Lab for Space Systems
LSS
Tokyo Institute of Technology

Initial In-Orbit Operation Result of Microsatellite HIBARI: Attitude Control by Driving Solar Array Paddles

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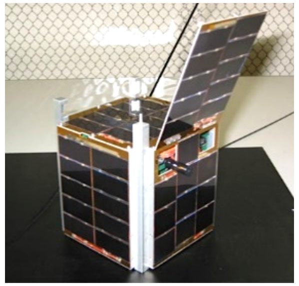
Tokyo Institute of Technology, Japan

Small Satellite Conference

Tokyo Institute of Technology SmallSat Projects

2003

CUTE-I

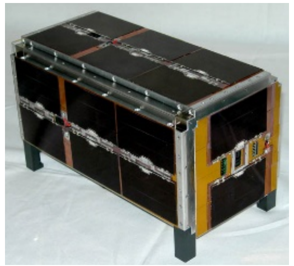


1U

World's 1st CubeSat

2006

Cute-1.7+APD

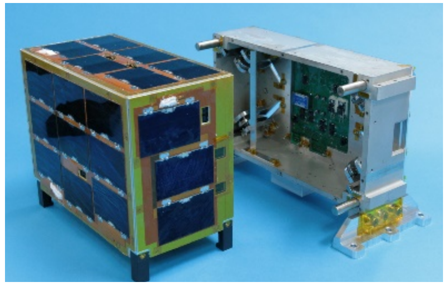


2U

Trying new design methodology

2008

Cute-1.7+APD II

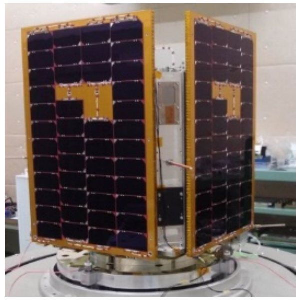


4U

World First observation of low energy particles by CubeSat

2014

TSUBAME

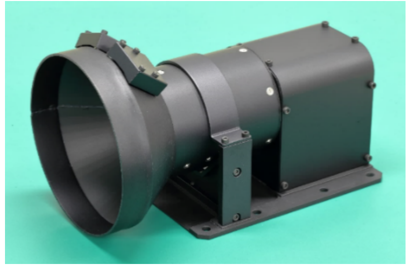


50kg

demonstrate CMG for Microsatellite

2019

DLAS

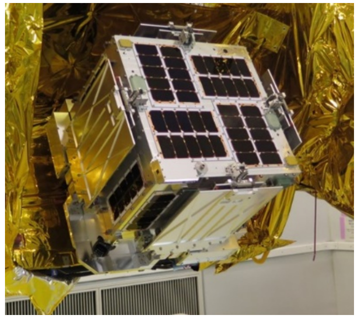


Earth Sensor + STT

3-axis attitude determination earth sensor using deep learning

2021

HIBARI

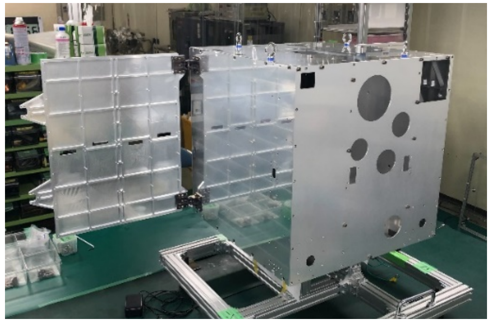


50kg

demonstrate variable shape function

2022~

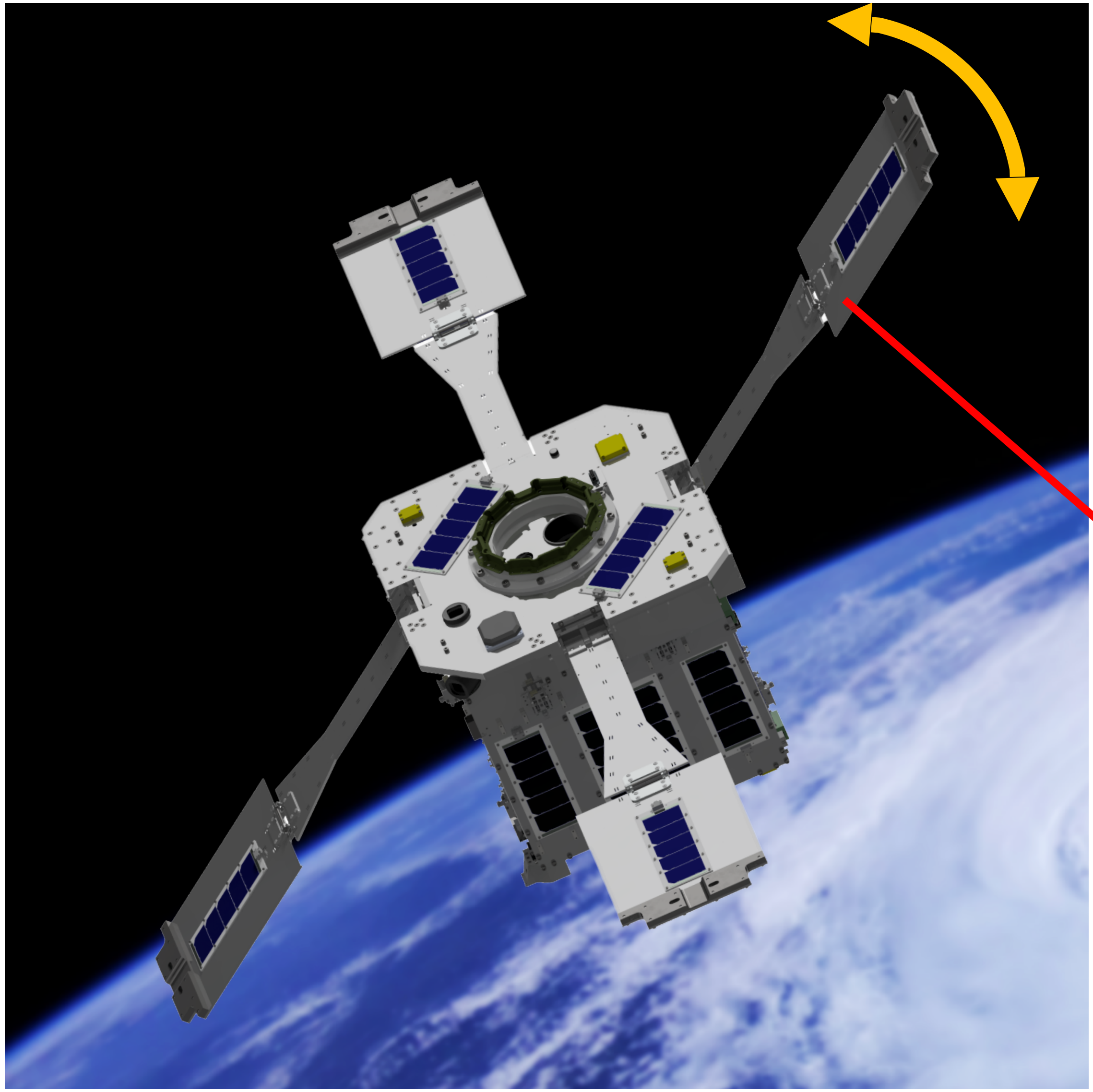
Petrel



50kg

UV + multi-spectral imaging

HIBARI Project



“HIBARI” = Skylark in Japanese

HIBARI satellite can move solar array paddles just like the bird’s wing.
This feature is not only to maximize power generation.

why do we move paddles?

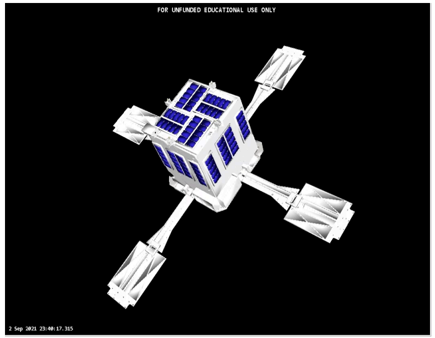
Variable Shape Function

Drives part of the satellite structure(e.g. solar array paddle), to actively changing the system shape in orbit.

