ORIGAMI PROJECT

On-orbit Demonstration of **Innovative Multifunctional Membrane Structure** for Ultra-lightweight Solar Arrays and Array Antennas by 3U CubeSat **OrigamiSat-1**

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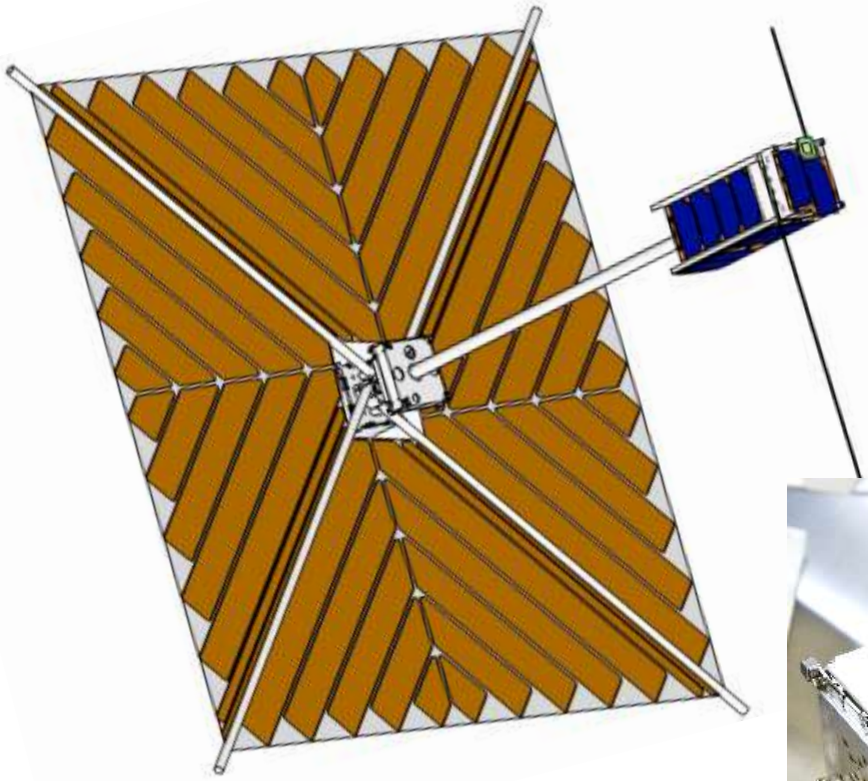
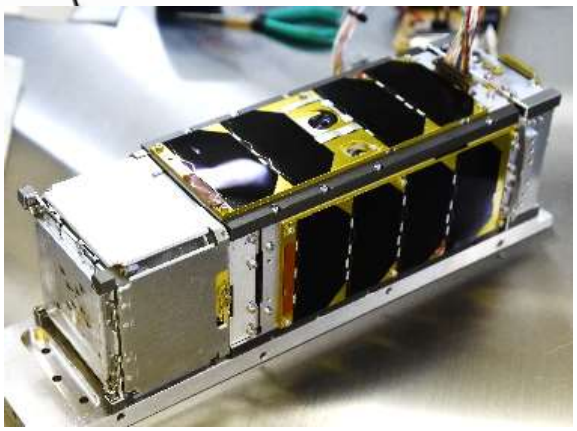
T. Kuratomi, Y. Shimoda, N. Hidaka, and K. Watanabe
WEL Research, Co., Ltd., Japan





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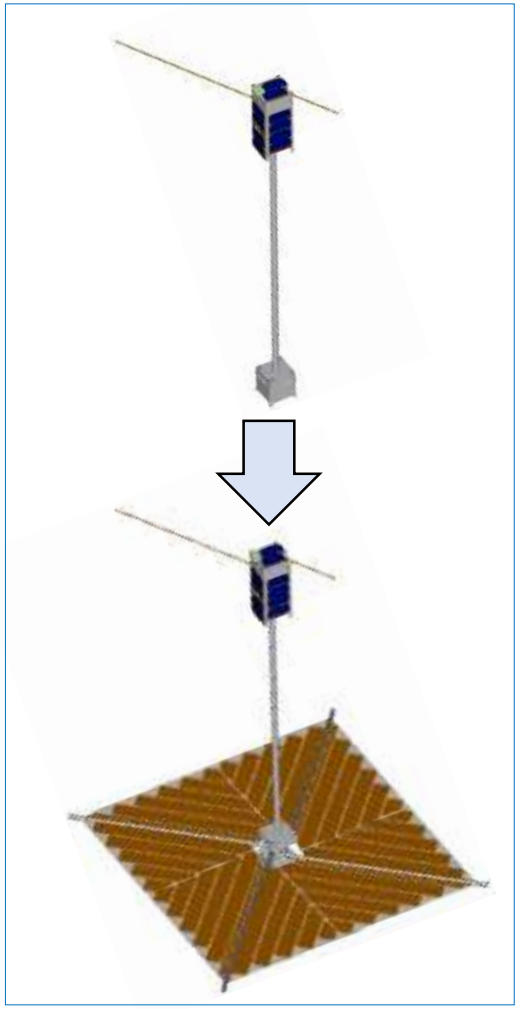

Applications of multifunctional membrane

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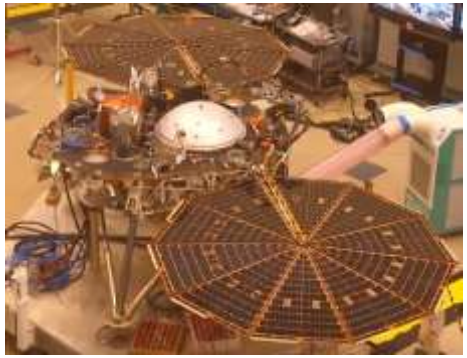
Further mass efficient solar arrays

ROSA (NASA) ~120 W/kg

UltraFlex (Northrop Grumman) 150 W/kg



TMSAP (JAXA) 150W/kg

→ Membrane arrays will achieve over **200W/kg**

Array Antennas (Active patch / Reflectarray)

ICEYE-X1

70kg satellite
~1.6m^2

©ICEYE

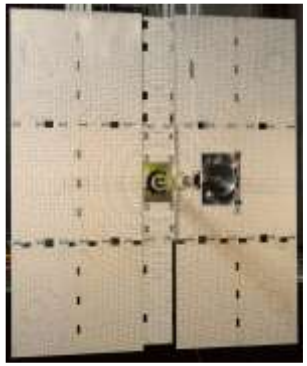
MarCO (NASA JPL)

13kg satellite, ~0.2m^2

©NASA

OMERA (NASA JPL)

6U CubeSat, ~1m^2



(Sauder, et al., 2019)

→ Antennas made of membrane

Major problems of multifunctional membrane

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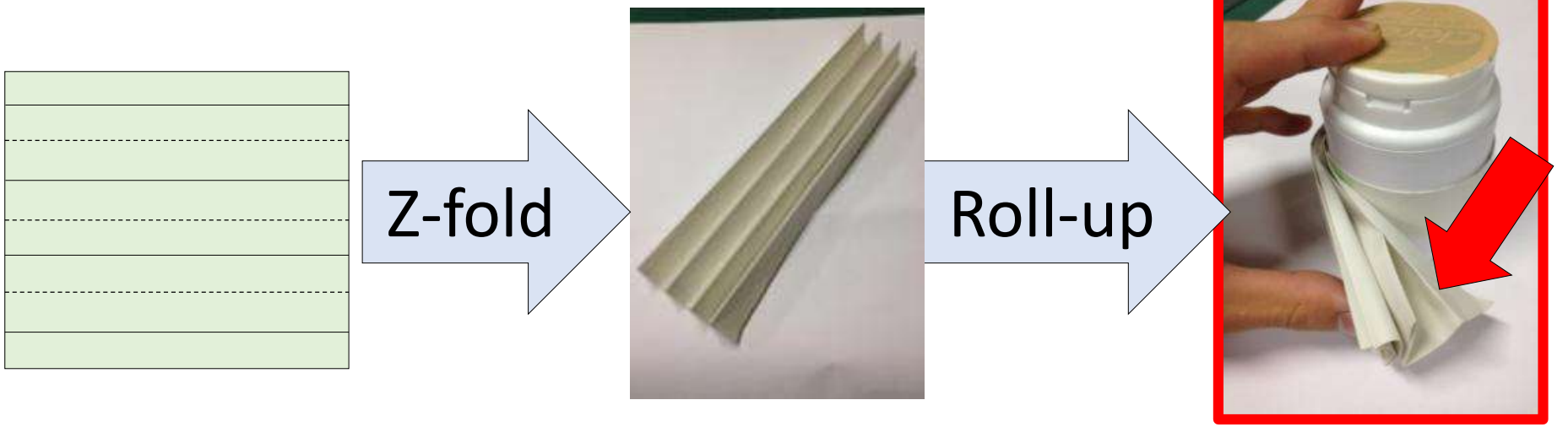
1) Difficulty of compact storage because of thickness effect.

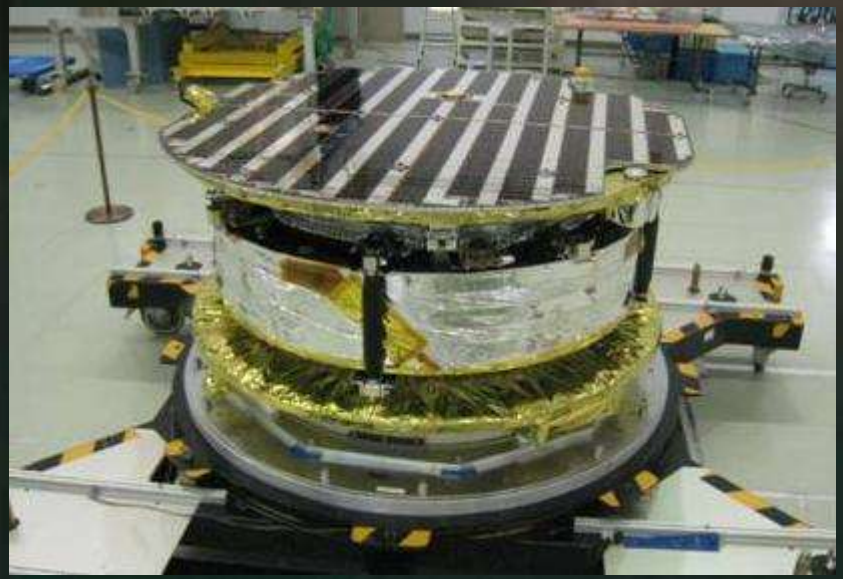


2) Reliable deployment only using small actuators.

