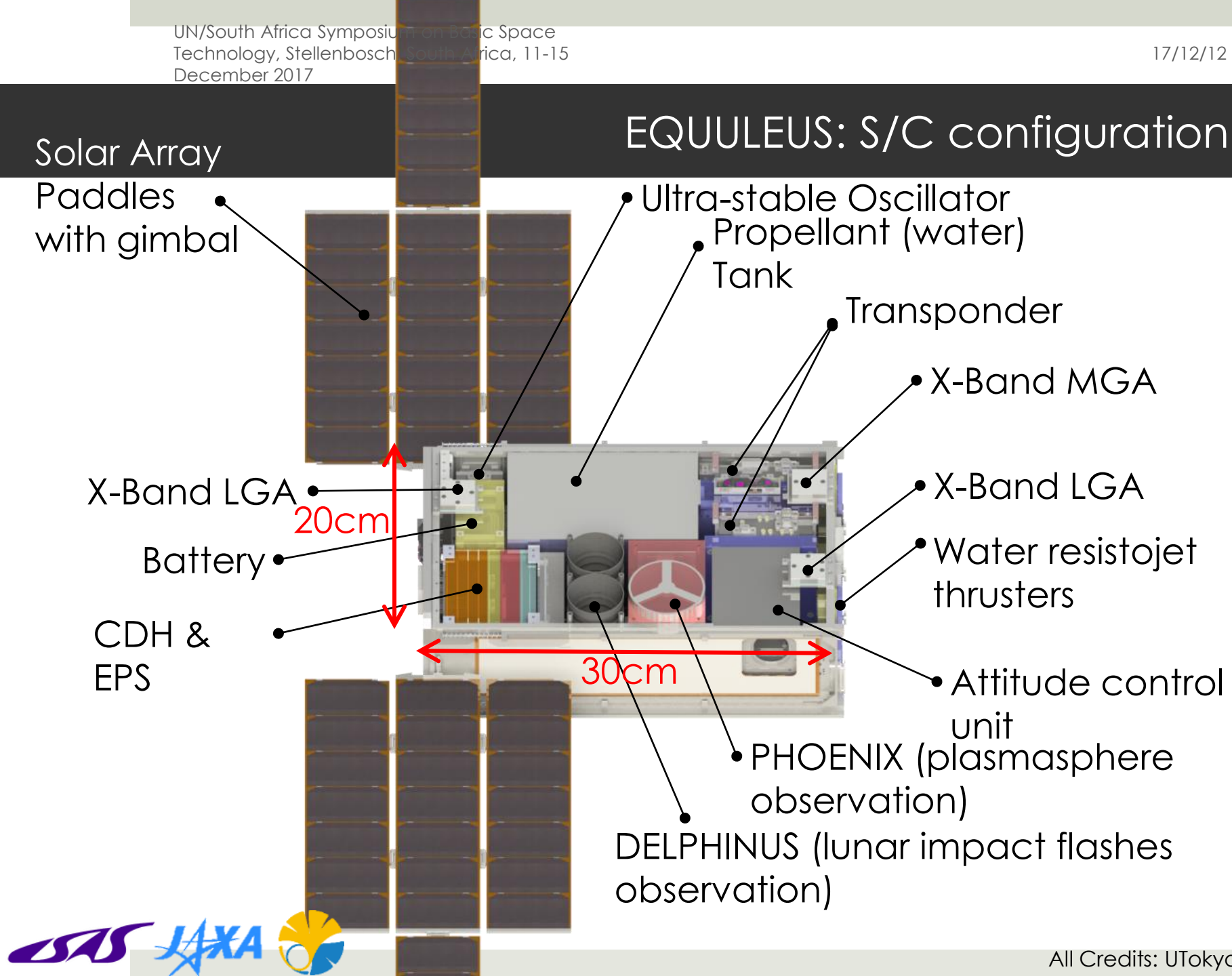
EQUULEUS: Science Goal #3

Lunar impact flashes observation from EML2 Halo orbit
For the first time !