- Attitude control using mass distribution and internal force torque generated by shape change

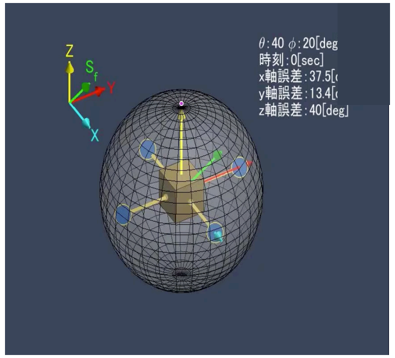
  （VSAC : Variable Shape Attitude Control）

Agile Attitude Maneuver



Capable of generating several times more torque than CMG for MicroSatellites

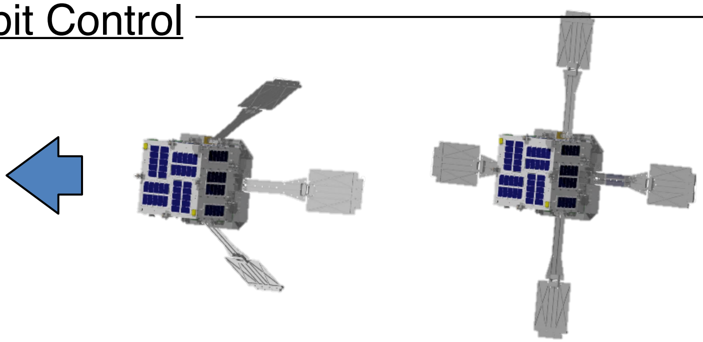
Non-holonomic Attitude Control



Capable of transition to any 3axis attitude

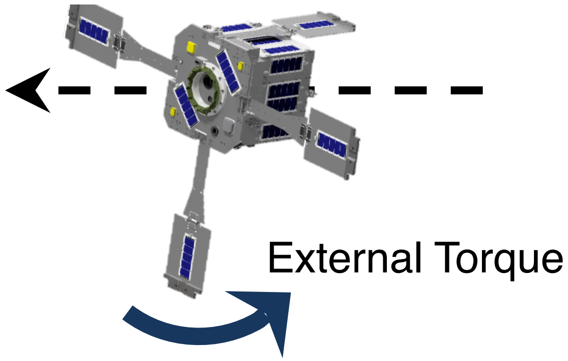
- Orbit/attitude control using external force/torque by becoming target shape

Orbit Control



Change the amount of external force

Attitude Control



Missions of HIBARI

Main Mission：

Demonstration of variable shape function and new attitude control method by driving solar array paddles

Success Criteria：

Minimum	• Confirm attitude change predicted by variable shape function of motor drive
Full	• VSAC ◦ Agility：＞15deg/10seconds (Equivalent to CMG, 2 times more than RW used in SmallSat) ◦ Pointing Accuracy：＜5deg
Extra	• VSAC ◦ Agility：＞30deg/10seconds ◦ Stability：＞300arcsec/1second • VSAC＋RW ◦ Stability：＞300arcsec/10seconds • confirmation of orbit/attitude change with controlled atmospheric resistance

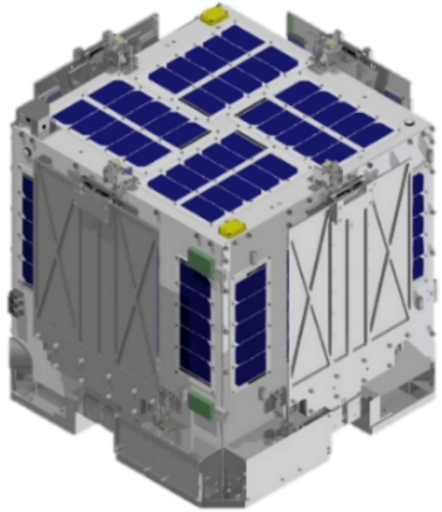
Development Schedule & Conference Presentations

FY	2018	2019	2020	2021	2022
Phase	Feasibility Study	◇MDR BBM ◇PDR	stop development due to COVID-19 EM ◇CDR	◇PQR FM ◇Launch	on-orbit Operation
Tests	◇ TID/SEE	◇ Paddle deployment ◇Elec Integrate	◇ Vib. ◇TVAC ◇Elec Integrate	◇ Vib./TVAC/Impact ◇ Long-term Debug	
Small Sat Conf.	△ **SSC18-WKI-05** “Variable Shape Attitude Control Demonstration with Microsat "Hibari“”	△ **SSC19-VII-02** “Concept Design and Development of 30kg Microsatellite HIBARI for Demonstration of Variable Shape Attitude Control”	△ **SSC20-V-07** “Engineering Model Development of HIBARI: MicroSatellite for Technology Demonstration of Variable-Shape Attitude Control”		△ **SSC22-WKII-05** “Initial In-Orbit Operation Result of Microsatellite HIBARI: Attitude Control by Driving Solar Array Paddles”

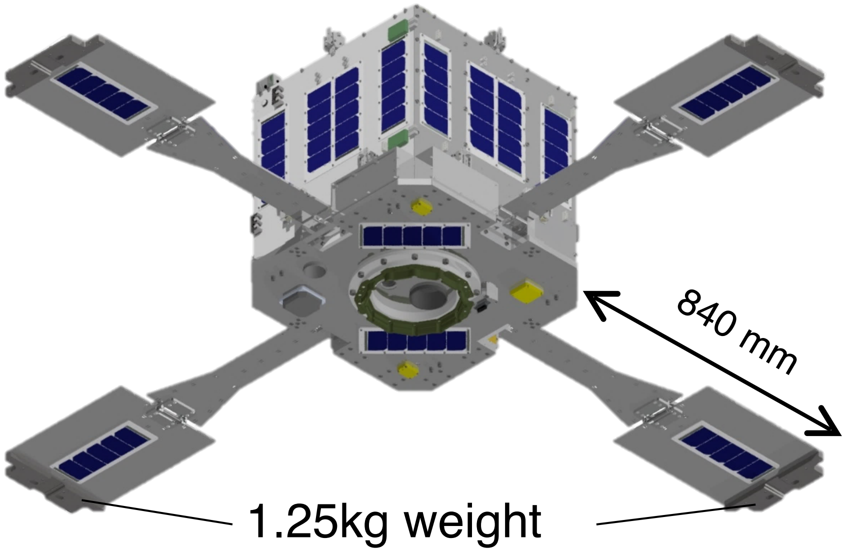
HIBARI System

Size	570 × 570 × 550 mm^3 (Paddle Stowed)
Mass	55kg (Bus 45kg, Paddle 2.5kg × 4)
Comm.	S-band Tx/Rx ×2 Globalstar Tx ×1
Power	Li-ion Battery: 161Wh Nominal generated power when sun pointing: 40W
Orbit	Sun-synchronous orbit (perigee altitude 547 km, apogee 565 km, orbital node local solar time 9:30)

