# PETREL for Astrophysics and Carbon Business

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**ABSTRACT**

A multi-purpose 50kg class microsatellite hosting astrophysical mission and earth remote sensing, "PETREL", will be launched in 2023. In the night side, PETREL observe the ultra-violet sky with a wide-field telescope covering 50 deg^2 for surveying transient objects related to supernovae, tidal disruption events, and gravitational wave events. Our UV telescope can detect the early phase UV emission from a neutron star merger occurred within 150 Mpc. In addition to the satellite observation, PETREL sends a detection alert including the coordinate and brightness of the UV transient to the ground via the realtime communication network within several minutes after detection to conduct follow-up observations with the collaborating ground based observatories over the world. In the day side, PETREL observes the surface of the earth by using the tunable multi-spectral cameras and a ultra-compact hyperspectral camera. Our potential targets are the tropical forests (Green Carbon) and coastal zones (Blue Carbon) in the tropical areas to evaluating the global biological carbon strages. For this purpose PETREL will conduct multiple scale mapping collaborating with drones and small aircraft not only satellite. The obtained data will be used for academical research and for business applications. The technical difficulty of this satellite is that carries out multi-purpose with different requirements, such as astronomical observations which requires a quite high attitude stability and the earth observations requiring a high pointing accuracy, with limited resources. If it is possible, a novel small satellite system or a business style can be realized that can share the payload with academia and industry. PETREL has been adopted as Innovative Satellite Technology Demonstration Program No.3 led by JAXA, and development is underway with the aim of launching in FY2023.

## INTRODUCTION

The research and development of the micro-satellite "PETREL"[1] is currently being carried out by an industry-academia collaborative team of several universities and companies, led by the Tokyo Institute of Technology, which are mutually sharing their strengths and cooperating with each other. PETREL has been selected for JAXA's Innovative Satellite Technology Demonstration No. 3 program, which aims to conduct multiple missions with a single satellite: land and ocean earth observation in day side and ultraviolet astronomical observation in night side. This will enable the realization of a new satellite format in which multiple objectives, such as business and science, can coexist.

## PROJECT PETREL

### *Project Overview*

We are conducting research and development by establishing an industry-academia collaboration team, aiming at the development of environmental business including space observation and the development of science by ridesharing of satellites. In earth observation, we focus on marine "blue carbon" (mangroves, seaweeds, and coral reefs) around the tropics to observe carbon dioxide absorption and emission, and to evaluate their biological activities.

Fig.1 shows an overview of Project PETREL, which aims to observe the Earth from various altitudes. We will observe the earth from various altitudes by cooperating with other devices such as aircraft and drones, and map the ecosystem by fusing data with different resolutions. As an observation method, we employ spectroscopic imaging in the visible light range. This is because photochemical reactions of photosynthetic plants mainly take place in the visible light range.

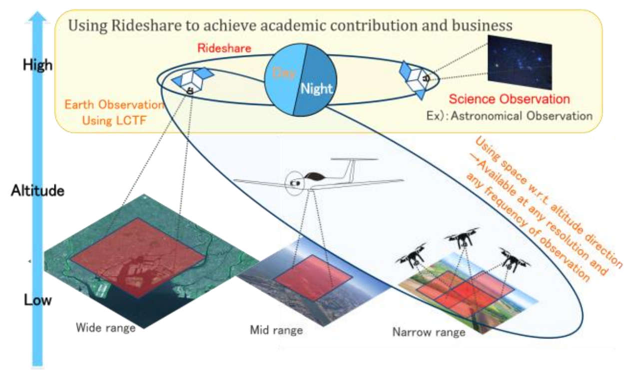


Fig. 1 Overview of Project PETREL

***Satellite Mission***

In the case of the Earth observation described above, a satellite can observe the Earth in the day side, but is on standby in the night side. In order to make effective use of this night side term, this satellite mount the ultraviolet telescope for astronomical observation (ride-sharing).
This telescope mounted on the satellite will observe instantaneous explosive phenomena such as neutron star binary mergers and supernova explosions, aiming to pioneer the field of time-domain astronomy.