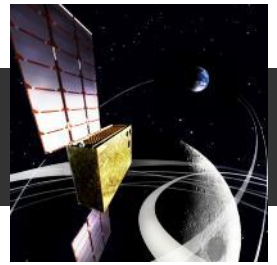
Credits: UTokyo/JAXA

EQUULEUS: S/C configuration



All Credits: UTokyo

Highlights



- OMOTENASHI and EQUULEUS are selected two of 13 CubeSats as to be secondary payload to NASA's EM-1 (Orion) mission.
- They will be world's firsts in several aspects
  - World's smallest moon lander (OMOTENASHI)
  - World's first small spacecraft to reach EML2 (EQUULEUS)
- These CubeSats pave the way for future deep space CubeSats, as well as cargo vehicles to cis-lunar region, by demonstrating novel trajectory control techniques with limited delta-V.
- These CubeSats also do necessary science for future manned/unmanned lunar exploration
- Both currently in testing phase
  - Trajectory design still continues.
- Current launch date is Late 2019
  - Initially was mid-2018, may delay further.

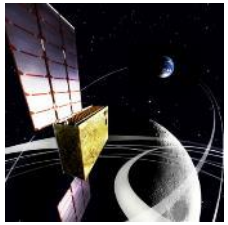
Thank you !

Special thanks to Daniel, Yukiko and local organisers for the support !

Follow the projects on:

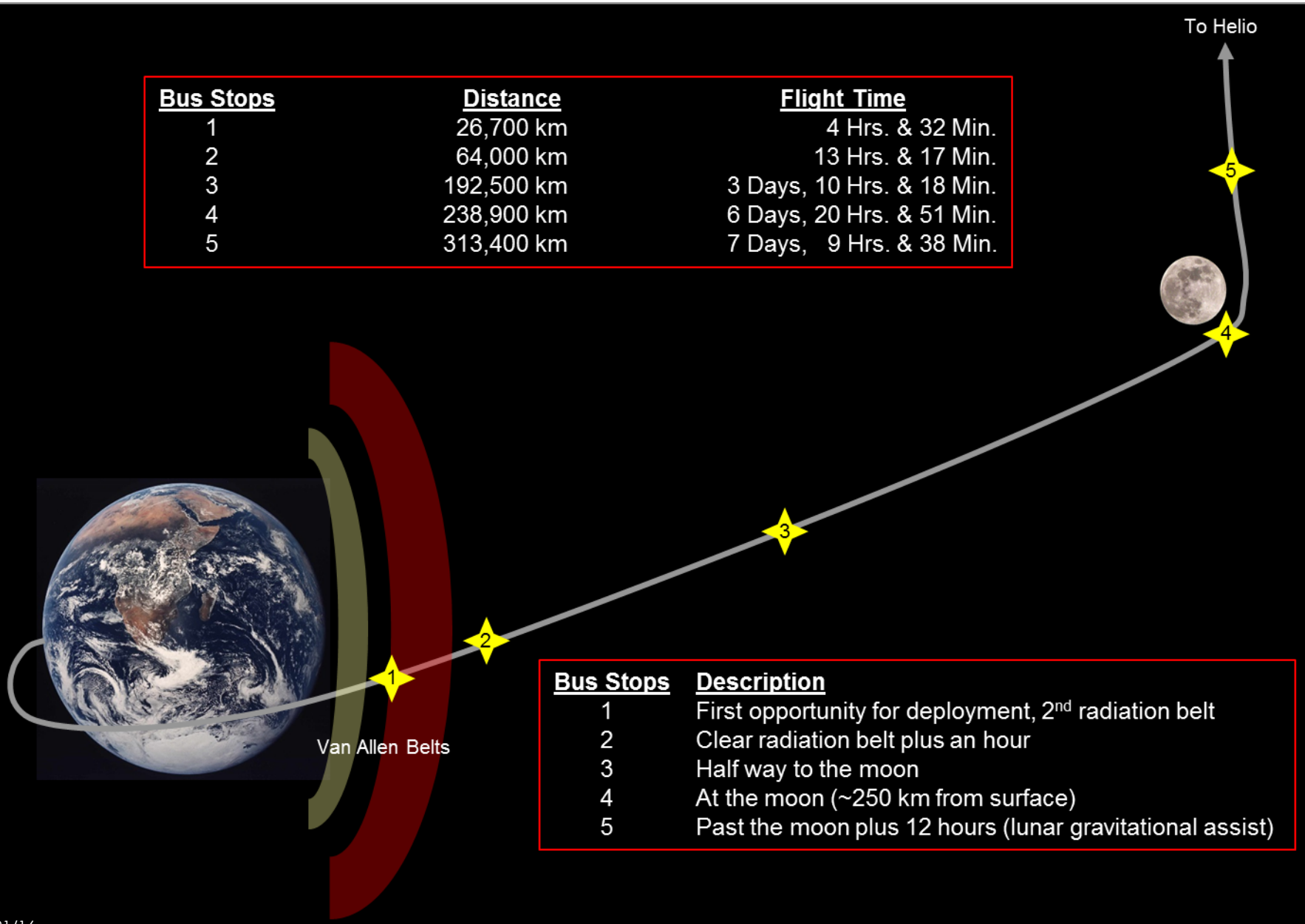
Website: http://www.isas.jaxa.jp/home/omotenashi/index.html