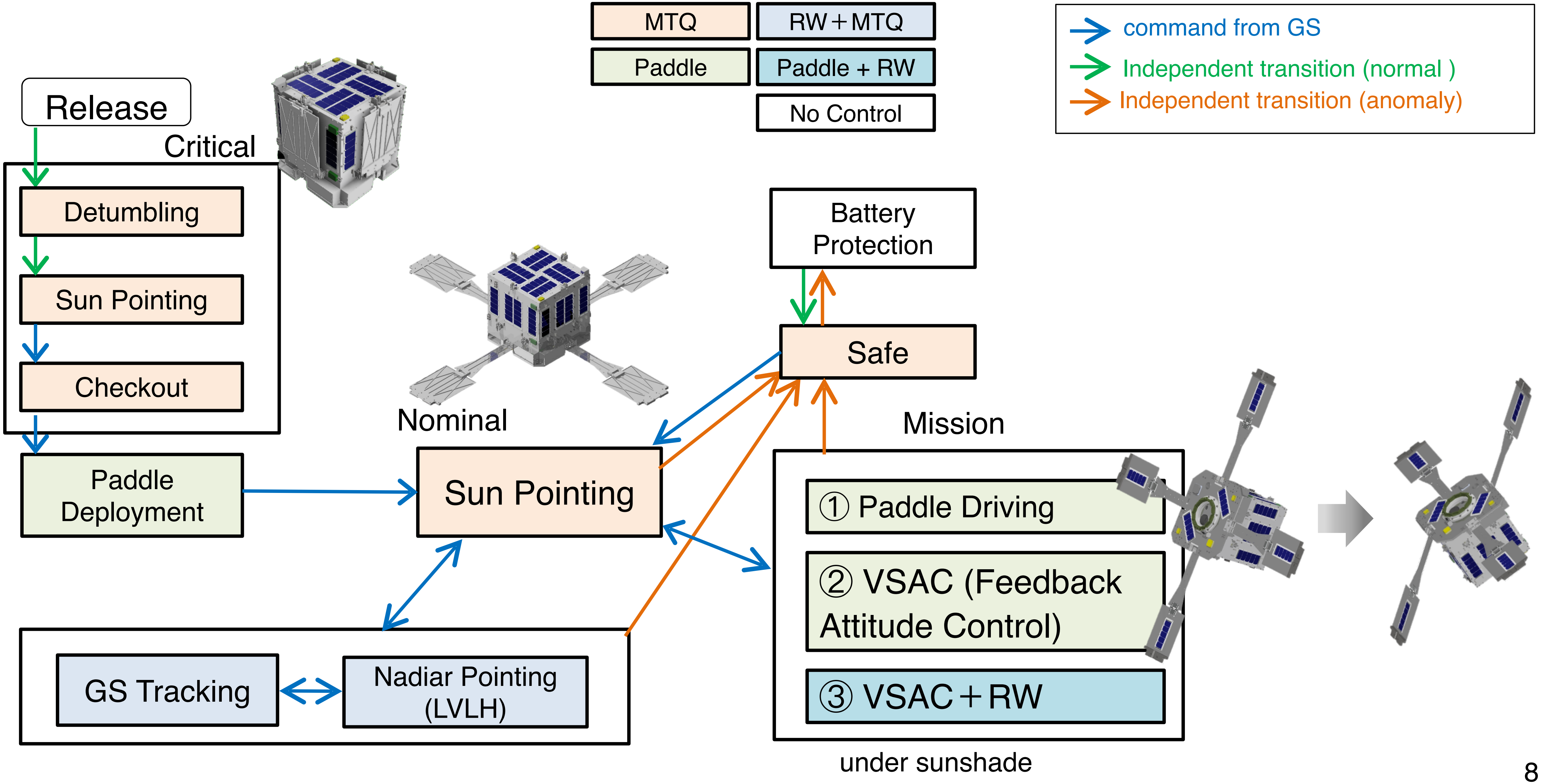
Paddle Stowed



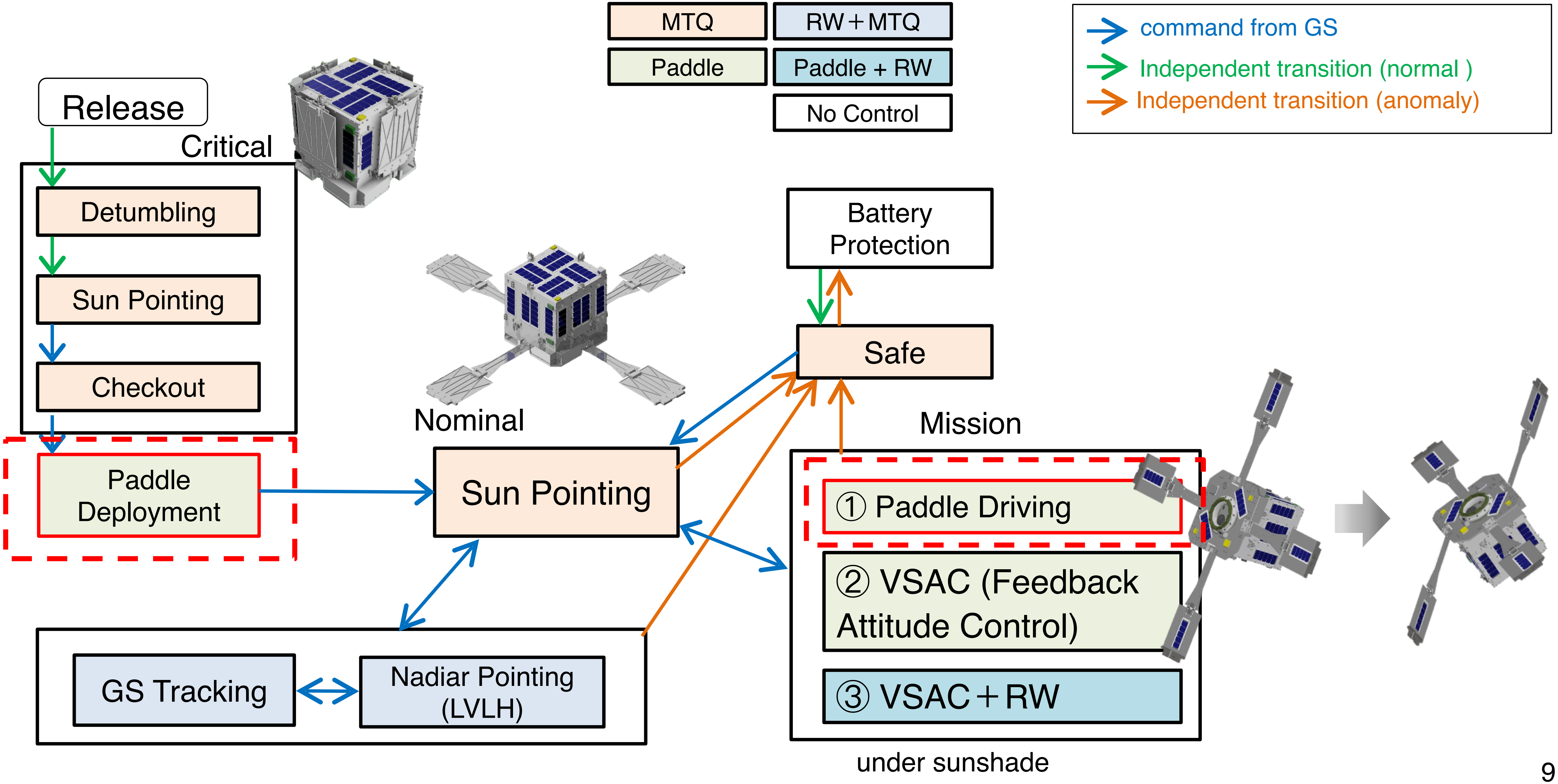
Paddle Deployed



Operation Mode

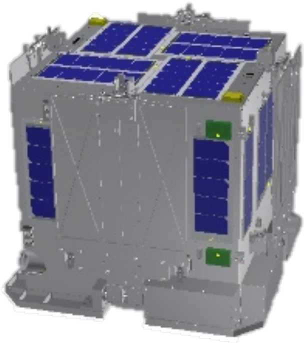


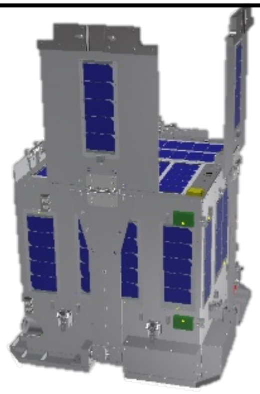
Operation Mode



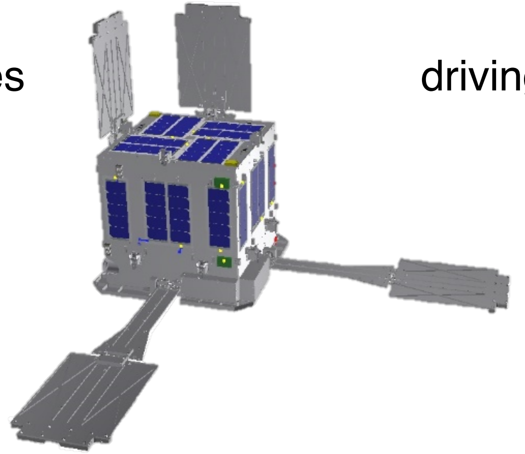
Operation Result - Paddle Deployment

paddle stowed	1st & 2nd Fusing of string		3rd & 4th Fusing of string		paddle deployed