As described in the previous sections, this satellite will realize two different missions with different requirements: the Earth observation focusing on blue carbon and the astronomical observation focusing on ultraviolet rays. The following sections describe the design and development status of the satellite system.

## SATELLITE SYSTEM

***System Overview***

This satellite is based on the knowledge obtained from the Variable Shape Attitude Control Demonstration Satellite "HIBARI"[2][3] developed by the Matsunaga-Chujo Laboratory of the Tokyo Institute of Technology, and is being developed by adding improvements and new elements for actual applications such as earth observation and astronomical observation, which are missions of the PETREL satellite.

Fig.2 shows an external view of the PETREL satellite, Table.1 shows its specifications, and Fig.3 shows its system diagram. The satellite consists of a satellite bus (CDH, COMM, EPS, and ADCS), and a mission system (earth observation and UV).

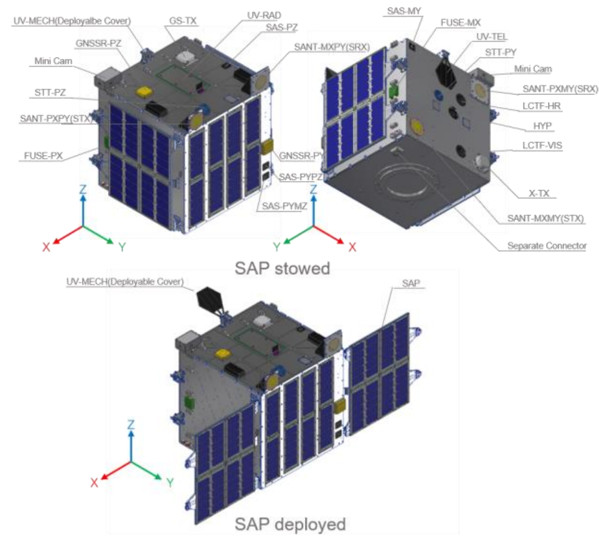


Fig. 2 Appearance of PETREL

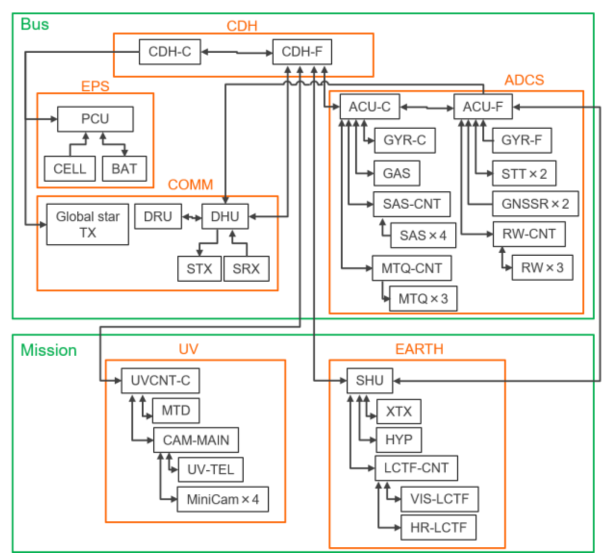


Fig. 3 System diagram

The coarse system with high radiation resistance handles processing that requires high reliability, while the fine system with high computing power handles command handling, control law operations, and other processing. The CDH and ADCS are equipped with an IF for communication with the outside of the satellite to facilitate debugging and HiLS, which simulates on-orbit dynamics and environment.

The HIBARI satellite did not use PPS because of low requirements for time management and program timing, but this satellite requires time management and timing management of each OBC due to the requirements of the observation mission. Therefore, it was necessary to modify the circuit board to be able to distribute the PPS to each system based on the PPS obtained from the GNSSR.