Twitter: @OMOTENASHI_JAXA

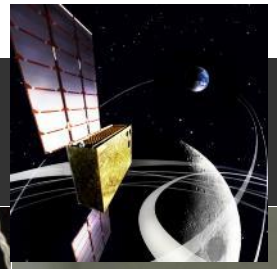


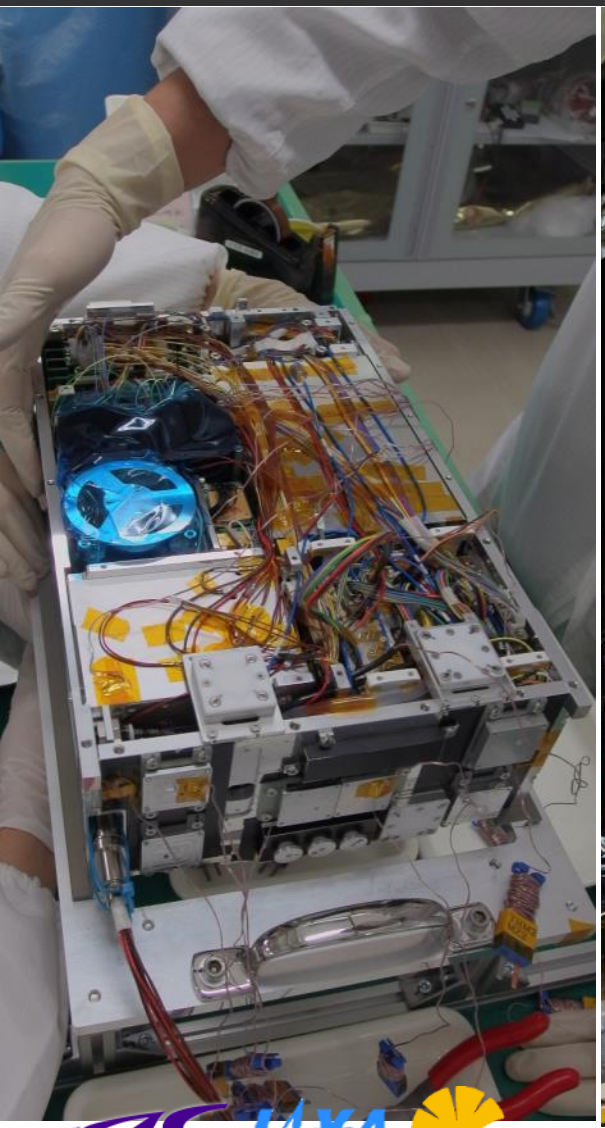
Website: http://issl.space.t.u-tokyo.ac.jp/equuleus/en/