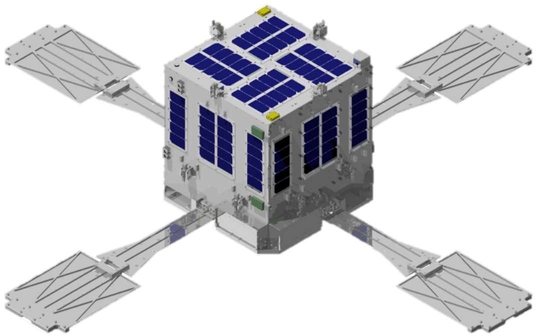


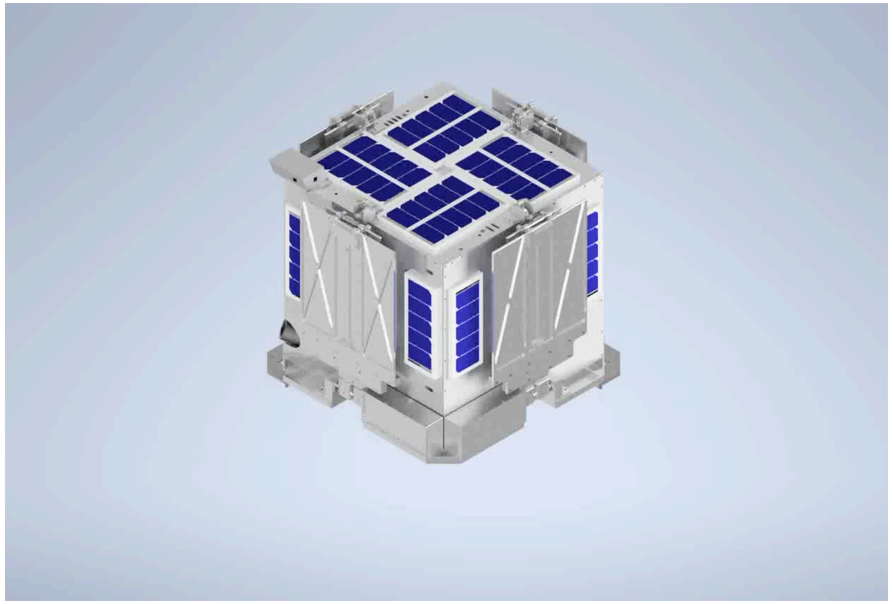


driving paddles



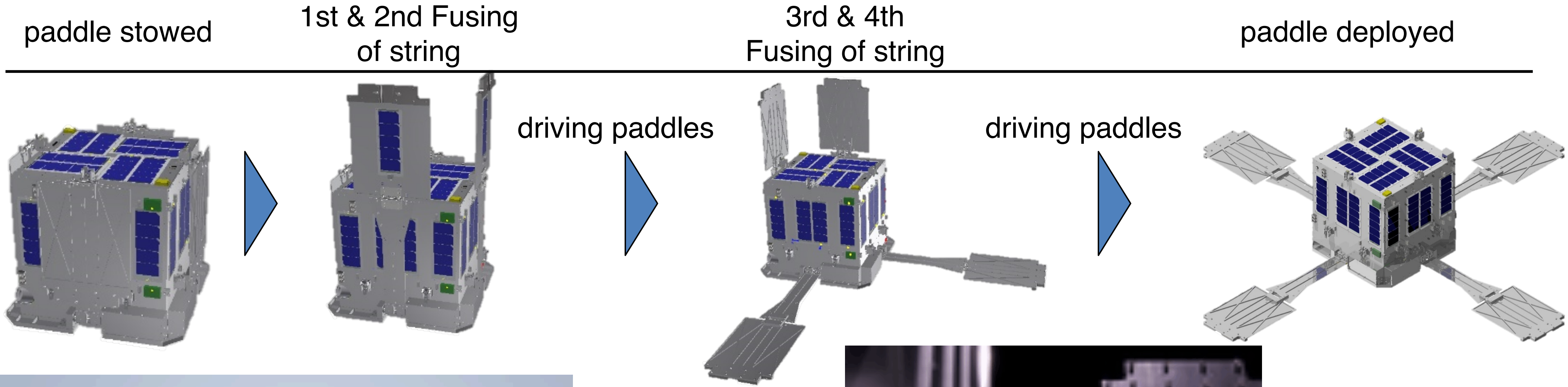
driving paddles

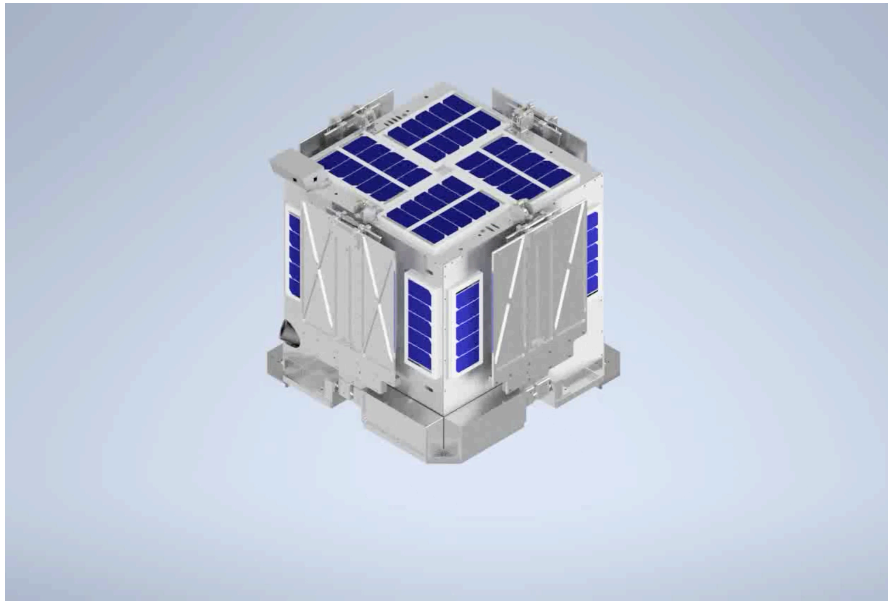




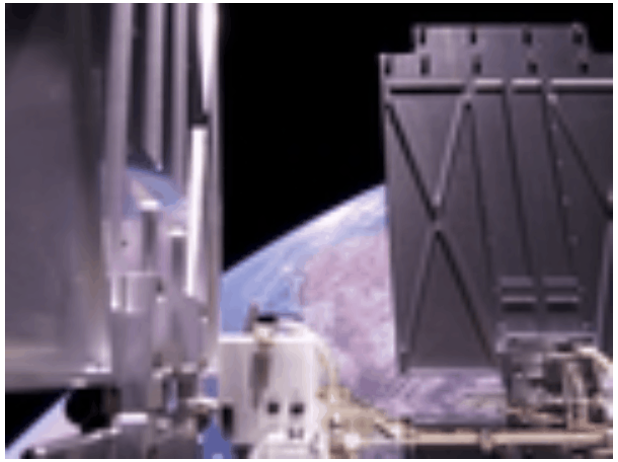
animation of deployment sequence

Operation Result - Paddle Deployment





animation of deployment sequence



on-orbit pictures by monitor camera during paddle drive after 4th fusing

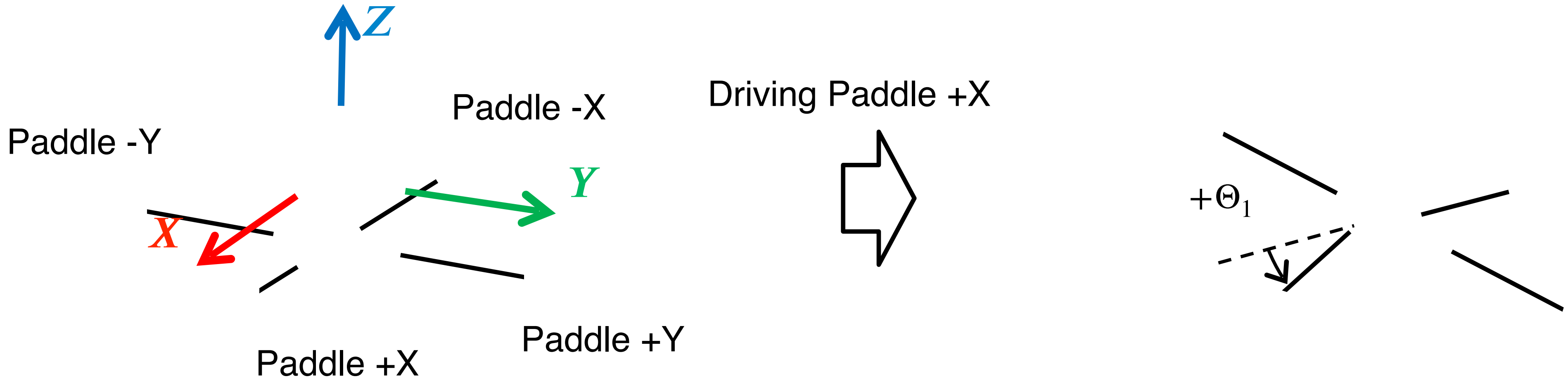
Paddle deployment was judged to be successful from the camera pictures and the value of attitude sensors

Paddle Drive Experiment

Paddle drive experiments are conducted to evaluate performance of the paddles.