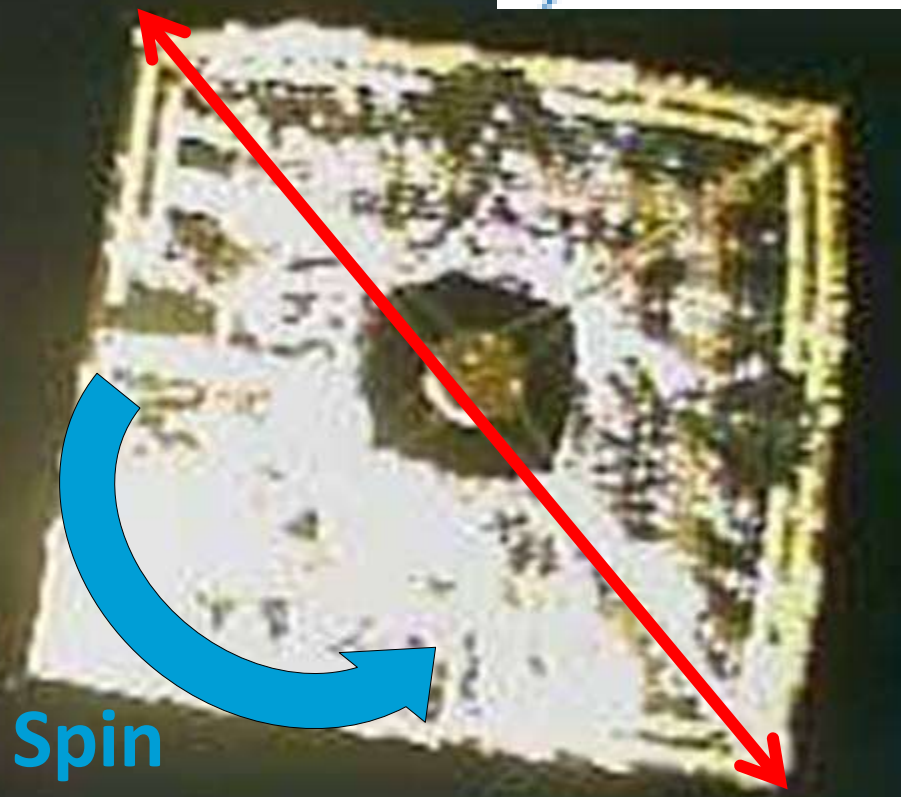
Deep Space Solar Sail Demonstrator

IKAROS

(2010)



20m

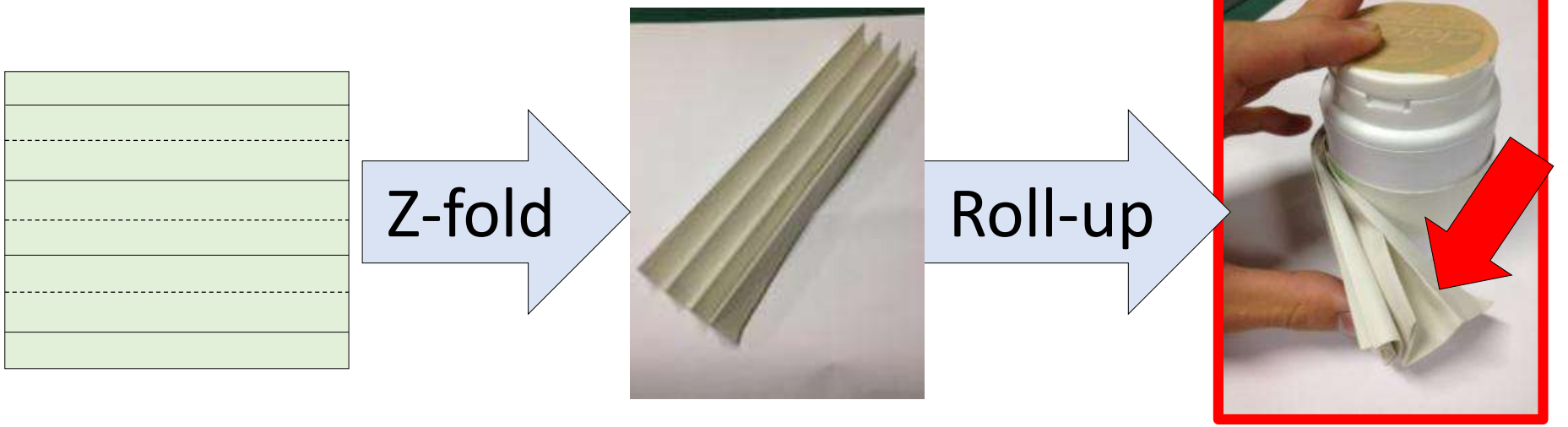


Spin

Major problems of multifunctional membrane

ORIGAMI PROJECT

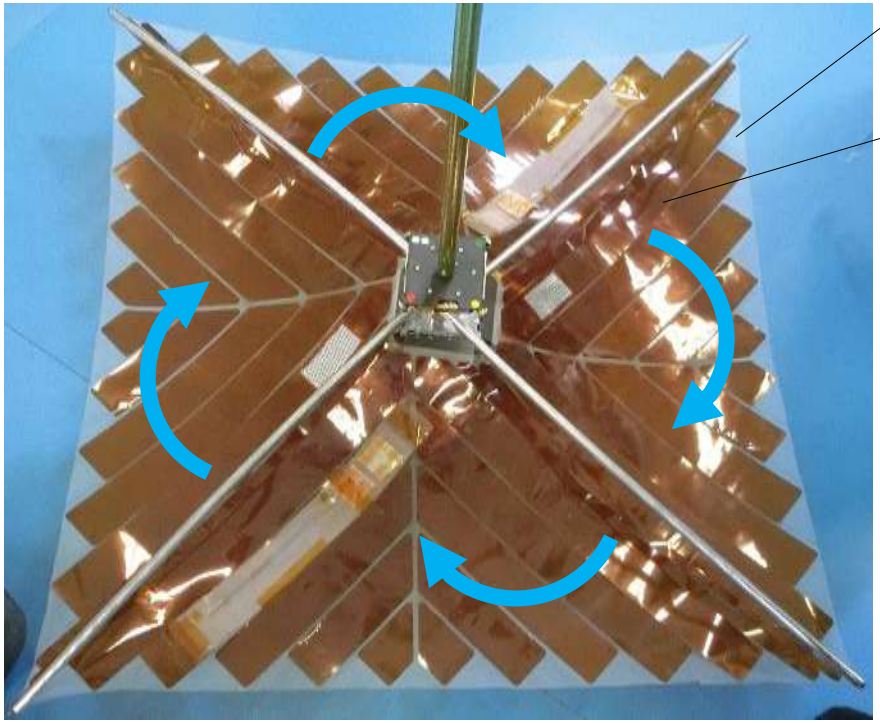
1) Difficulty of compact storage because of thickness effect.



2) Reliable deployment only using small actuators.

[Mission 1] Deployment of multi-functional membrane **EM model**

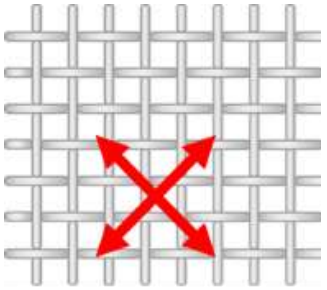
ORIGAMI PROJECT

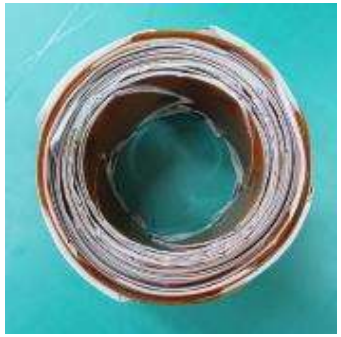


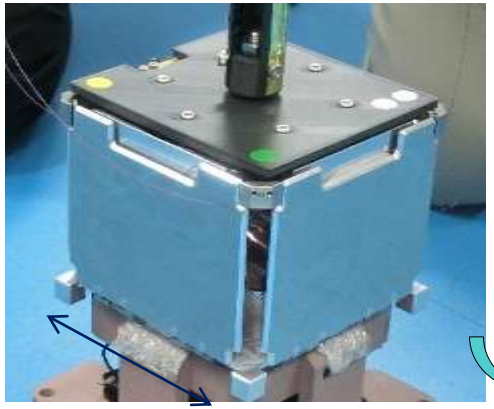
82μm-thick Polyester plain-woven fabric

75μm-thick Polyimide film (Dummy for thin-film solar cells etc.)

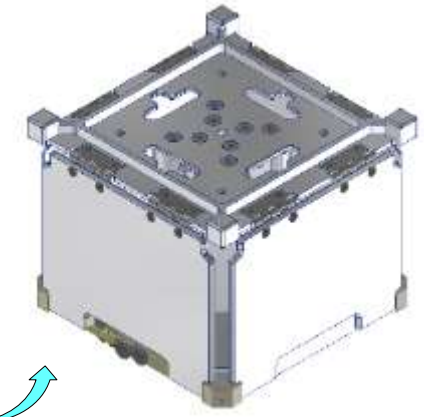
1. Plain-woven textile



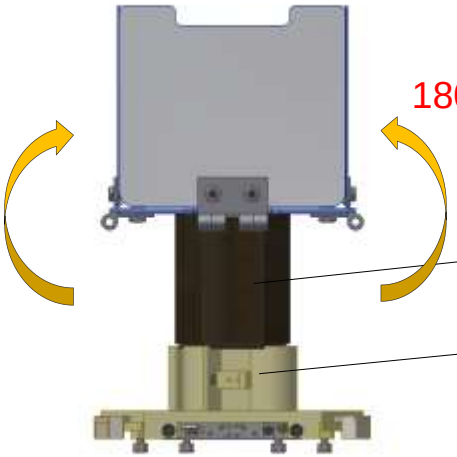




100mm



Flipped



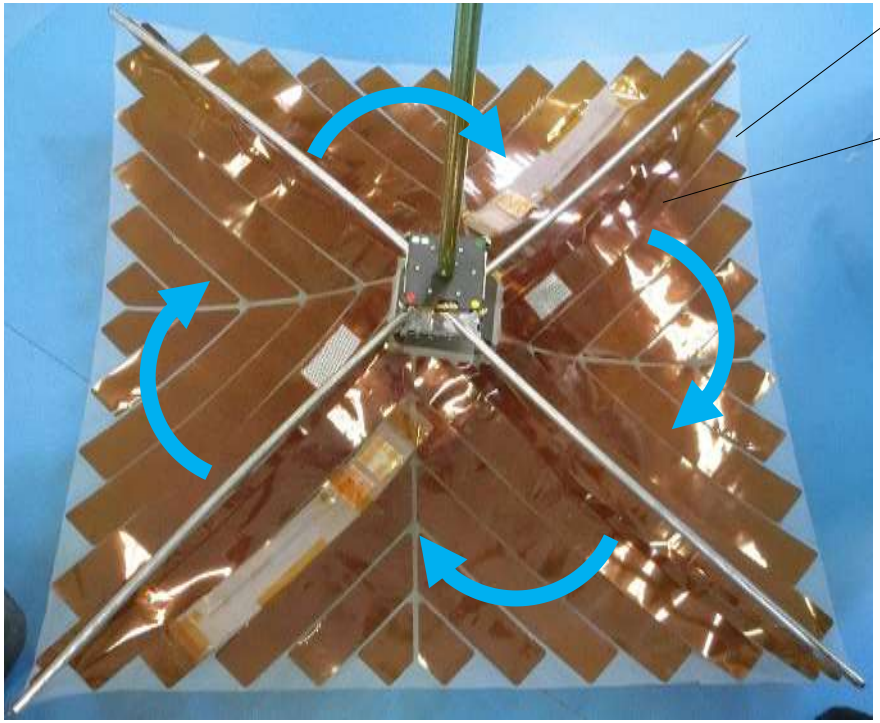
180 deg deployment

Hub for membrane

Hub for CFRP booms

[Mission 1] Deployment of multi-functional membrane **EM model**

ORIGAMI PROJECT

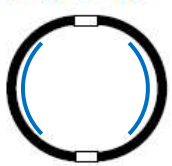


82μm-thick Polyester plain-woven fabric

75μm-thick Polyimide film (Dummy for thin-film solar cells etc.)