Table. 1 PETREL specification

| | Content |
|---|---|
| Mission | Hyper/Multi Spectral Earth Observation<br>Ultraviolet Astronomical Observation |
| Structure/Size | 1280×490×610 (Deployment)<br>2 deployable Solar array paddle |
| Mass | <65kg |
| Power | Power generation: 150.7W<br>Battery capacity: 9600mAh |
| Attitude Control | STT-based 3-axis control |
| Communication | S-band UP: 1Kbps<br>S-band DOWN: 100K~1Mbps<br>X-band DOWN: 20Mbps<br>Global Star: 9byte/packet or over |
| Data Storage | Mission Data (SHU): 64GByte×2<br>HK (DRU): 2GByte |

In addition, although dedicated circuit boards had been designed and made for each subsystem, the development of new satellites including PETREL required detailed changes in voltage settings and communication standards for each component, making circuit board modifications indispensable. Therefore, based on the boards developed for PETREL a power distribution board (mPDU board) and communication boards (ACU-C board and ACU-F board) were newly made. As a result, the same combination of boards can function as subsystems for CDH, ADCS, etc., and can operate a variety of devices (Fig.4).

In addition, based on the ACU-C board, a board that supports analog sensor value input (SAS-CNT board) and a board equipped with a driver circuit (MTQ-CNT board) were also created. The common use of these boards enabled the common use of software, which led to a reduction in development man-hours while improving the quality of the boards.

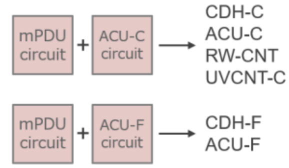

Fig. 4 Circuit Board Commonality

### *Configuration*

Fig.5 shows a diagram of the field-of-view layout of the each component. The main field-of-view-requiring equipment is placed in the ±Y plane, where there is no field-of-view obstruction by the SAP. The solar cells are placed in the +Y plane and are oriented to this surface when the sun oriented attitude. The UV-RAD (Heat dissipation surface), which requires a field of view in the orthogonal direction to the observation axis (-Y axis), is located in the +Z plane, and the attitude control is performed to prevent sunlight and earth albedo from entering this plane, especially in the standby attitude in normal mode and the UV astronomical observation attitude described below.

The STT for the earth observation attitude (STT-PZ) has an offset angle to the Y-axis to avoid direct sunlight when the satellite is sun oriented attitude. STT, GNSSR, SANT, etc., which may not be used depending on the satellite's attitude due to the field of view, are prepared and arranged in multiple locations. These are used by switching them as necessary.

The hexagonal deployable cover shown in Fig.1 is installed to prevent contamination from solid fuel from adhering to the UV telescope during launch.

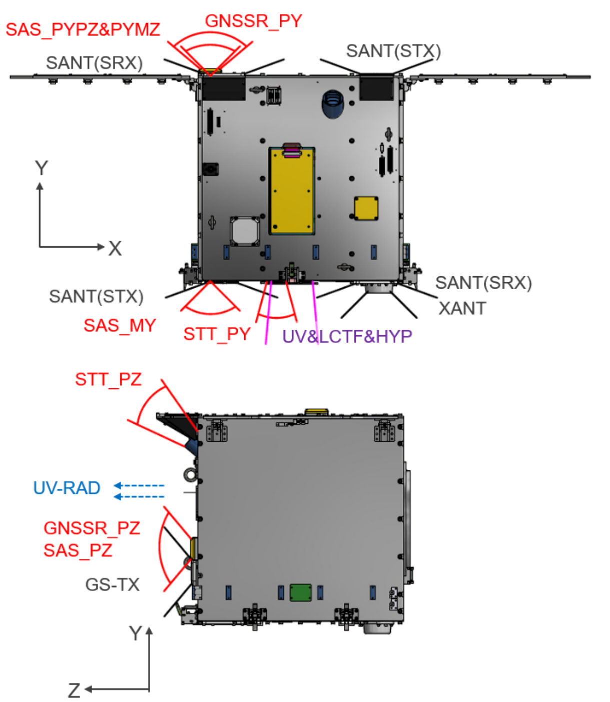


Fig. 5 FoV layout of component

### *Satellite Mode*

Fig.6 shows the satellite mode transition diagram and Table.2 shows the definition of each mode. Satellite modes are distinguished according to the power supply status and attitude control, operation details at each operation. In addition, sub modes are provided under satellite modes. The sub modes do not spread to all systems, but are defined as those whose operation changes only within a few systems. This simplifies the system by eliminating the need to provide satellite modes for all sub modes.