Parameters:

number of driving paddles, drive angle, max drive angular velocity, max drive angular acceleration



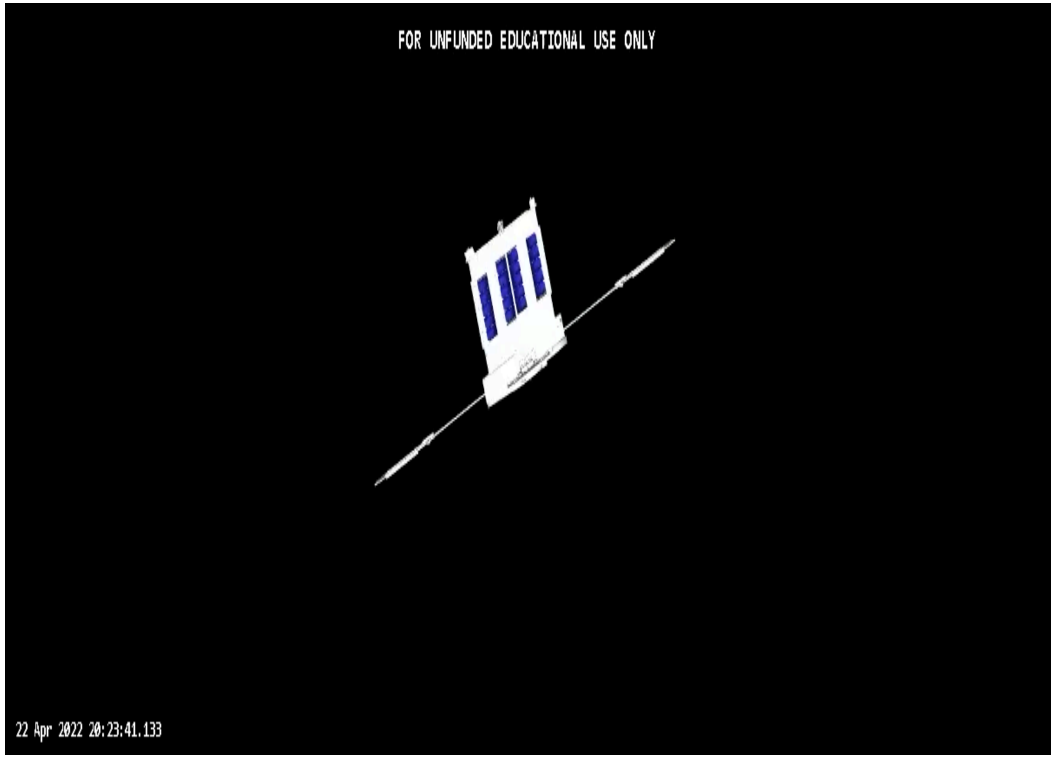
Experiment No.	Driving Paddles & Driving Angle [deg]	Maximum Angular Velocity [deg/s]	Maximum Angular Acceleration [deg/s2]
1	+X : 0 → +20	1	1
2	+Y : -22 → +30	2	1
3	+X : 0 → +60 -X : 0 → -60	4	1

↓ more agile experiment

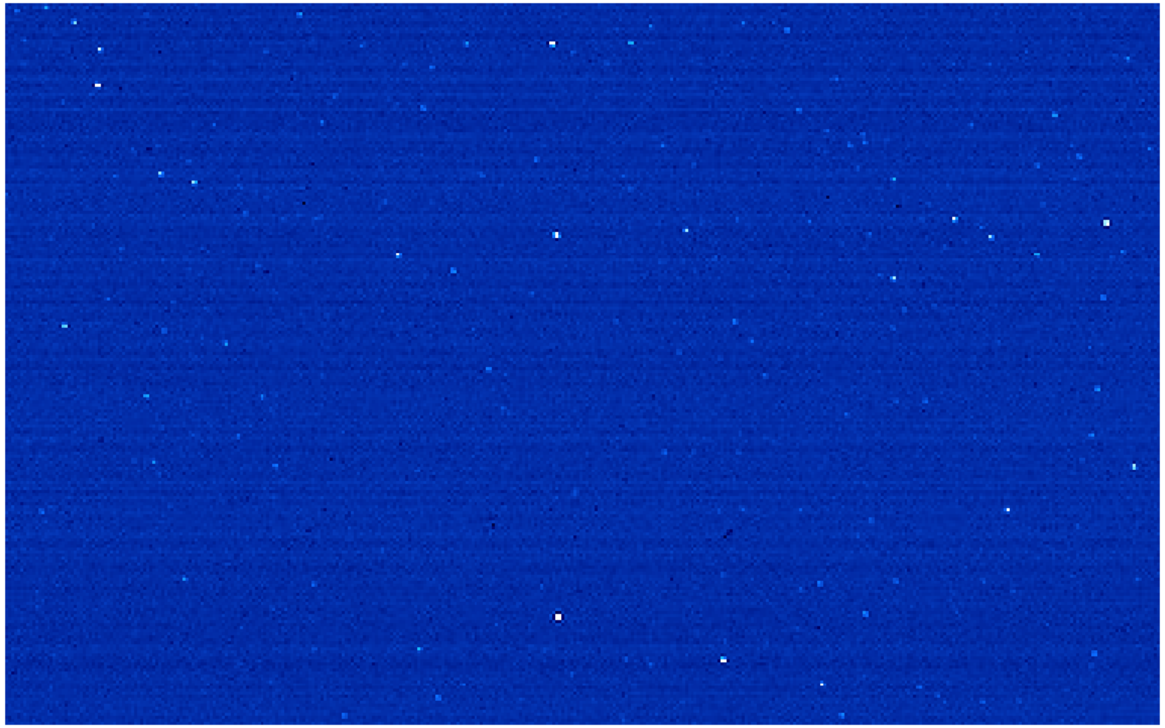
Operation Result - Paddle Drive Experiment(1/3)

Paddle +X : 0 → +20 deg, max drive angular velocity : 1 deg/s, max drive angular acceleration : 1 deg/s^2

On-orbit simulation video(4x speed)



Star pictures taken during paddle drive (4x speed)

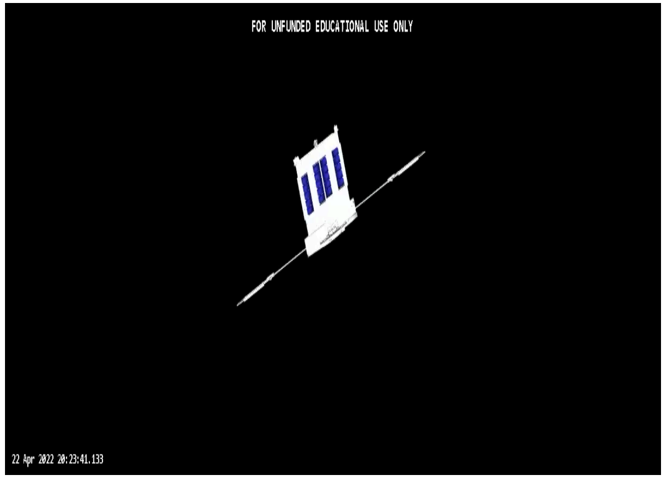


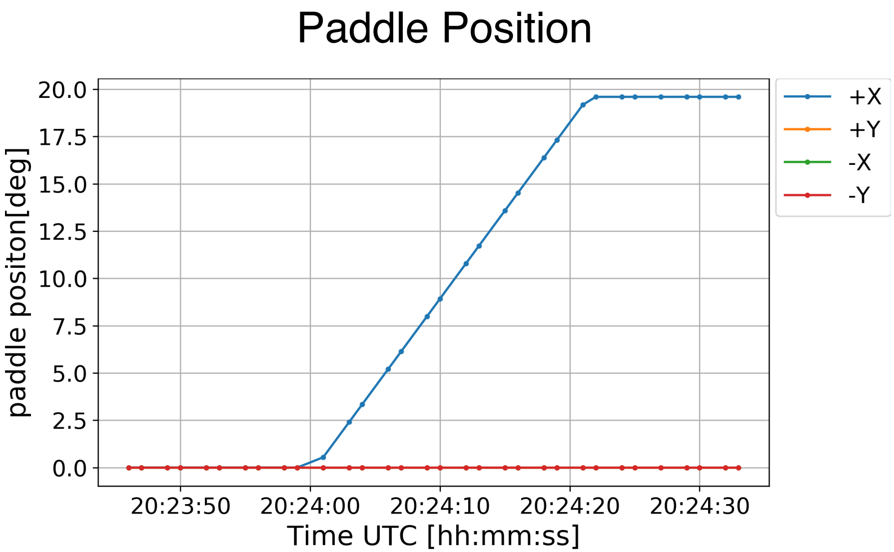
When the paddle is driven, the direction of the star stream changes!!