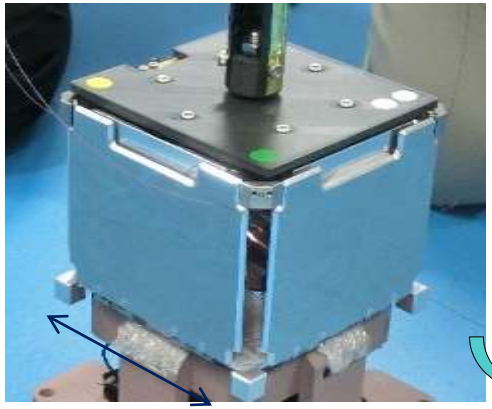
2. Hybrid boom

Deployed



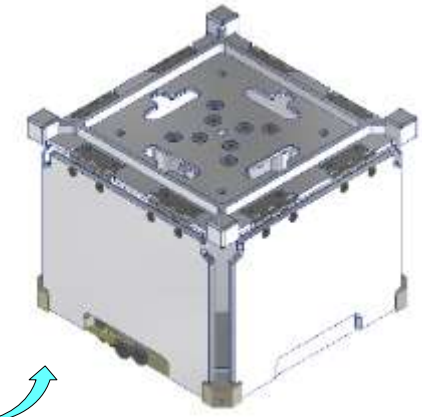
Stored

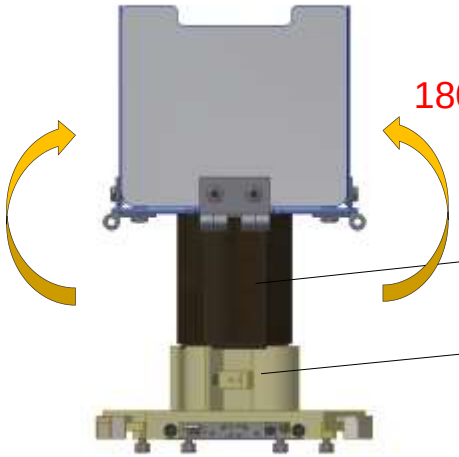
Tubular CFRP boom
(2 metallic convex tapes are installed)



100mm

Flipped





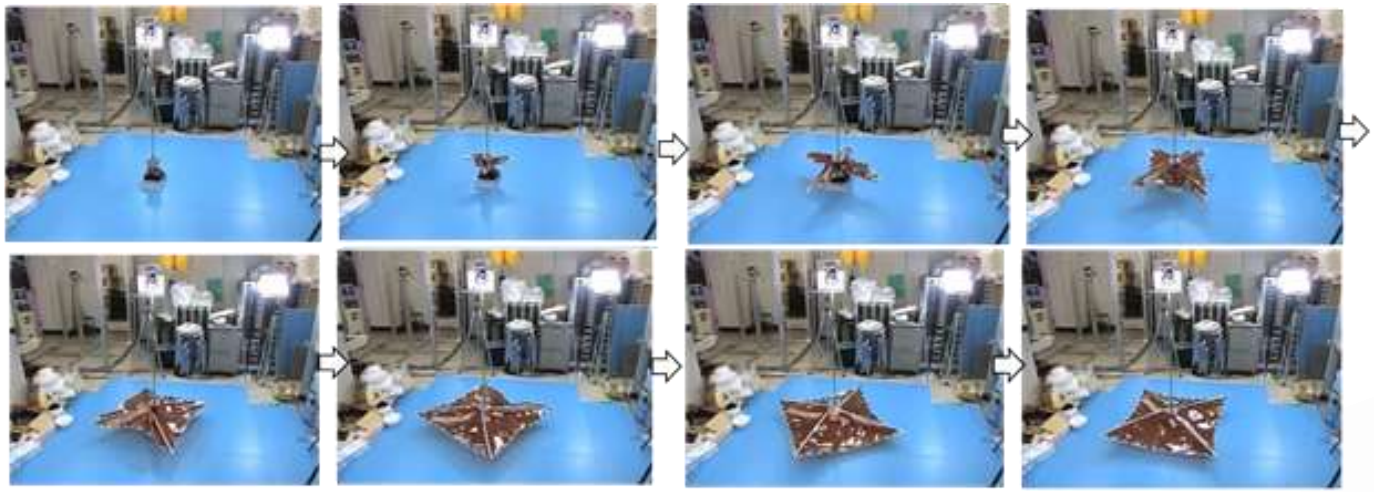
180 deg deployment

Hub for membrane

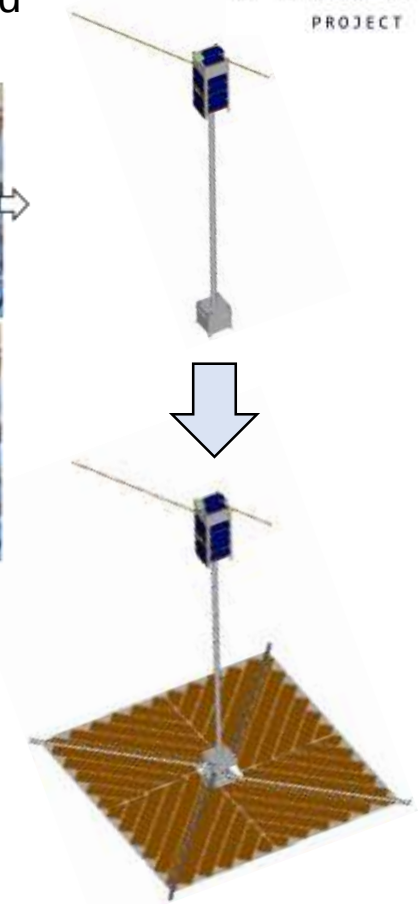
Hub for CFRP booms

Ground deployment test with extendable mast

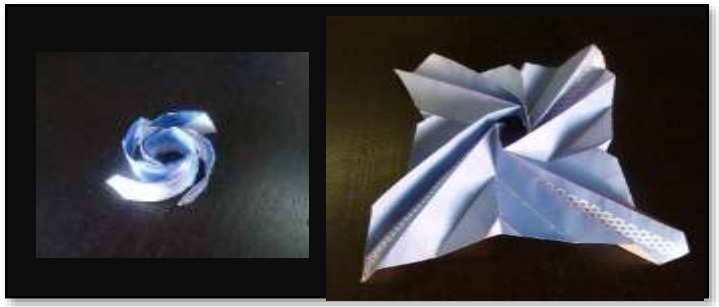
- Four membrane corners (four membrane boom tips) are suspended from ceiling

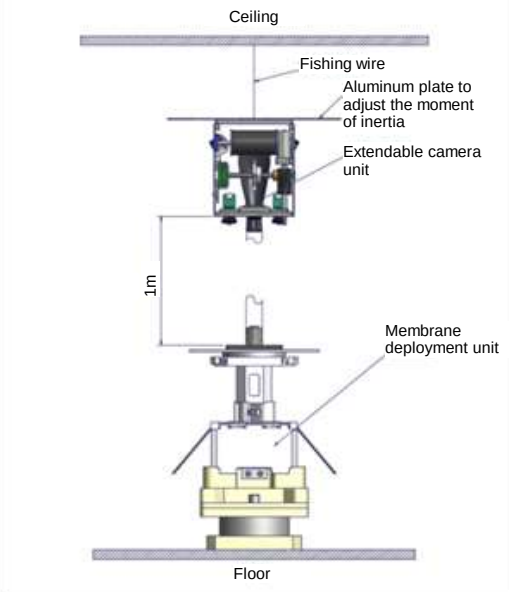


(Apr. 2017, at Hiroshi Furuya Lab, Tokyo Tech)



Ref: Folding pattern demonstration using Origami (Flasher pattern)





Deployment test under microgravity (x0.7 scale model)

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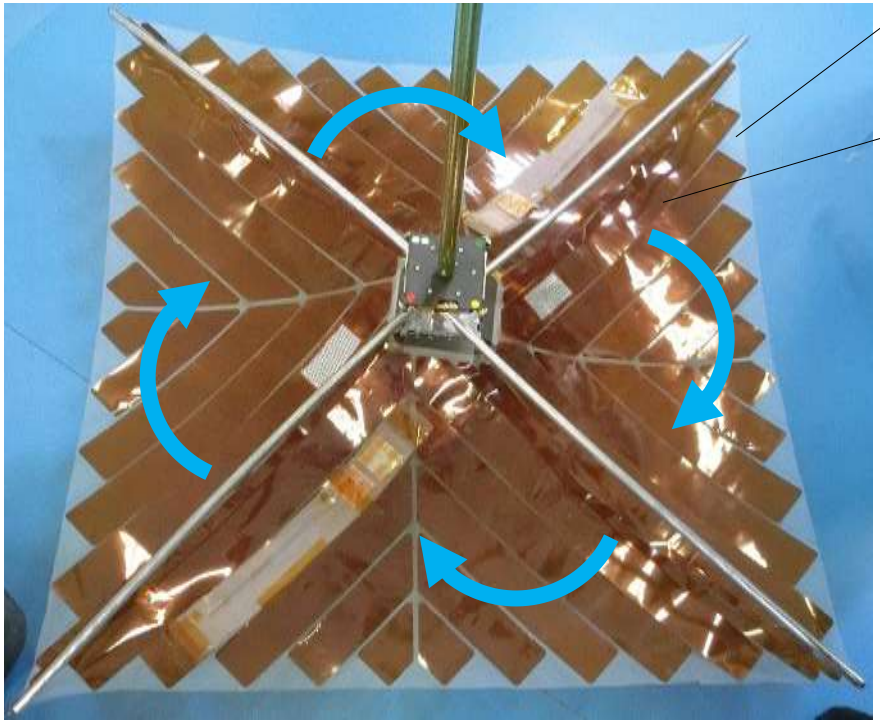
- ✓ Objective: Observe deployment behavior of OrigamiSat-1's membrane under microgravity

In January 2016, deployed inside aircraft MU-300.