In the event of a satellite release or power reset, the system first transitions to the initialize mode and then transitions autonomously to the critical mode or safe mode depending on the SAP deployment status. If an anomaly occurs in the satellite after SAP deployment, the system autonomously transitions to safe mode and returns to normal mode by command based on the judgment of the ground.

In normal mode, the satellite adopts a three-axis sun-oriented control (standby attitude) in consideration of the heat dissipation surface of the scientific components, recharges the satellite in the sunshade or toward the mission, and performs communications such as command uplinks in the S-band. When a large-capacity data downlink is required, the satellite is shifted to the downlink mode by command and pointed to the ground station. In the earth observation mode and astronomical observation mode, which are the missions of the satellite, the satellite uses the IAS (Image Attitude Sequence) as an imaging sequence to control the attitude and take images.

Each mode is basically preset with fixed settings such as power on/off and attitude control mode, which can be rewritten on orbit.

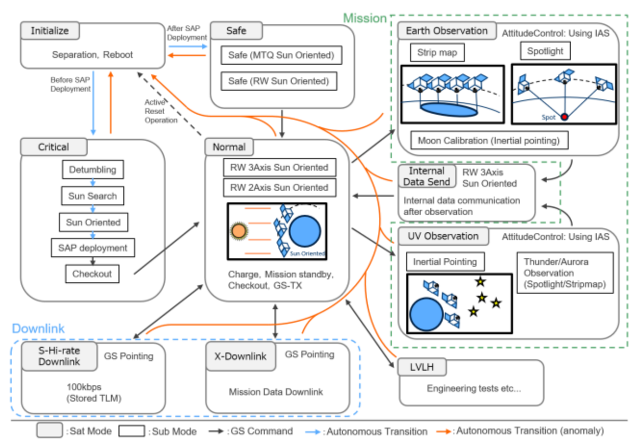


Fig. 6 Sat mode transition diagram

Table.2 Definition of Sat mode

| Sat mode | Content |
|---|---|
| Initialize | Enters at satellite reboot.<br>Each power supply startup and SAP<br>The mode is selected according to the deployment status (critical or safe) and performs autonomous transition. |
| Critical | From satellite release to the establishment of sun oriented control.<br>Detumbling, sun search, and sun oriented control are performed. and later SAP deployment. |
| Safe | In the event of an anomaly<br>The purpose is to ensure the safety of the satellite. |
| Normal | Satellite charging for sunshade and mission during normaly operation. |
| S-Hi-rate Downlink | HK data downlink<br>Real time communication |
| X-Downlink | Mission data downlink |
| Earth Observation | Capture the earth surface image using LCTF/HYP camera. This mode has following sub mode.<br>・Strip map mode<br>・Spotlight mode<br>・Moon calibration mode |
| UV Observation | Mainly astronomical observation using ultraviolet telescope. This mode has following sub mode.<br>・Inertial Pointing<br>・Thunder/Aurora observation |
| Internal Data Send | For mission data communication inside the satellite |
| LVLH | Maintain the LVLH attitude.<br>Using engineering test. |

### *Image Attitude Sequence*

This satellite is aware of generalization from any perspectives. One of them is the Image Attitude Sequence (IAS). The satellite has different attitude control requirements for earth observation and astronomical observation, and different control laws and commands for each of these would complicate the system. The IAS is a combination of actions used in the guidance sequence, such as image capture preparation, aiding start attitude, and position of the image capture start point, which are switched by parameters. The fig.7 shows an overview of IAS. First, after arriving at the latitude argument for the start of image capture preparation, the satellite maneuvers from an arbitrary attitude to the attitude for the start of the image capture approach run.

Then, when it reaches the specified point on orbit, it starts a run toward the angular velocity required for image capture, enters the target area, and captures images. This allows the required attitude and satellite angular velocity to be stabilized before imaging.