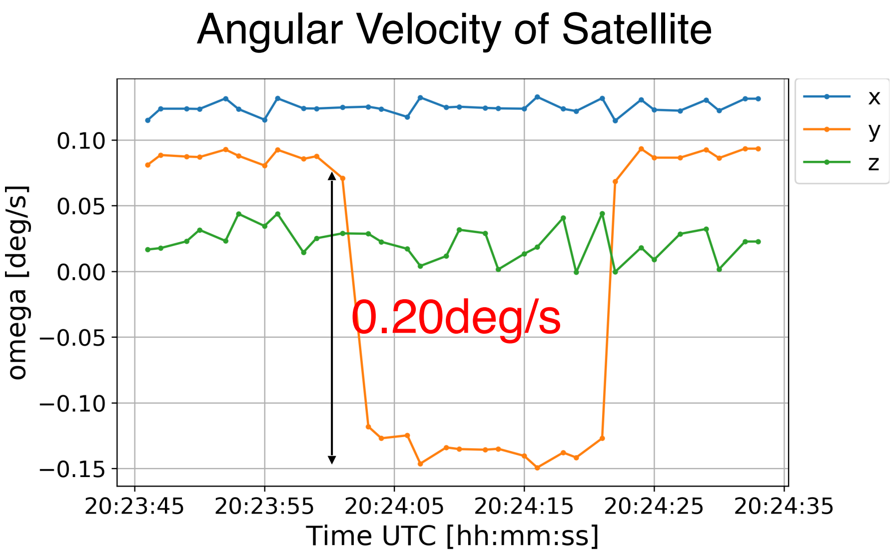
Operation Result - Paddle Drive Experiment(1/3)

Paddle +X : 0 → +20 deg, max drive angular velocity : 1 deg/s, max drive angular acceleration : 1 deg/s^2

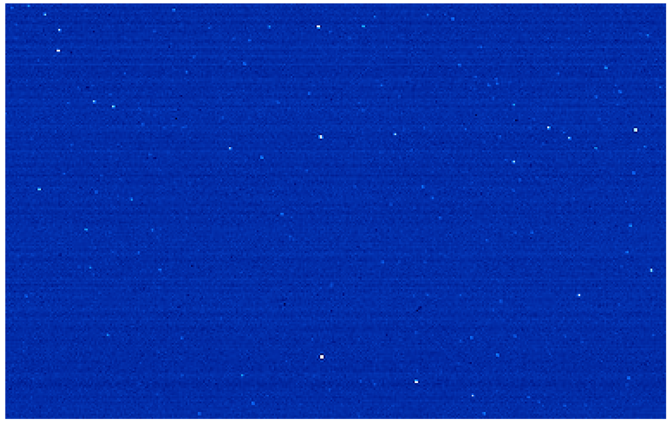
On-orbit simulation video(4x)







Star pictures taken during paddle drive (4x)



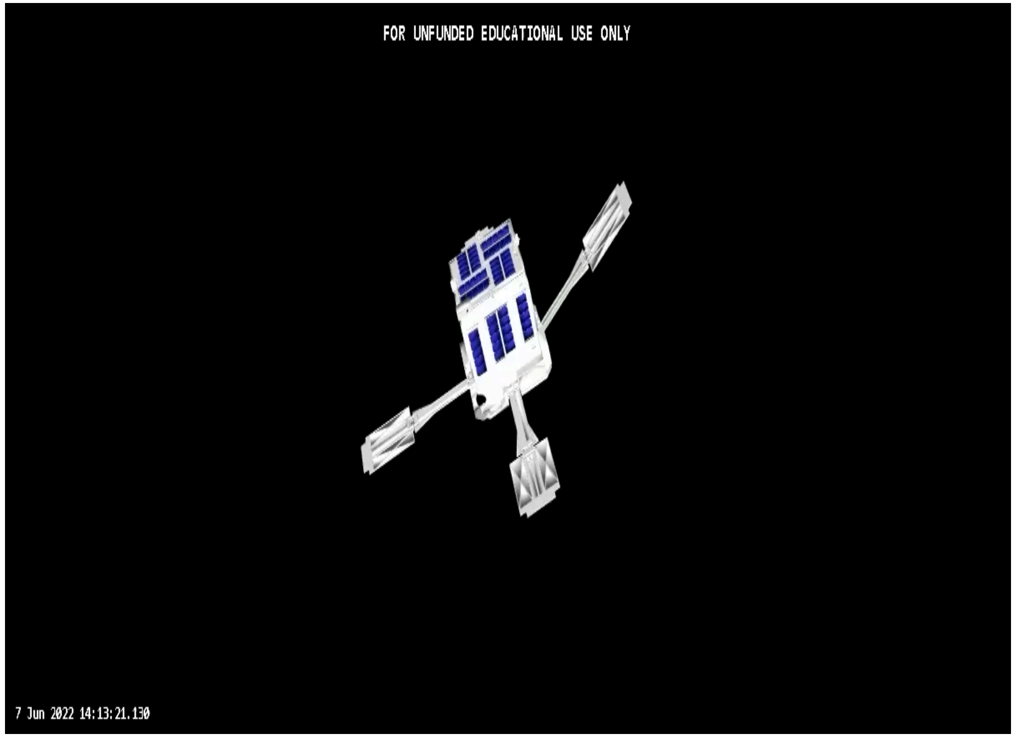
- The y-axis component of the satellite body angular velocity is generated by the reaction force torque during +X paddle drive
- This makes an attitude change equivalent to 4degrees

agility : 4deg/20seconds

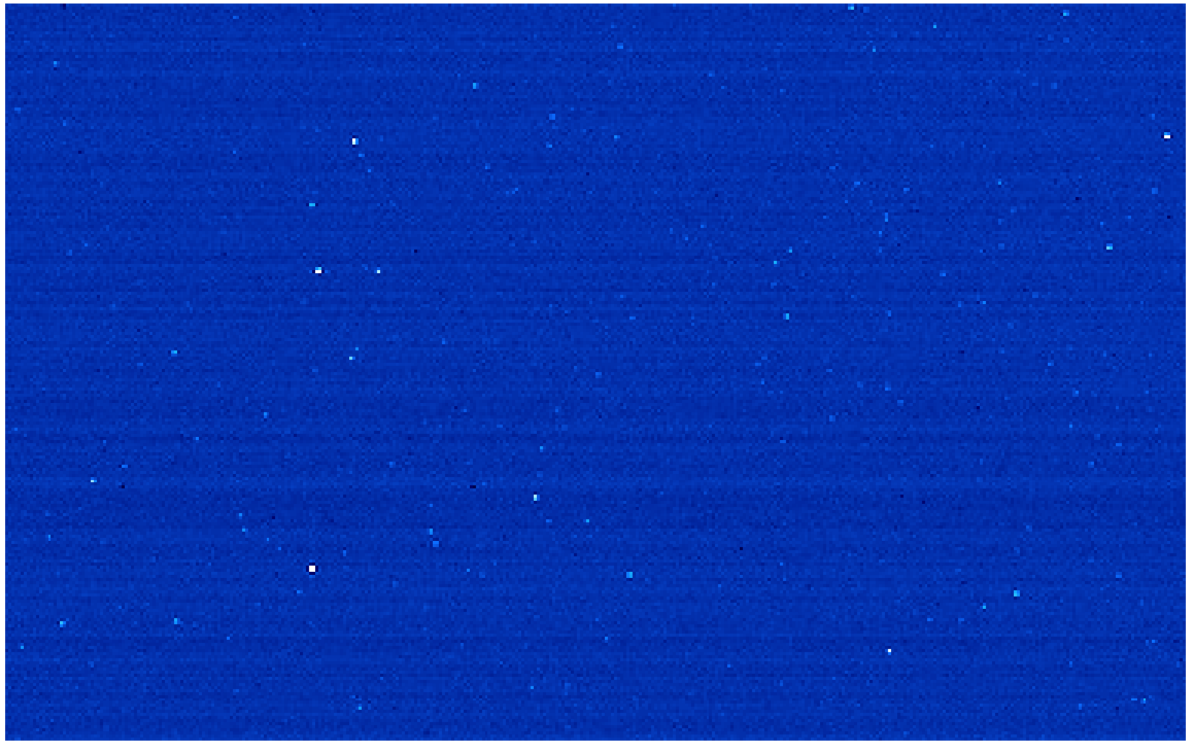
Operation Result - Paddle Drive Experiment(2/3)

Paddle +Y : -22 → +30 deg, max drive angular velocity : 2deg/s, max drive angular acceleration : 1deg/s^2

On-orbit simulation video(4x speed)