Not deployed completely, due to stress-relaxation of CFRP.
-> CFRP boom's deployment force has been increased.

[Mission 1] Deployment of multi-functional membrane EM model

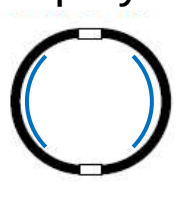


82μm-thick Polyester plain-woven fabric

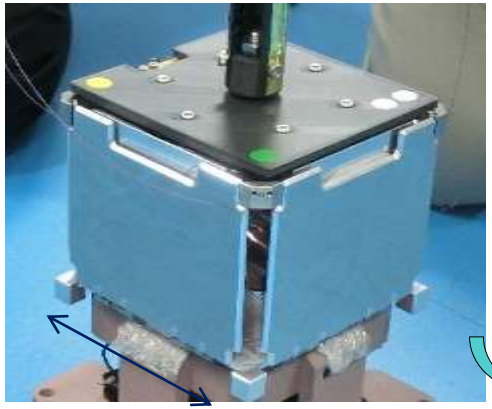
75μm-thick Polyimide film (Dummy for thin-film solar cells etc.)

Deployed

Stored

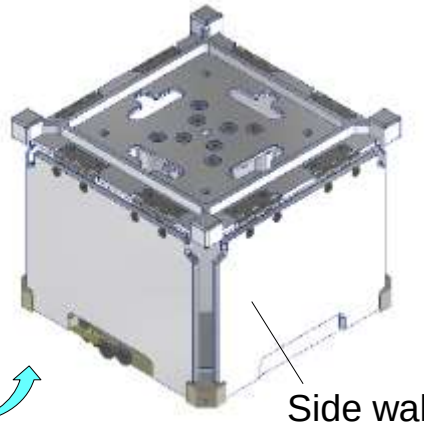


Tubular CFRP boom
（2 metallic convex tapes are installed）

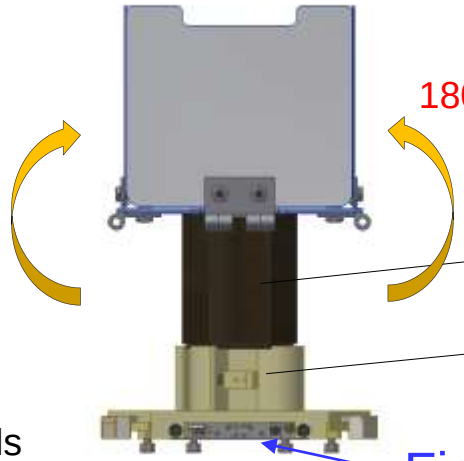


100mm

Flipped



Side walls



180 deg deployment

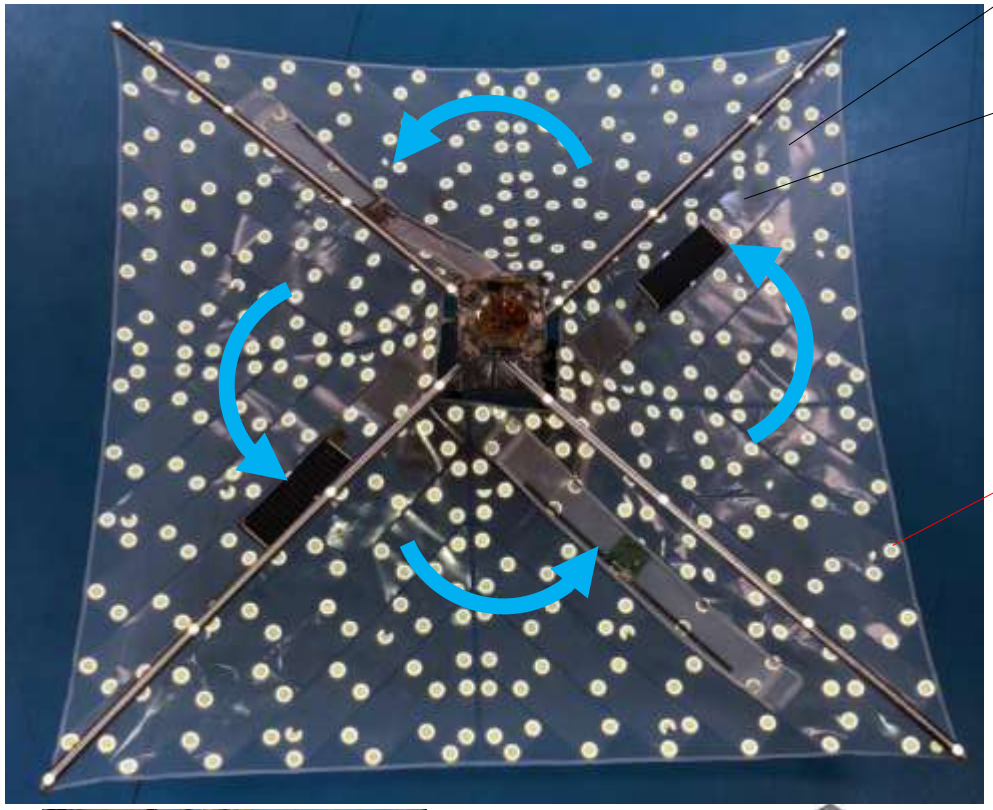
Hub for membrane

Hub for CFRP booms

Fishing wire cut

[Mission 1] Deployment of multi-functional membrane **FM model**

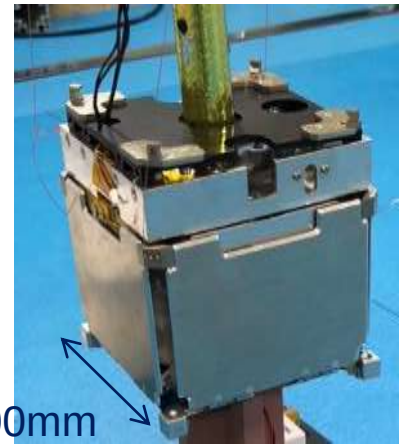
ORIGAMI PROJECT



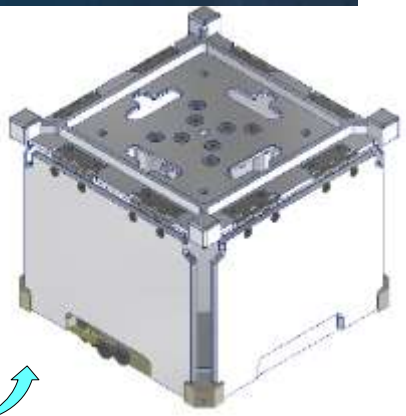
82μm-thick Polyester plain-woven fabric

50μm-thick Superio-UT film (Dummy for thin-film solar cells etc.)
- Transparent film is used to reduce the shadowing effect on the satellite bus.
- Following actual devices are attached: **CIGS thin-film solar cells**, **On-membrane SMA antenna**, **Sphere solar cells**.

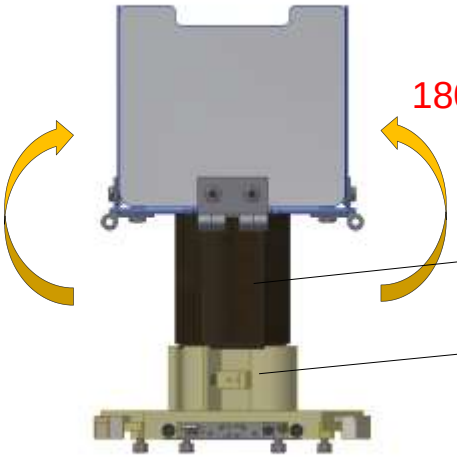
Retro-reflective markers are attached throughout the membrane for shape and deployment motion measurement



100mm



Flipped



180 deg deployment

Hub for membrane

Hub for CFRP booms

3U CubeSat OrigamiSat-1 / FO-98

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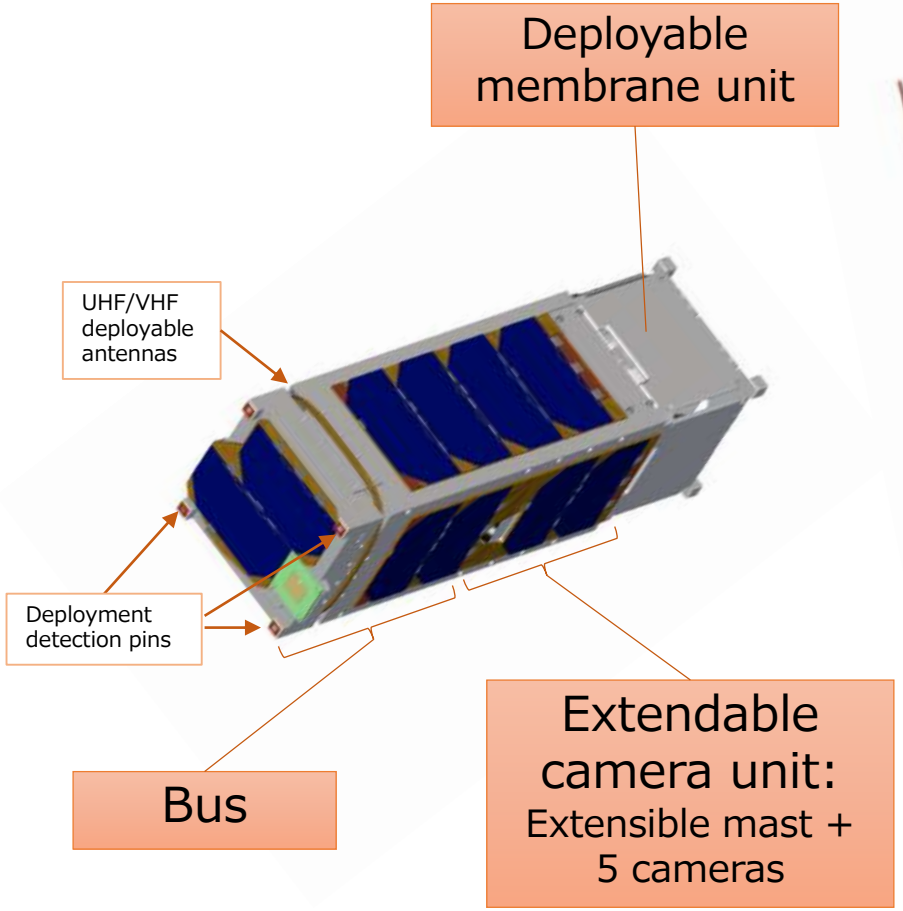
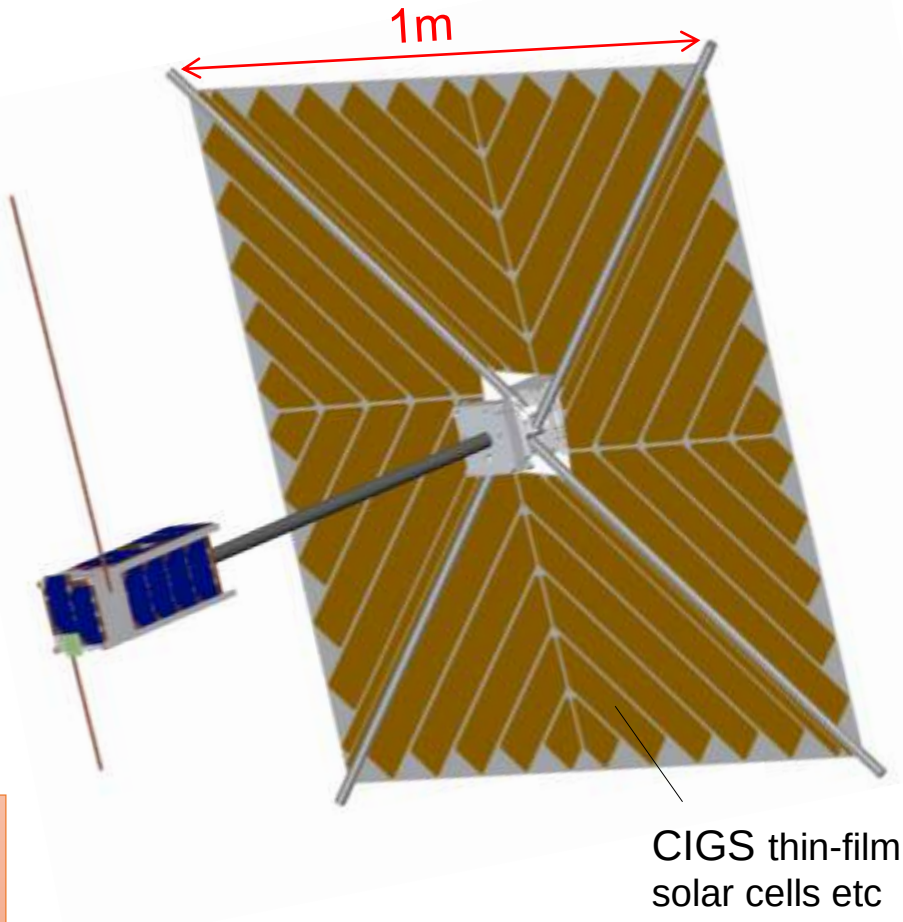
X: 100 × Y: 100 × Z: 340.5 mm