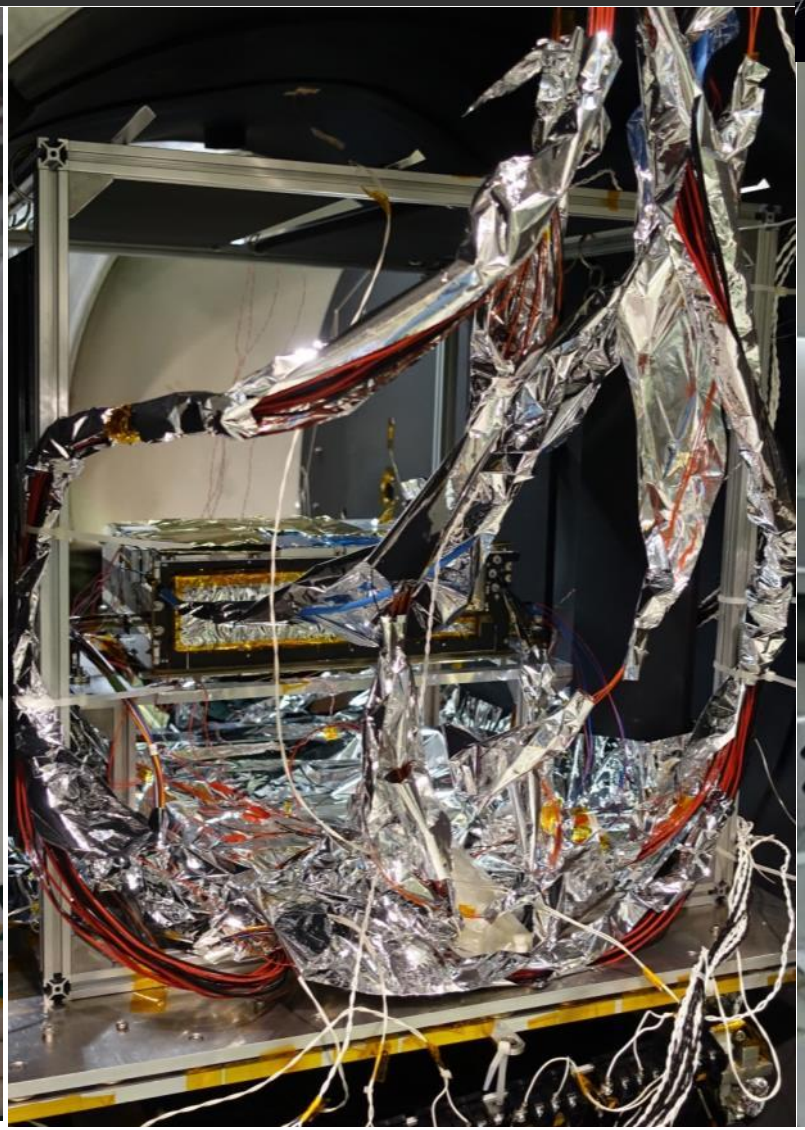
Twitter: @EQUULEUS_en


To Helio
Bus Stops | Distance | Flight Time
1 | 26,700 km | 4 Hrs. & 32 Min.
2 | 64,000 km | 13 Hrs. & 17 Min.
3 | 192,500 km | 3 Days, 10 Hrs. & 18 Min.
4 | 238,900 km | 6 Days, 20 Hrs. & 51 Min.
5 | 313,400 km | 7 Days, 9 Hrs. & 38 Min.
1
2
3
4
5
Van Allen Belts
Bus Stops | Description
1 | First opportunity for deployment, 2nd radiation belt
2 | Clear radiation belt plus an hour
3 | Half way to the moon
4 | At the moon (~250 km from surface)
5 | Past the moon plus 12 hours (lunar gravitational assist)

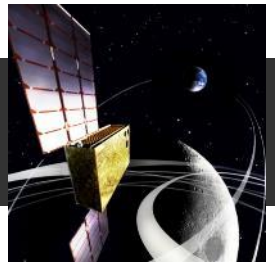
EQUULEUS: Current status





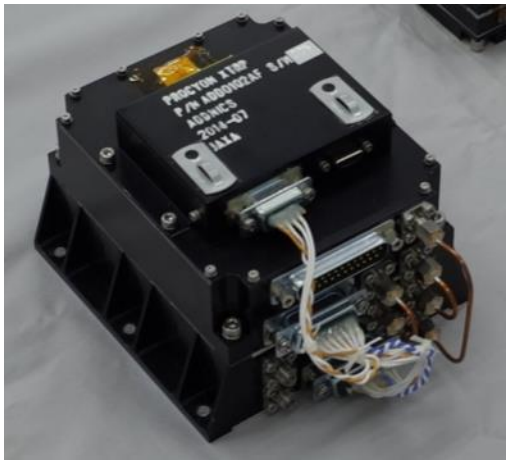


EQUULEUS: Advancements



- Miniaturization of the deep space bus (e.g. deep space communication transponder) into the CubeSat form factor

XTRP demonstrated in PROCYON (2014)