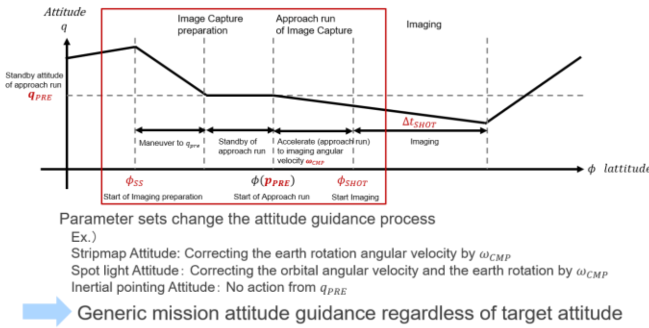


Fig. 7 Image Attitude Sequence

## DEVELOPMENT

PETREL was originally scheduled to be installed on JAXA's Epsilon Launch Vehicle No. 6, but due to a change in the launch scheme, the launch vehicle was changed and various preparations and adjustments are underway. The mechanical environment has been changed accordingly, so the satellite's main structure has been remanufactured, the thermal design has been reviewed, and various mechanical environment tests, such as vibration tests and thermal vacuum tests, are in progress.

The electrical system has almost completed the operation check of each onboard component and the coupling between subsystems, and the onboard software, including the implementation of the various satellite modes mentioned above, is being developed, and performance evaluation tests using HiLS simulating the on-orbit environment, health checks, and operational practice are in progress. PETREL is currently under development with the aim of launching in FY2023.

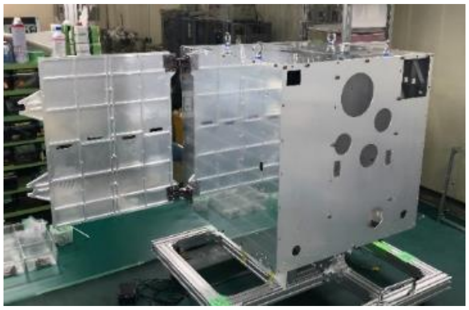

Fig. 8 pre-assemble of structure

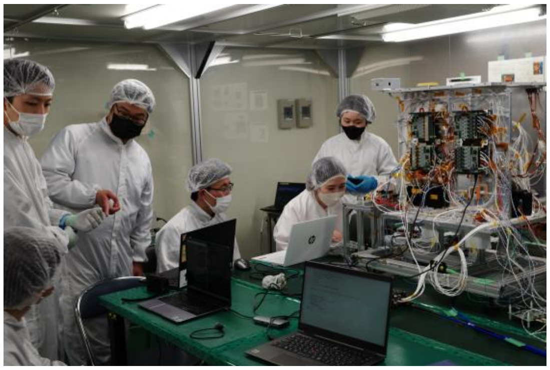

Fig. 9 Electrical Performance Test

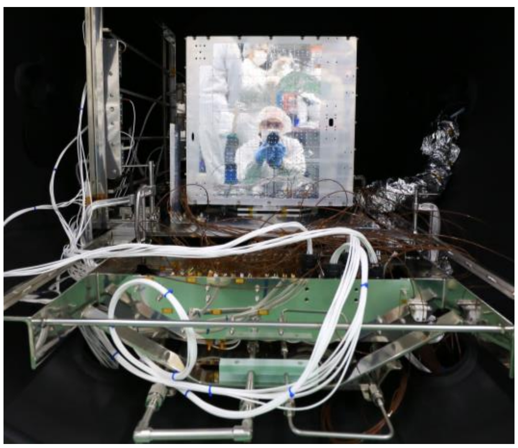

Fig. 10 Telescope Thermal Vacuum Test

**CONCLUSION**

This paper described the system design and current development status of the microsatellite PETREL, which is currently under development. In order to achieve the coexistence of multiple objectives such as business and science, we are constructing a simple satellite system by finding commonalities and generalizing the system (common electronic circuit board, common attitude control, etc.) to prevent the system from becoming too complex. In addition, development toward launch is being promoted through industry-academia collaboration by sharing each other's advantages.

***Acknowledgments***

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