4.1 kg

Designed for 3 missions.

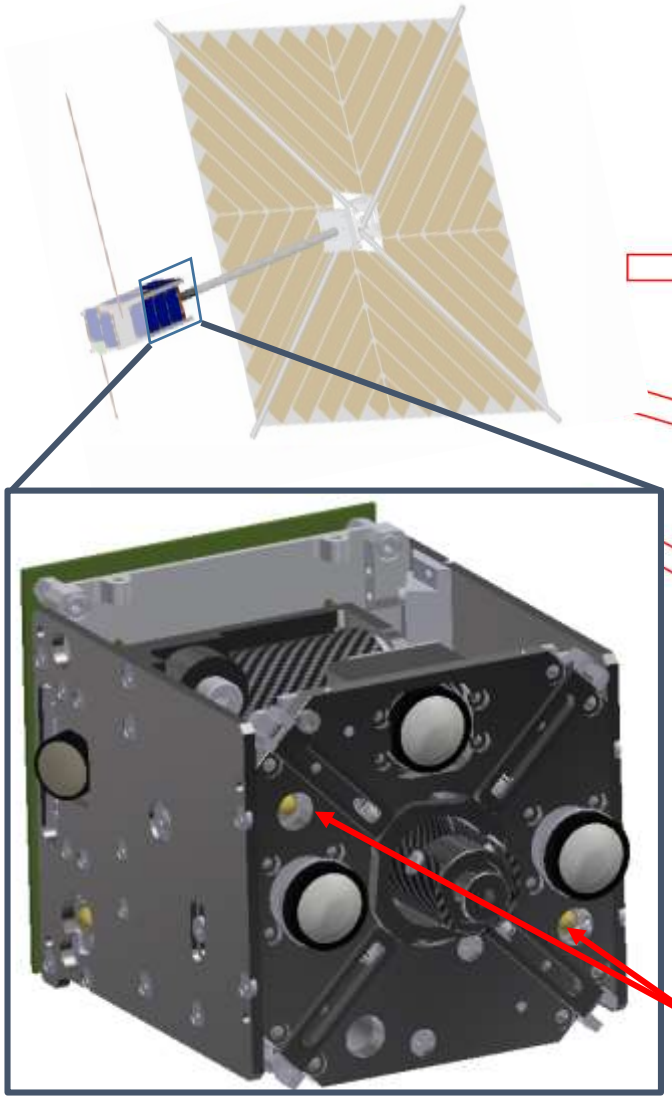




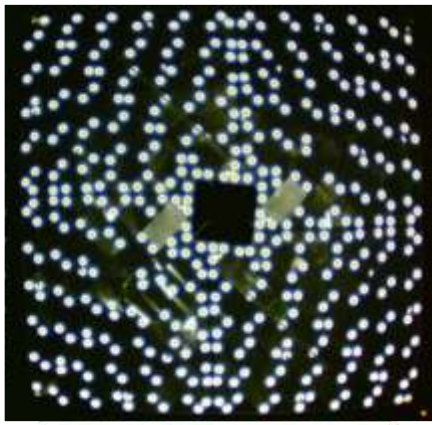
Deployed configuration

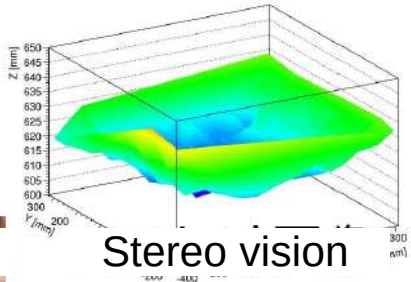
[Mission 2] On-orbit measurement of deployable structures using cameras

- ✓ **Measurement of**
  1. **Deployment dynamics**
  2. **Deployed shape**



Photos





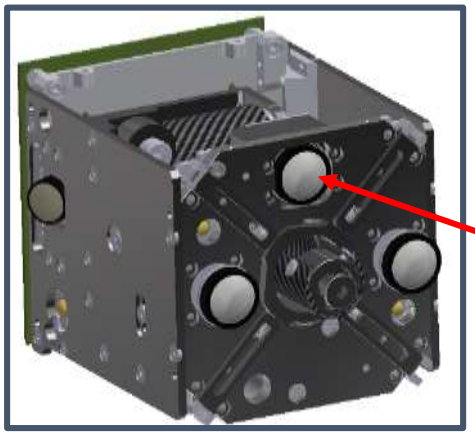
Movie

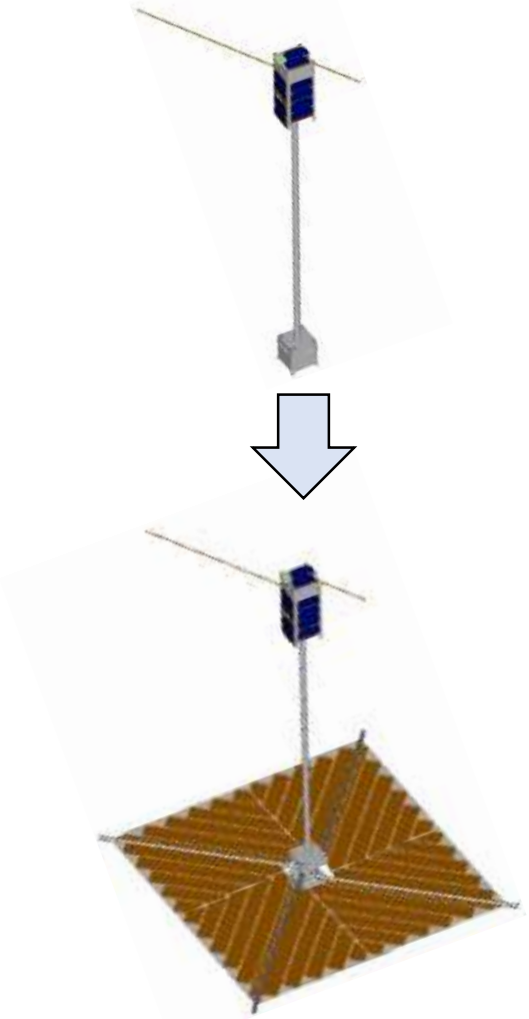
Stereo vision

White LED: Light source for camera shooting

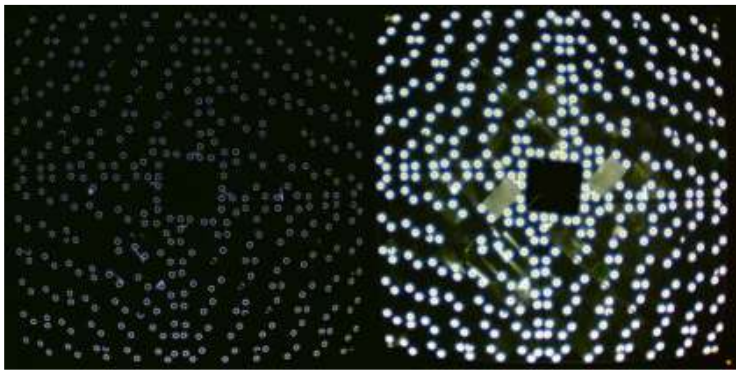
Movie shooting during membrane deployment

- ✓ 320x240, 80fps movie





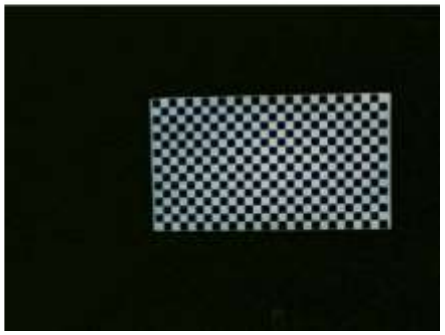
Estimation of out-of-plane shape by stereo vision