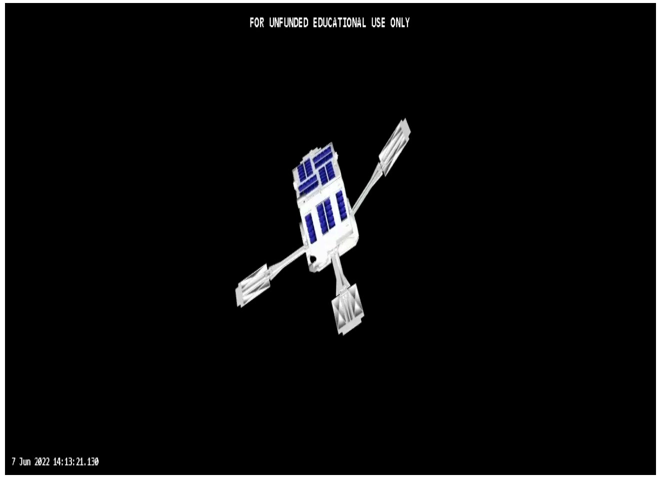
Star pictures taken during paddle drive (4x speed)



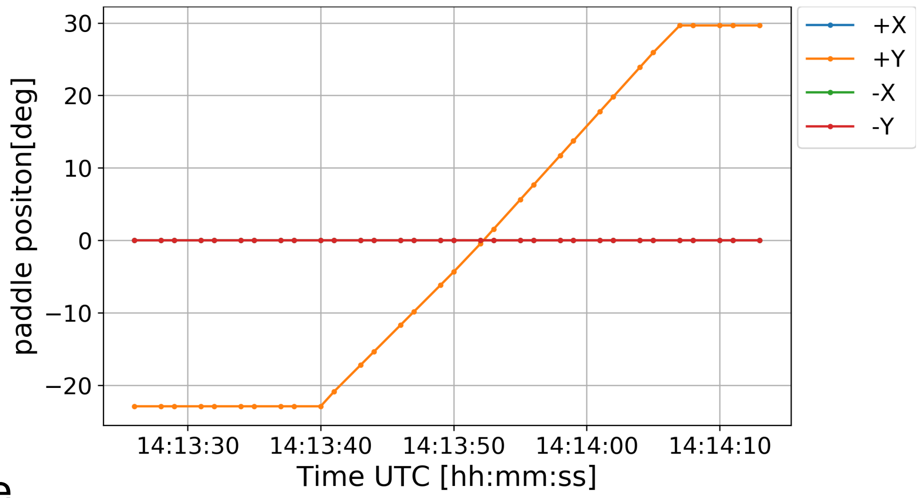
Operation Result - Paddle Drive Experiment(2/3)

Paddle +Y : -22 → +30 deg, max drive angular velocity : 2deg/s, max drive angular acceleration : 1deg/s²

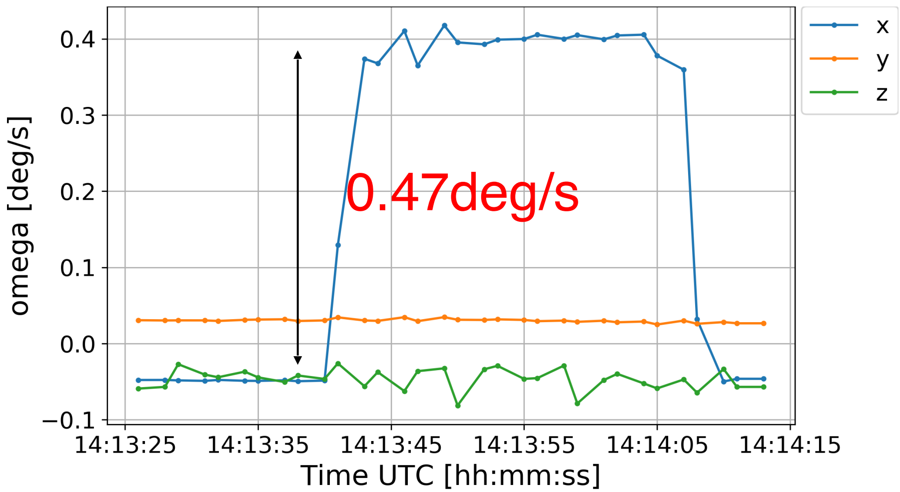
On-orbit simulation video(4x)



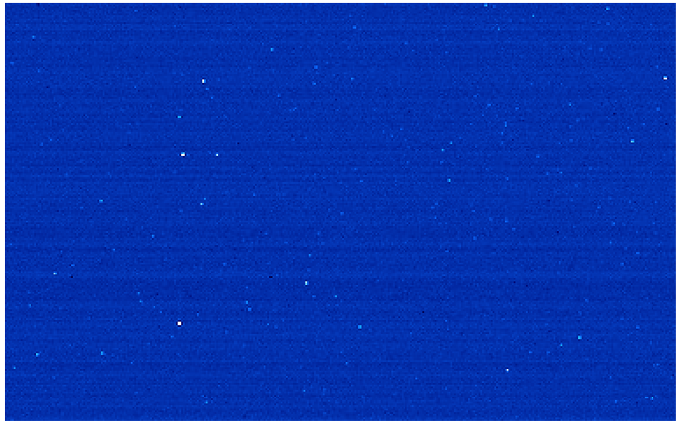
Paddle Position



Angular Velocity of Satellite



Star pictures taken during paddle drive (4x)



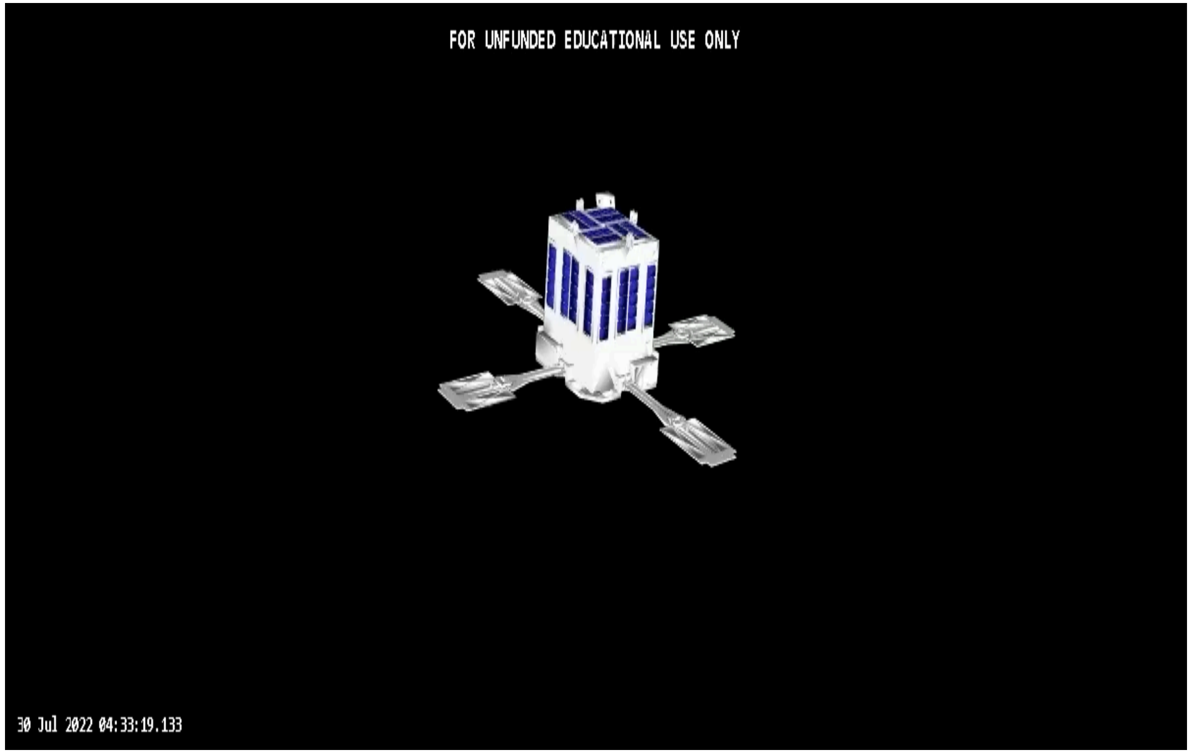
- The x-axis component of the satellite body angular velocity is generated by the reaction force torque during +Y paddle drive
- This makes an attitude change equivalent to 13degrees