*XTRP: X-band Transponder

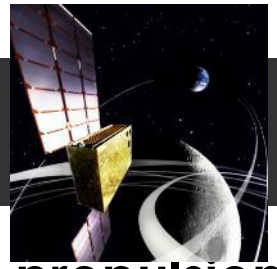
* Miniaturization
* Modularization
* Reduction of RF output
* Reduction of power consumption

XTRP being developed for CubeSat (EQUULEUS)

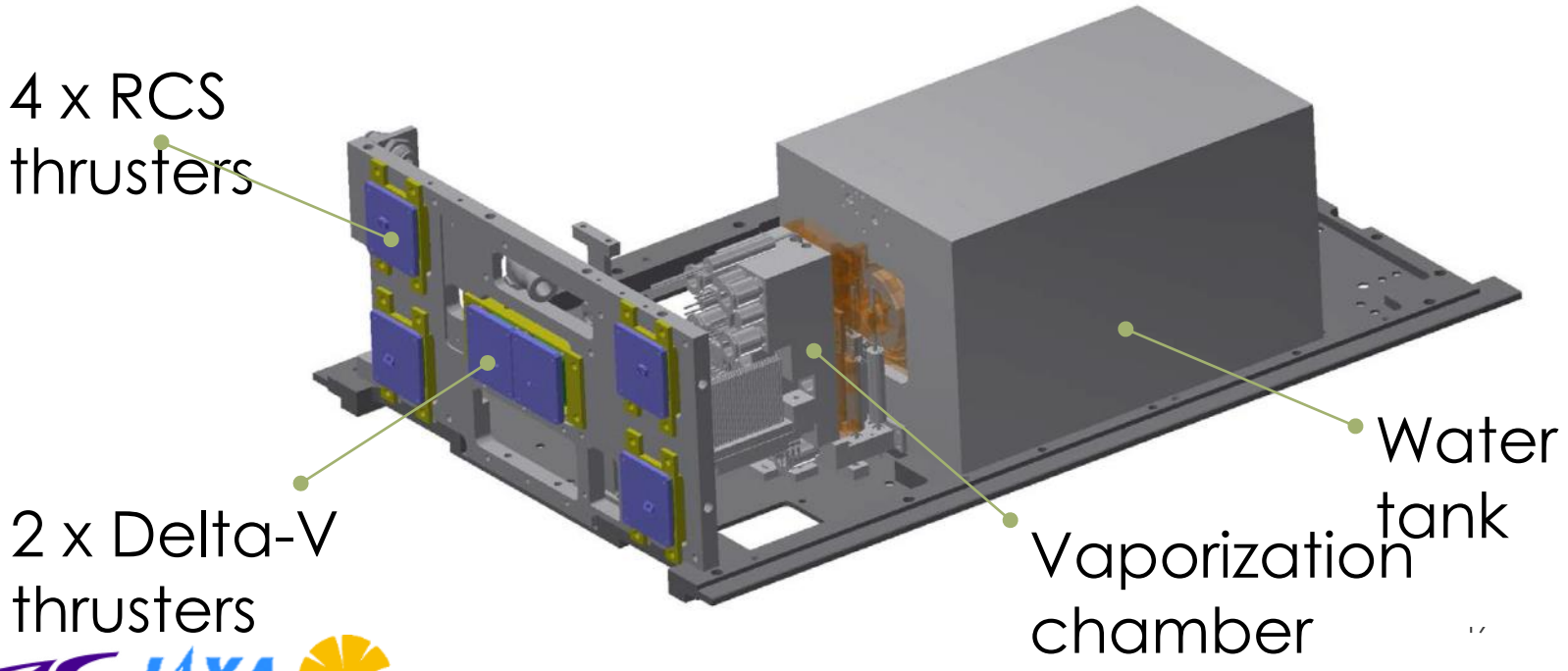
Digital Processing Module &Rx Module

Power Amplifier & XTx Module

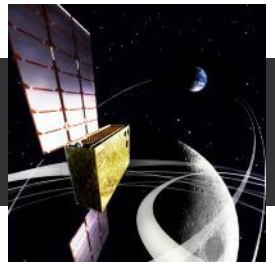
EQUULEUS: Advancements

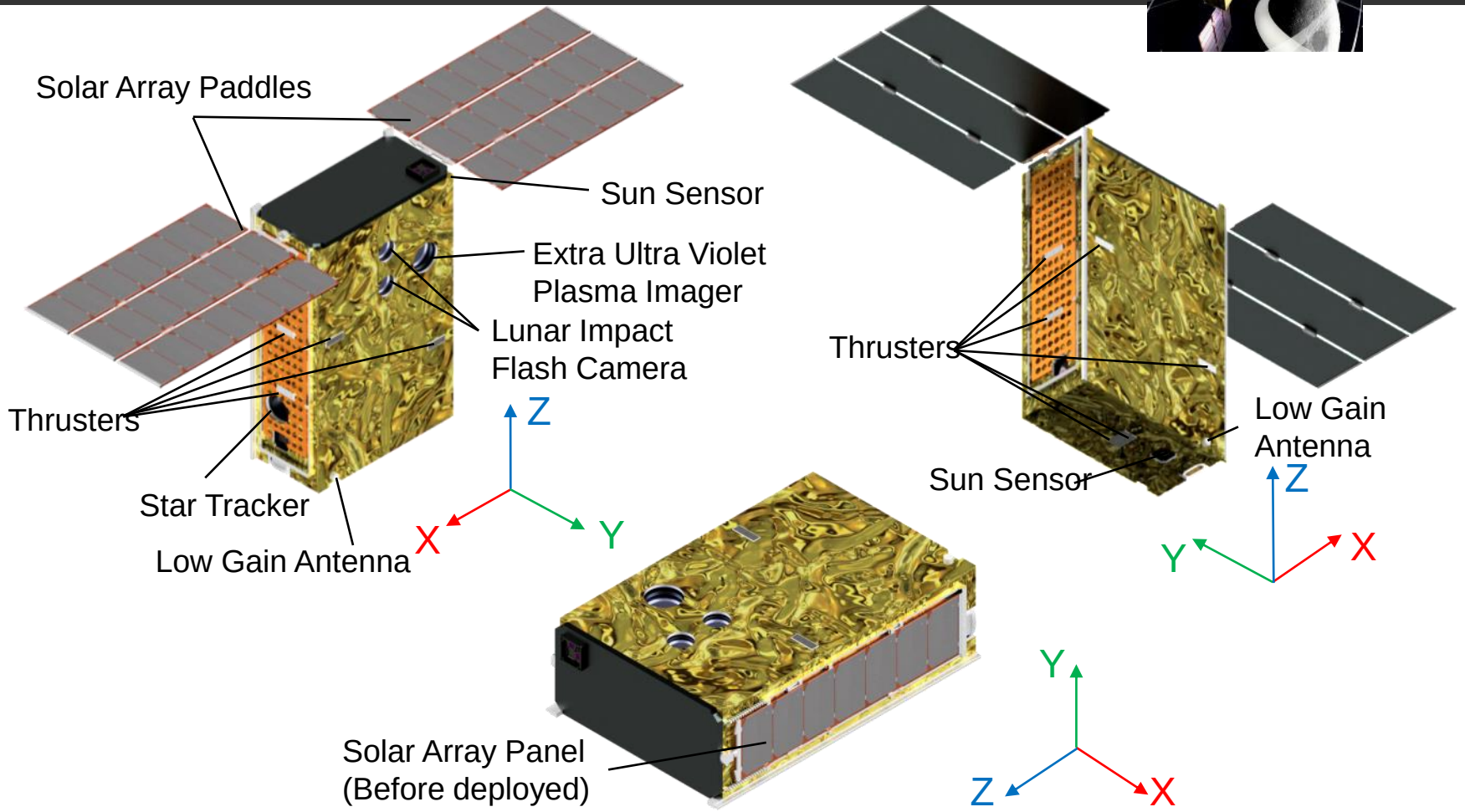


- Development of the new resistojet (warm gas) **propulsion system using water** as the propellant.
  - Water is **perfectly safe, non-toxic propellant**, which is advantageous when we consider piggyback launch.
    - Isp = 70 sec, 2+4 uN, total delta-V ~80 m/s.
  - Future in-situ space resource utilization age



EQUULEUS: S/C Overview





EQUULEUS has fundamental bus systems for deep space missions within 6U CubeSat (deep space communication, power, thermal control, attitude control, propulsion).