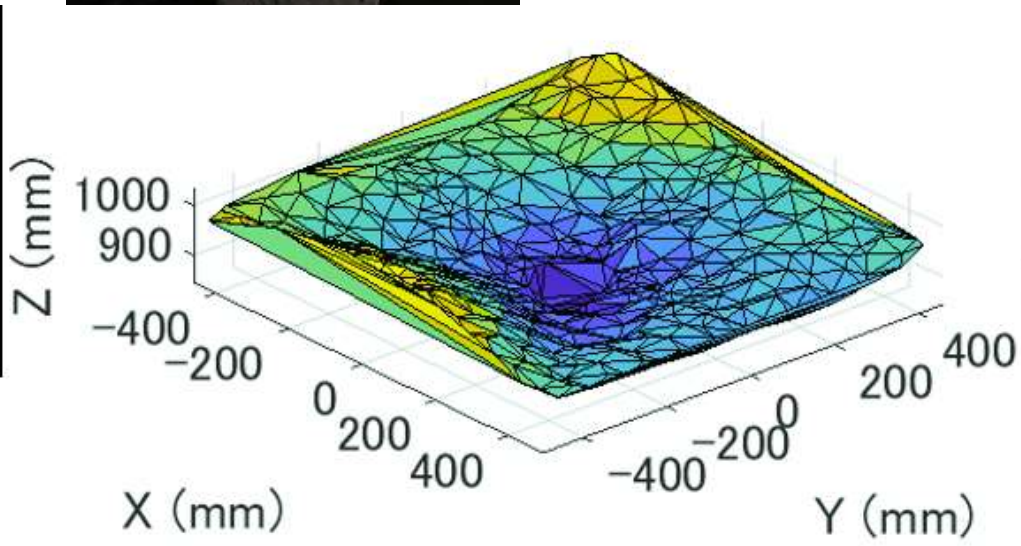


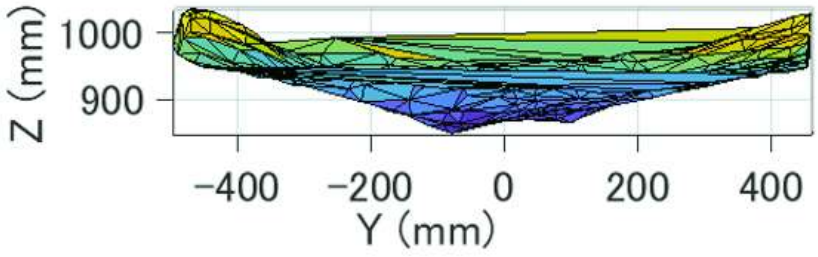
2592 × 1944
325KB

Accuracy evaluation using checker board (1m distance)

Lens distortion correction	Standard deviation
Without correction	4.8 mm
With correction	4.0 mm

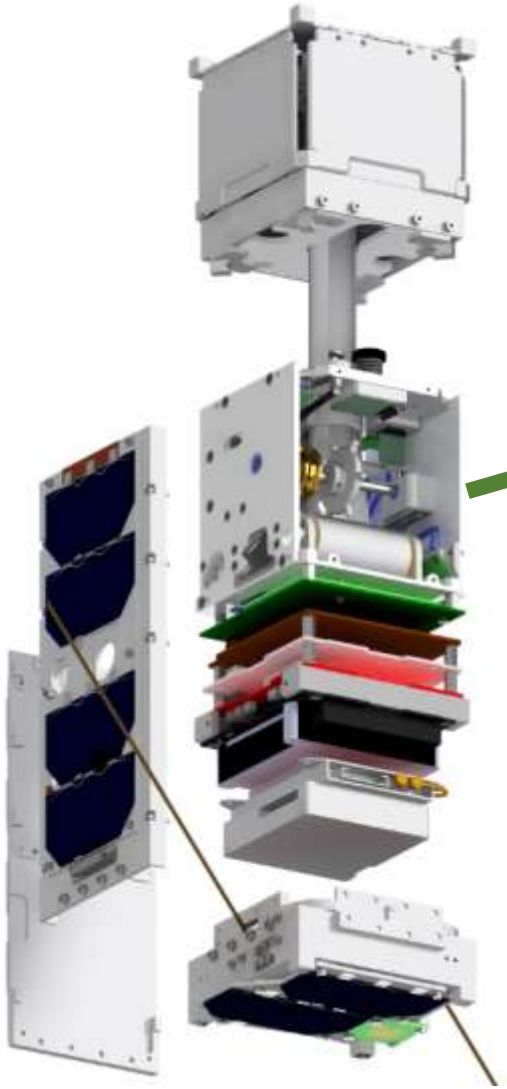






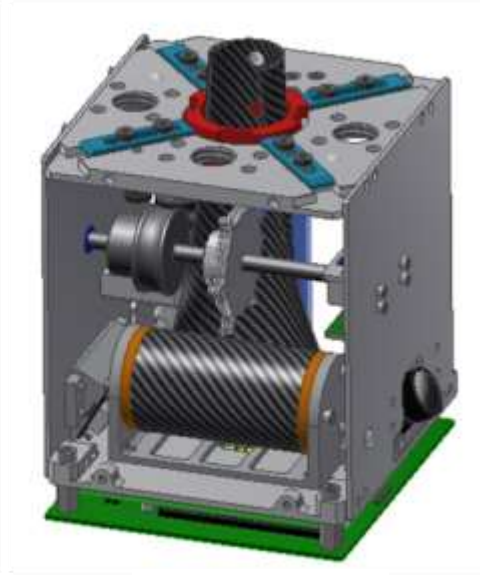
✓ 100mm deformation is successfully detected

Extendable camera unit: **Launch lock mechanism** and **Mast extension mechanism**