Agility : 13deg/28seconds

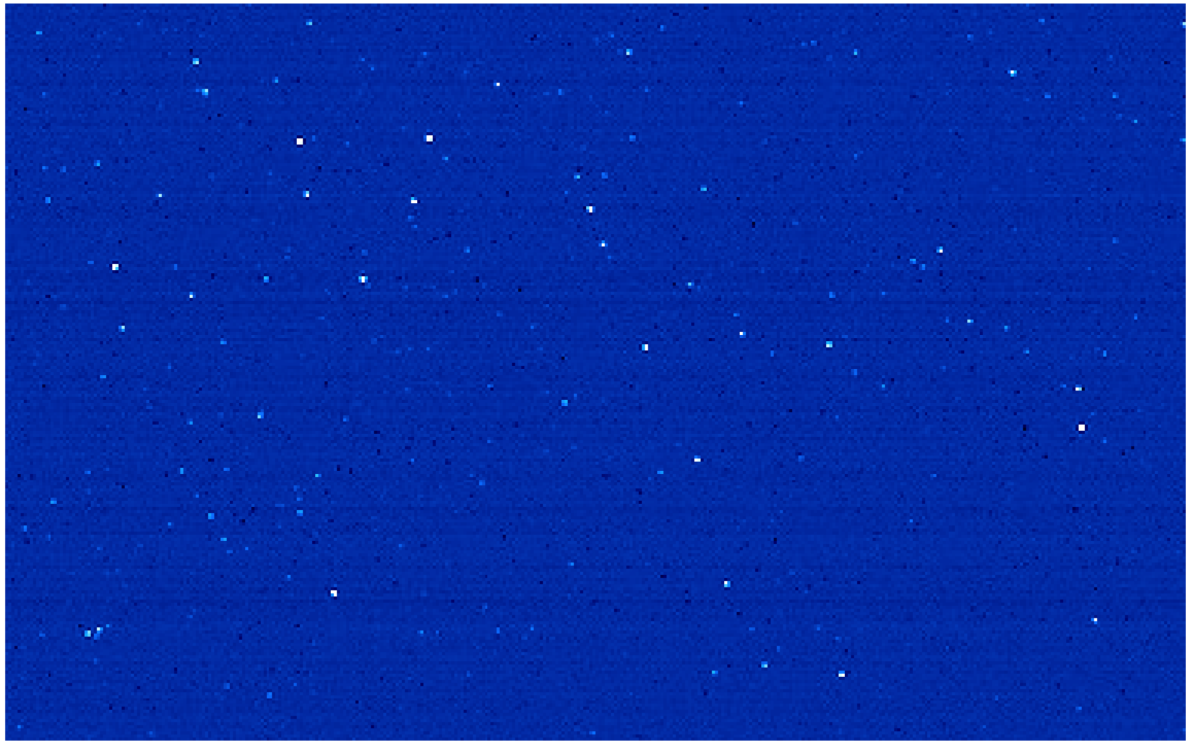
Operation Result - Paddle Drive Experiment(3/3)

Paddle +X : 0 → +60deg, Paddle –X : 0 → -60deg
max drive angular velocity : 4 deg/s, max drive angular acceleration : 1 deg/s^2

On-orbit simulation video(4x speed)



Star pictures taken during paddle drive (4x speed)

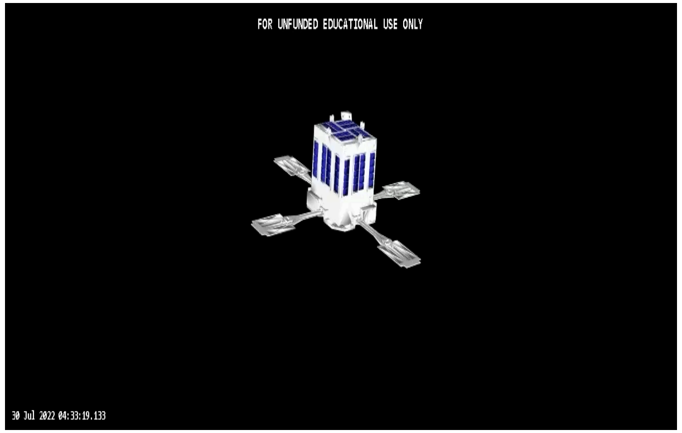


Operation Result - Paddle Drive Experiment(3/3)

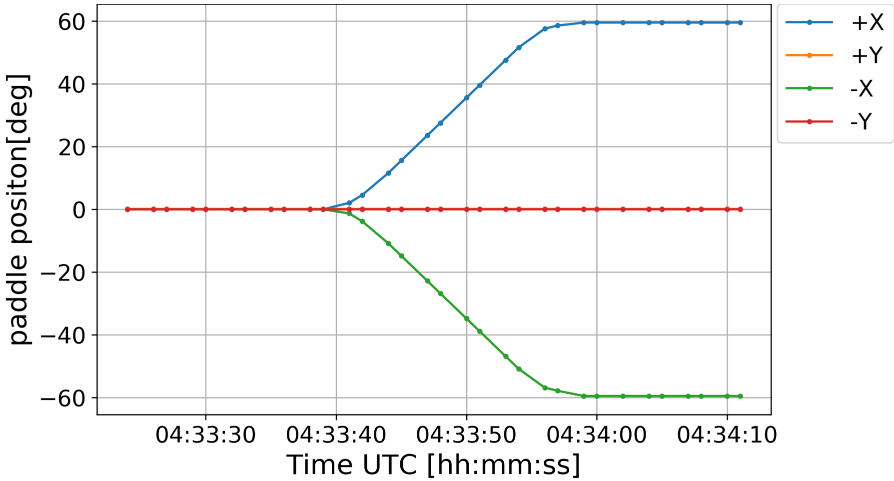
Paddle +X : 0 → +60deg, Paddle –X : 0 → -60deg

max drive angular velocity : 4 deg/s, max drive angular acceleration : 1 deg/s^2

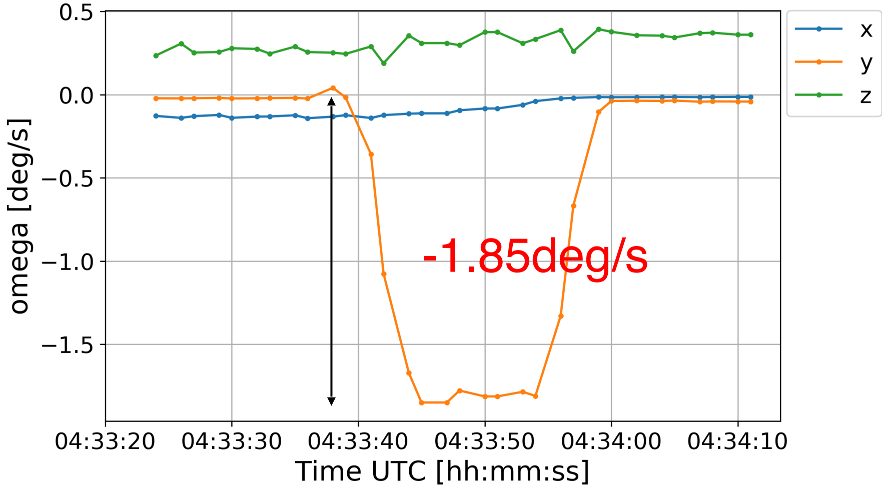
On-orbit simulation video(4x)



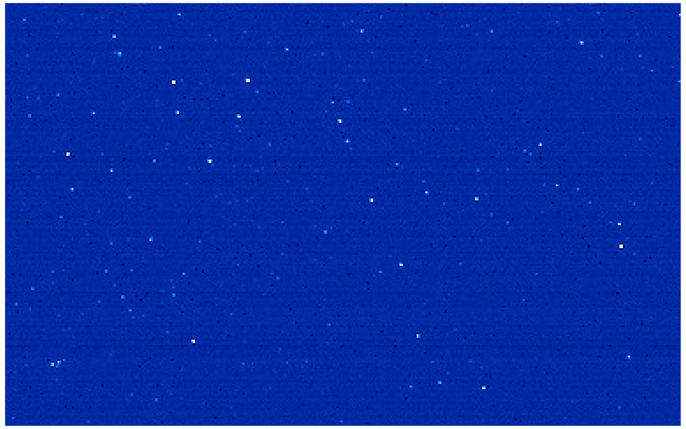
Paddle Position



Angular Velocity of Satellite



Star pictures taken during paddle drive (4x)



- The y-axis component of the satellite body angular velocity is generated by the reaction force torque during +X and -X paddle drive
- This makes an attitude change equivalent to 25degrees

Agility : 25deg/15seconds = 16deg/10seconds

Full success achieved!! (15deg/10seconds)

Conclusion

- We have developed the 50kg Variable Shape Function demonstration satellite HIBARI.

- HIBARI is doing paddle drive experiments on-orbit to evaluate performance as attitude control actuator and has achieved full success in terms of agility (15deg/10seconds, Equivalent to CMG, 2 times more than RW used in SmallSatellite).

- We aim to achieve further agility and stability with Variable Shape Function and apply it to applications such as multi-point observation.