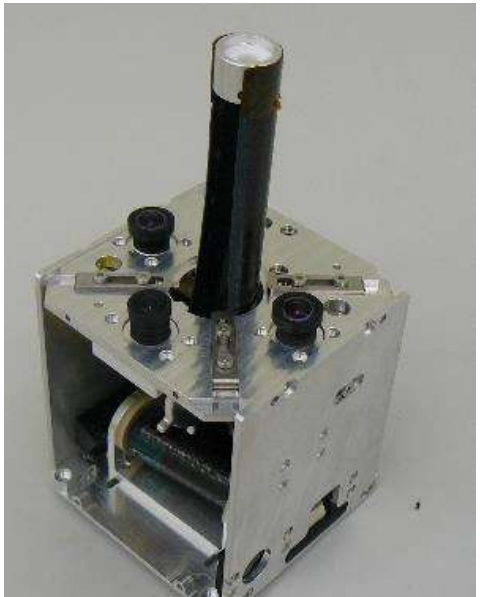


Bottom part of membrane deployment unit

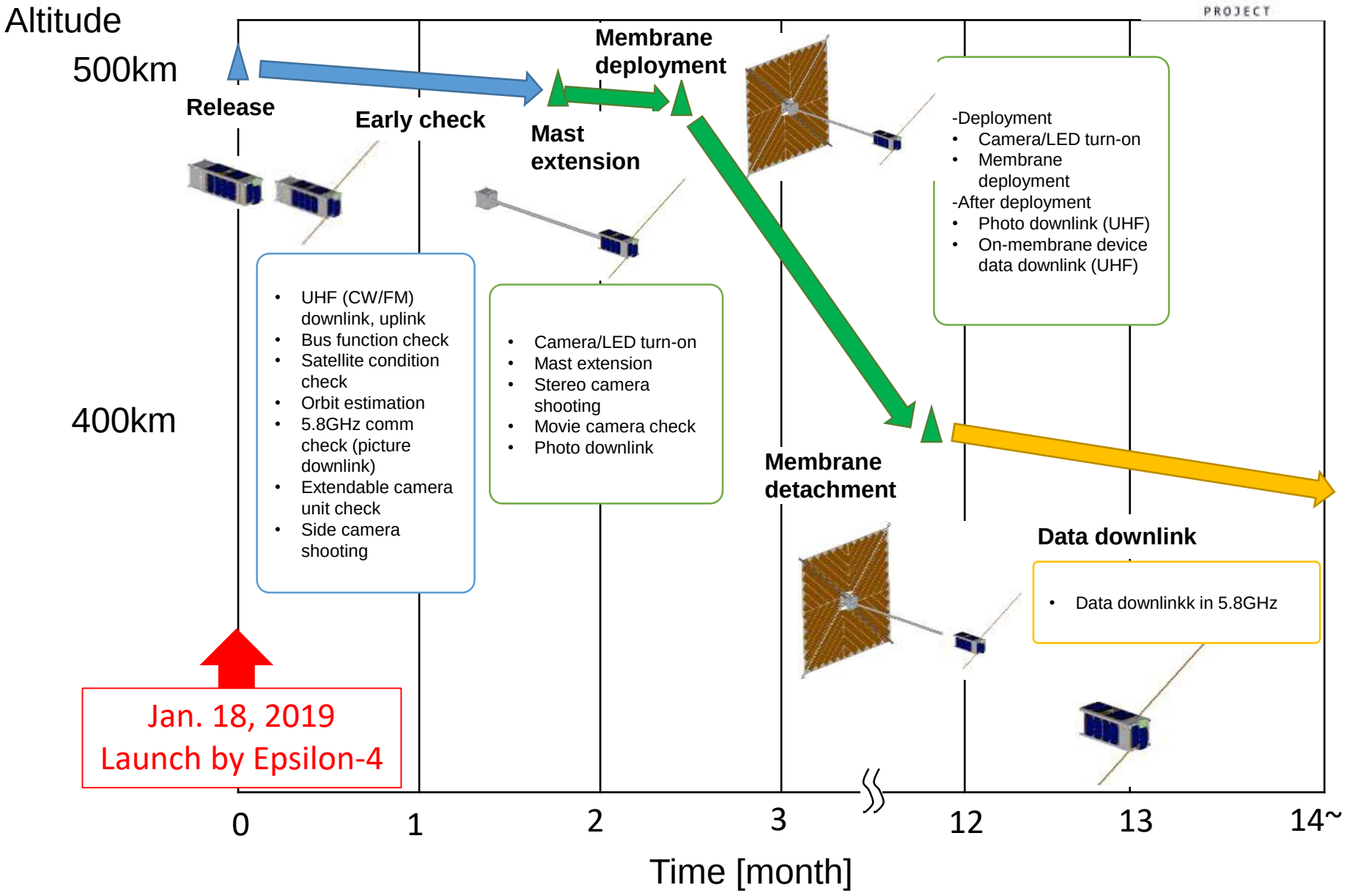
Extendable camera unit



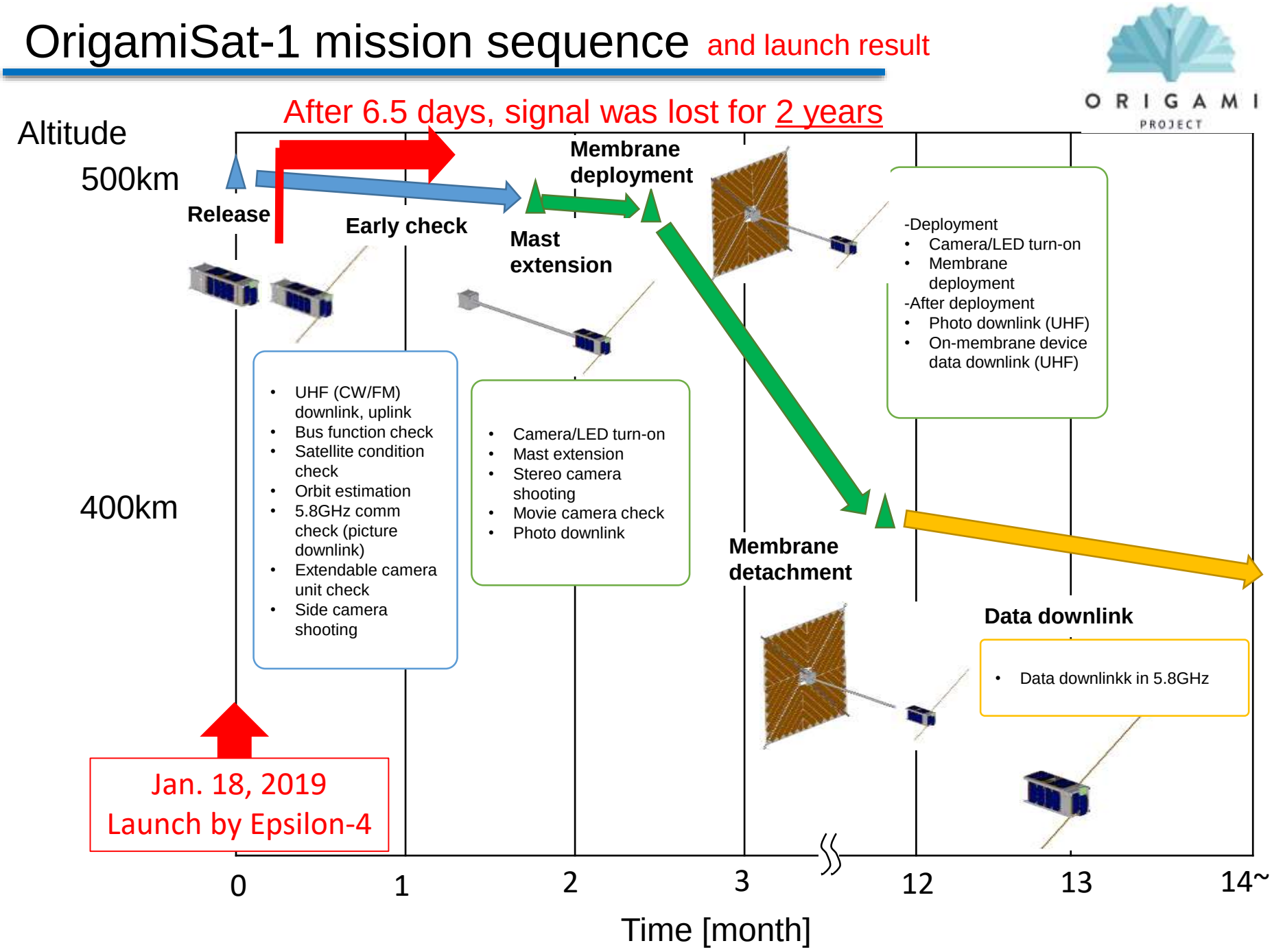
Membrane deployment unit is hidden



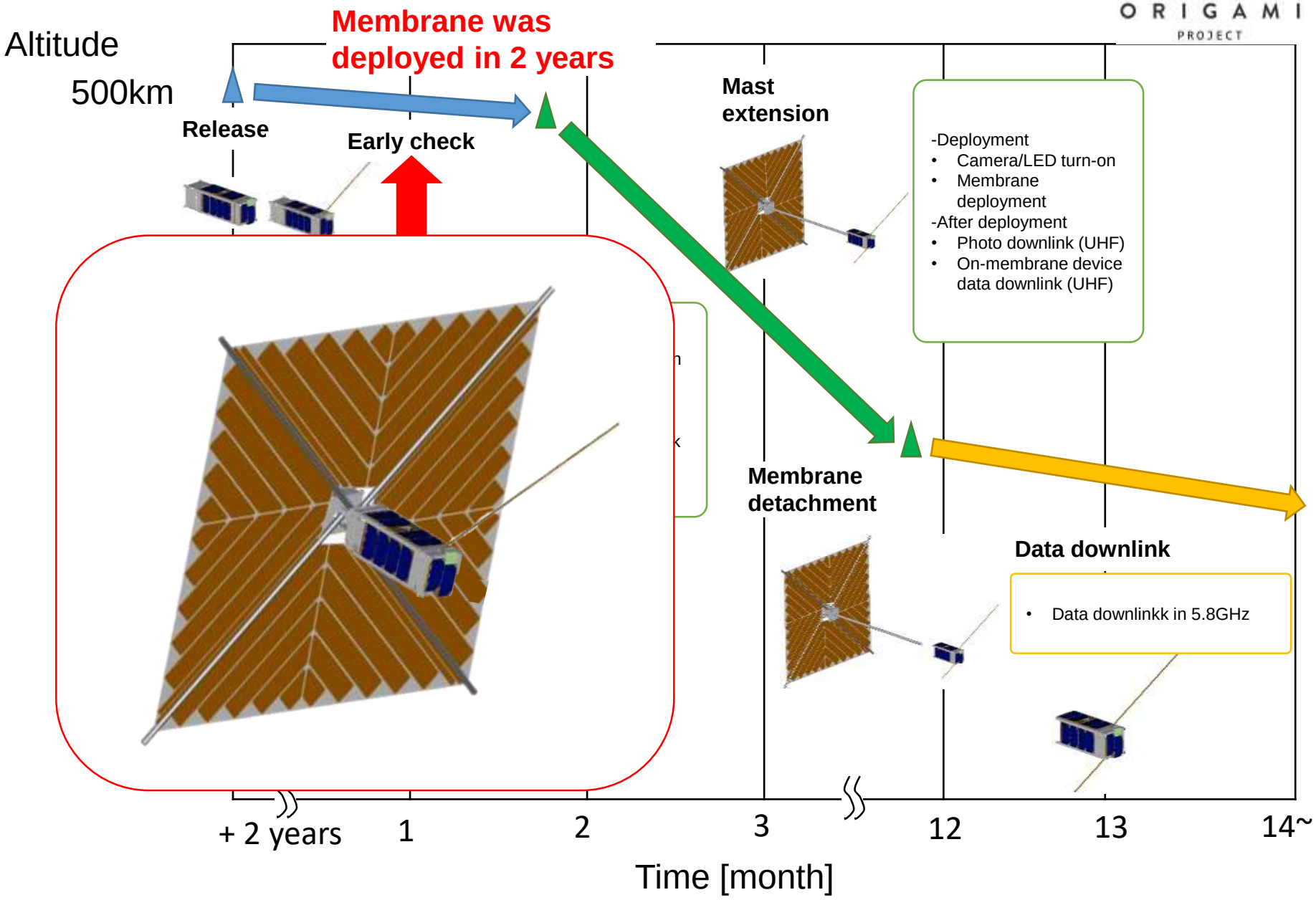
OrigamiSat-1 mission sequence and launch result



OrigamiSat-1 mission sequence and launch result



OrigamiSat-1 mission sequence and launch result



Detachment mechanism for extendable mast

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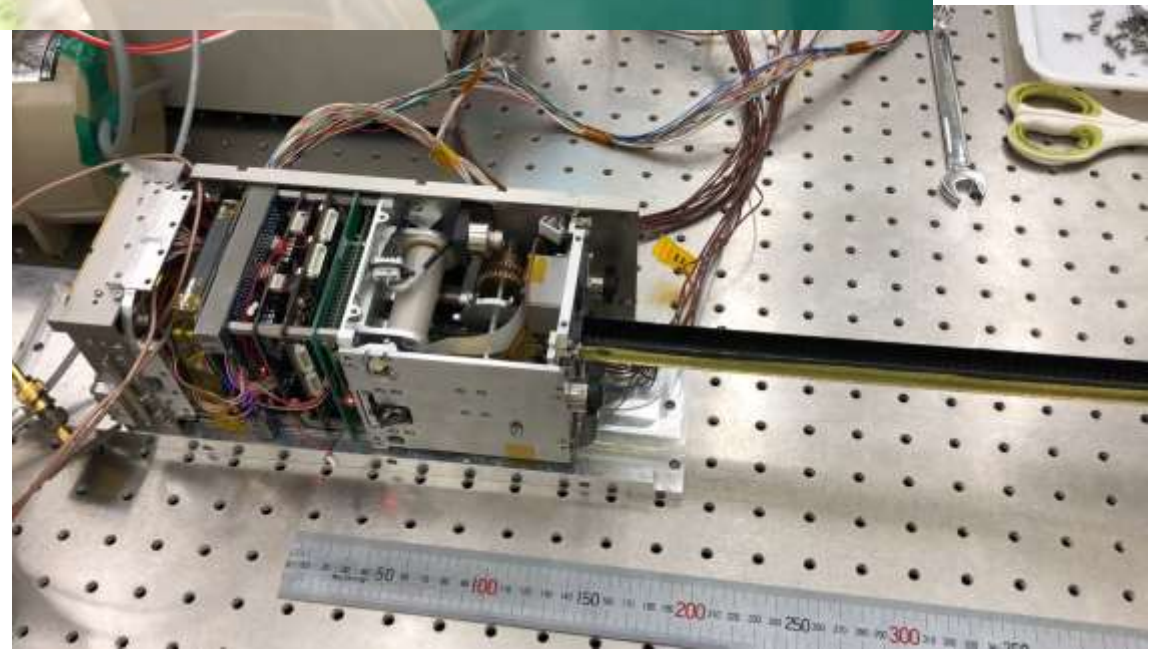


[Mission 3] Amateur radio communication

ORIGAMI PROJECT

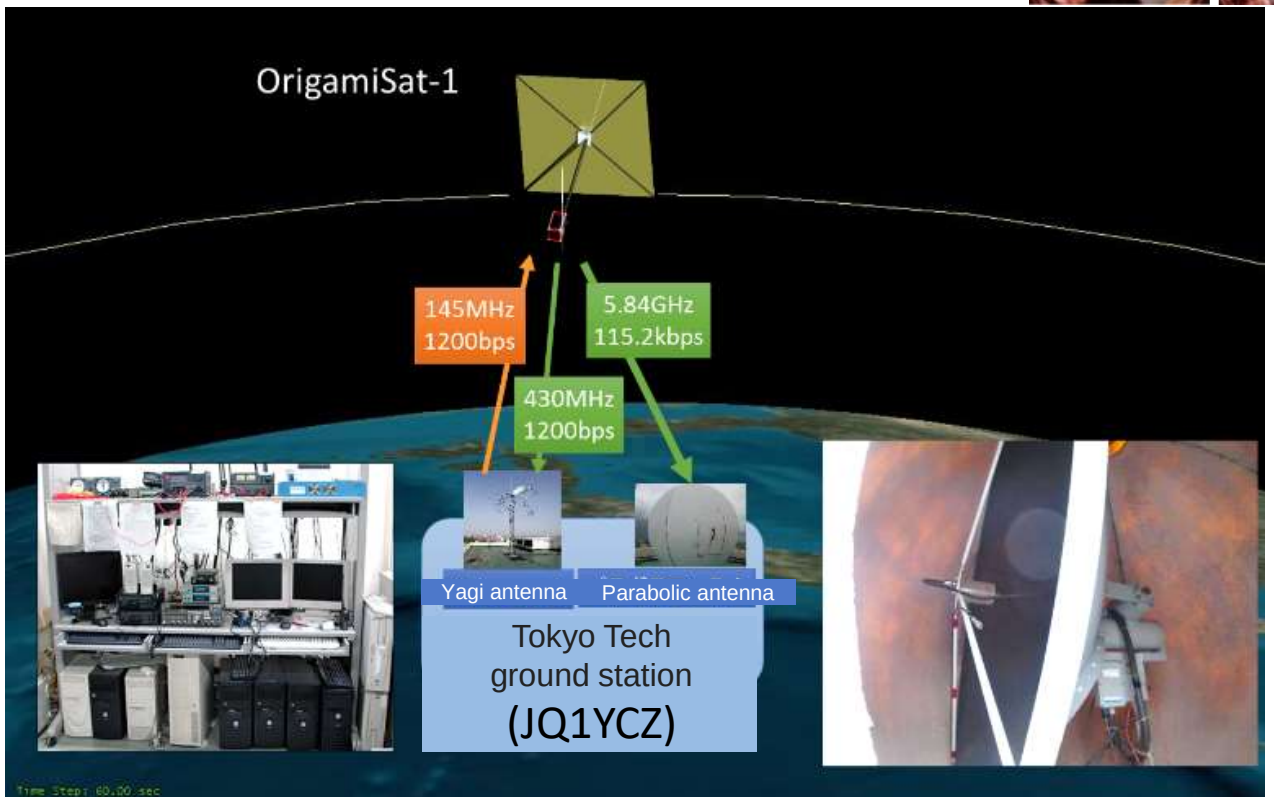
(1) Use of VHF/UHF-band: Command and telemetry

✓ Collaboration with amateur radio operators' community.

(2) Use of 5.84GHz: Mission data downlink

✓ Aims at training of new satellite communication system developed by FITSAT-1 (Niwaka) developed by Fukukoka Institute of Technology (Released from ISS in 2012).

Satellite's call sign:
JS1YAX

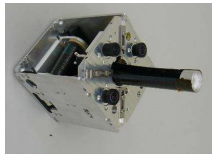


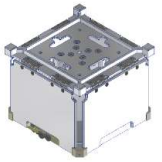
OrigamiSat-1 development team

ORIGAMI PROJECT

Principal Investigator	H. Sakamoto (Associate Professor, Tokyo Tech)
Project Manager	H. Nakanishi (Associate Professor, Tokyo Tech)
Student Project Manager	K. Ikeya (Graduate student, Tokyo Tech)

Core team





Hiroki Nakanishi Lab
3 students

Hiroshi Furuya Lab
4 students

Extendable camera unit

Bus

Tokyo Tech

Deployable membrane unit

Hiraku Sakamoto Lab
9 students

WEL Research, Co., Ltd.

Sakase Adtech, Co., Ltd.

Tokyo Metropolitan Univ.
Prof. Ayako Torisaka

Radio Research Club (JA1YAD)

Tokyo Tech
Hirokawa Lab
Prof. Takashi Tomura

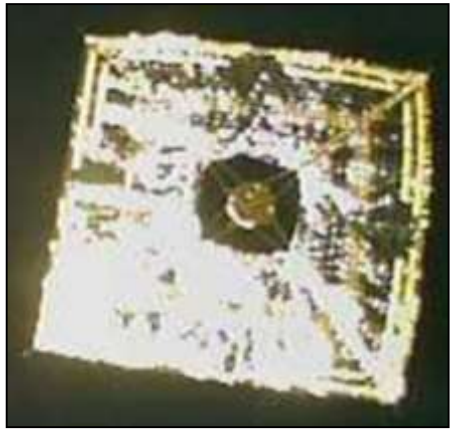
Aircraft Micro-gravity experiment :

Nihon University
Miyazaki Lab
Prof. Masahiko Yamazaki

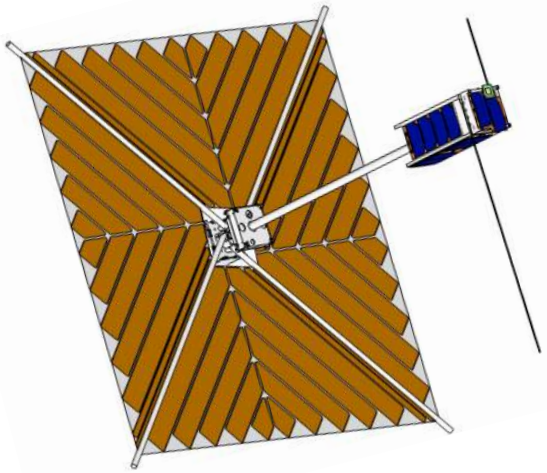
Technical support : ISAS JAXA

HELIOS mission, to be launched in 2022

ORIGAMI PROJECT

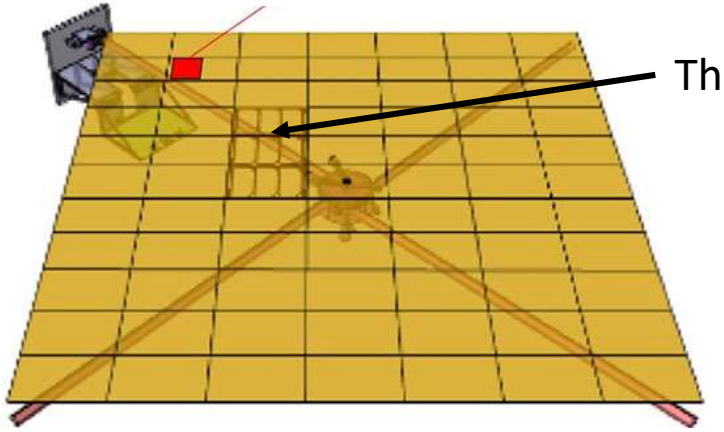


IKAROS (JAXA), 2010



OrigamiSat-1 (Tokyo Tech), 2019-present

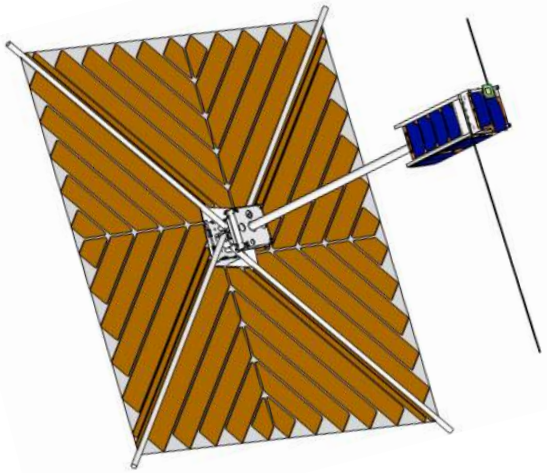
5th generation phased array transceiver



HELIOS (Sakase Adtech), to be launched in 2022

T. Kusumoto, SSC21-WKV-01

Summary



OrigamiSat-1 (Tokyo Tech), 2019-present

- The major significance of the structural concept is that it allows the attachment of film devices throughout the membrane.
- This was achieved by two features: (i) use of textile and (ii) invention of hybrid boom made of tubular carbon composite and metal convex tapes.
- In addition, a visual membrane measurement system consisting of stereo cameras and an extendible mast was developed.

OrigamiSat-1 Papers

Journal Paper

- K. Ikeya, et al., “Significance of 3U CubeSat OrigamiSat-1 for space demonstration of multifunctional deployable membrane,” Acta Astronautica, Vol. 173, 2020, pp. 363-377, https://doi.org/10.1016/j.actaastro.2020.04.016.
- A. Torisaka, et al., “Development of shape monitoring system using SMA dipole antenna on a deployable membrane structure,” Acta Astronautica, Vol. 160, Jul. 2019, pp. 147–154.

Conference Paper

- H. Sakamoto, et al., “CubeSat Design for Space Demonstration of Deployable Membrane Structure Technologies,” 2015-f-74, 34th International Symposium on Space Technology and Science (ISTS), Hyogo, Japan, July 4-10, 2015.
- Y. Shimoda, et al., “Development of Stereo Camera System for Accurate Observation of Large Deployable Membranes in Orbit,” AIAA-2016-1473, 3rd AIAA Spacecraft Structures Conference, SciTech2016, San Diego, California, USA, Jan. 4-8, 2016.
- H. Furuya, et al., “Deployment Properties with Gravity Compensation Devices for Boom-Membrane Integrated Wrapped Structures,” AIAA-2016-2167, 3rd AIAA Spacecraft Structures Conference, SciTech2016, San Diego, California, USA, Jan. 4-8, 2016.
- Y. Shimoda, et al., “Development of Stereo Camera System for Accurate Observation of Deployable Membranes Onboard CubeSat,” AIAA-2017-0167, SciTech2017, Grapevine, Texas, USA, Jan. 9-13, 2017.
- H. Furuya, et al., “Micro-gravity Testing of Boom-Membrane Integrated Deployable Structures for Micro-satellites”, AIAA-2017-0618, 4th AIAA Spacecraft Structures Conference, SciTech2017, Grapevine, Texas, USA, Jan. 9-13, 2017.
- H. Furuya, et al., “Boom/Membrane Integrated Deployable Space Structures for Small Satellites,” 4th International Symposium on Solar Sailing, Kyoto, Japan, pp.1-4, Jan.17-20, 2017.
- H. Nakanishi, et al., “Development of Nano-Satellite OrigamiSat-1 with Highly Functional Deployable Membrane,” 4th International Symposium on Solar Sailing, Kyoto, Japan, pp.1-4, Jan.17-20, 2017.
- T. Chubachi, et al., “Hybrid Self-deployable Tubular CFRP Booms for Deployable Membrane,” 4th International Symposium on Solar Sailing, Kyoto, Japan, pp.1-7, Jan.17-20, 2017.
- H. Sakamoto, et al., “Development of CubeSat OrigamiSat-1 for Space Demonstration of Deployable Membrane Structure Technologies,” No. 2017-f-023, 31st International Symposium on Space Technology and Science, Jun. 3-9, 2017.
- T. Chubachi, et al., “Undesired Equilibrium Configurations of Boom-Membrane Integrated Structure during Deploying Motion,” AIAA-2018-0695, AIAA Spacecraft Structures Conference, SciTech2018, Kissimmee, Florida, USA, Jan. 8-12, 2018.
- T. Amamoto, et al., “Modeling of Composite Booms’ Deployment Dynamics under Microgravity Based on Ground Tests,” AIAA-2018-1435, AIAA Spacecraft Structures Conference, SciTech2018, Kissimmee, Florida, USA, Jan. 8-12, 2018.
- T. Chubachi, et al., “Deployability of Boom-Membrane Integrated Structure on OrigamiSat-1,” No. 2019-k-41, 32nd International Symposium on Space Technology and Science (ISTS), Fukui, Fukui, Japan, June 15-21, 2019.
- S. Kadonishi, et al., “Compact Packaging of Planar Gossamer Space Structures Using Textile Membranes,” No. 2019-k-42, 32nd International Symposium on Space Technology and Science, Fukui, Japan, Jun. 15-21, 2019.

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