Flight Demonstration Results of the 50kg-class Deep-space Probe (PROCYON)

-Initial Acquisition at Warkworth Observatory and X-band VLBI Technologies-

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4th International VLBI Technology Workshop

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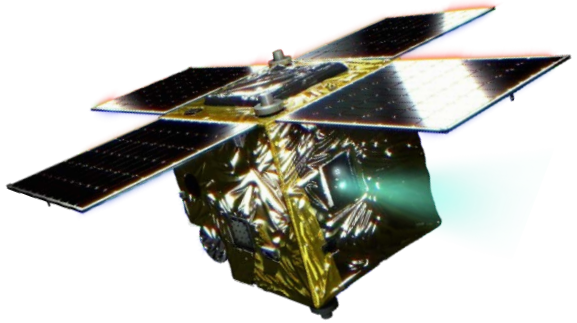
- Remote telemetry demodulation
- Summary

PROCYON

（PRoximate Object Close flYby with Optical Navigation）

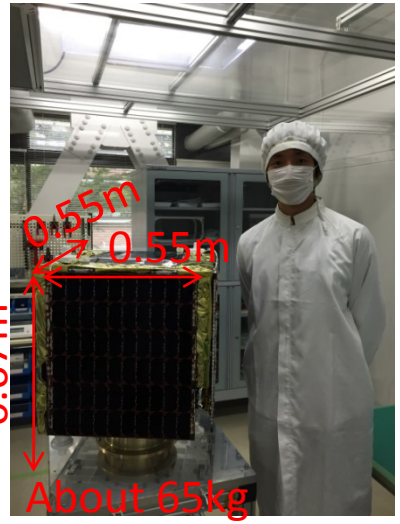
The world's first, full-scale, 50kg-class deep-space probe

- Jointly developed by the Univ. of Tokyo and JAXA/ISAS just 1 year
- Launched as a secondary payload of HAYABUSA2 on 3 Dec. 2014



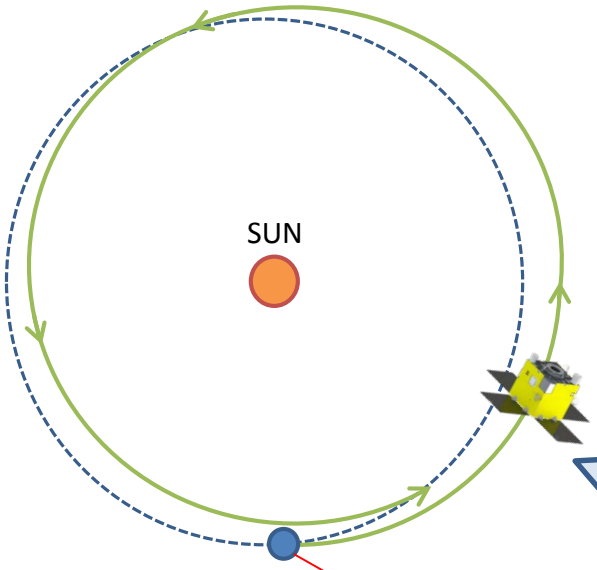
Physical dimension	0.67 × 0.55 × 0.55 m
Weight	67 kg (wet), 65 kg (dry)

- Having almost every key technologies for deep-space exploration
  - Attitude and orbit control system
    - RW, FOG, STT, and NSAS
  - Reaction control system / Electric propulsion system
    - Xe cold gas jet thruster and Xe ion thruster
  - Navigation system
    - Coherent 2-way range, Doppler, and DDOR
  - X-band deep-space telecommunication system
    - UL: 7.1 GHz, DL: 8.4 GHz



Primary Mission

Demonstration of micro-spacecraft bus system for deep space exploration (requires 2~3 months)

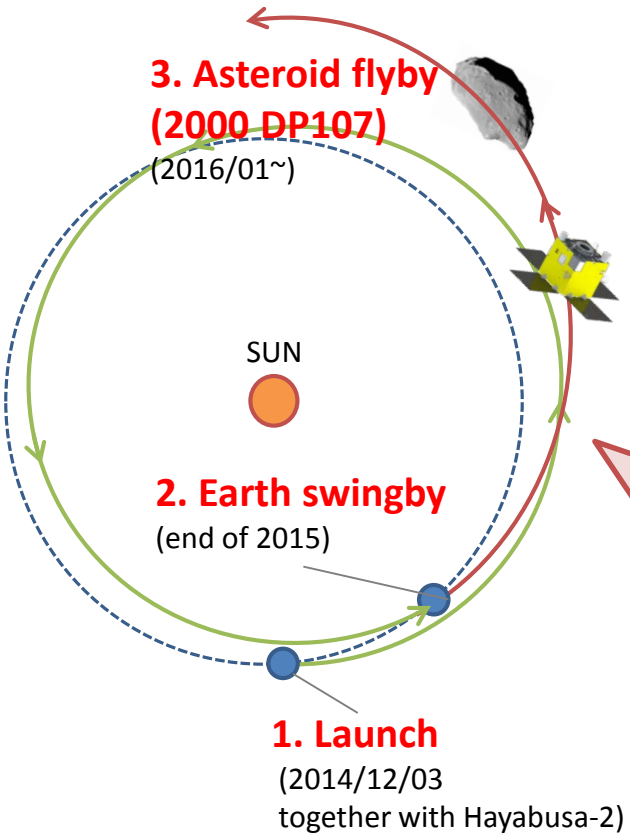


Launch
(2014/12/03,
together with Hayabusa-2)

- **Power** generation/management (>240W)
- ***Deep space thermal design** (to accommodate wide range of Solar distance (0.9~1.5AU) and power consumption mode (EP on/off))
- **Attitude** control (3-axis, 0.01deg stability)
- ***Deep space communication & navigation**
  - High efficiency (GaN SSPA, >30%)
  - High RF output (>15 W)
  - Precise nav by novel "Chirp DOR"
- ***Deep space micro propulsion system**
  - RCS for attitude control/momentum management (8 thrusters)
  - Ion propulsion system for trajectory control (1 axis, Isp=1000s, thrust=300uN, overall ΔV=400m/s)

Secondary (advanced) Mission

Engineering/Scientific mission to advance/utilize deep space exploration (~L+1.5yr)



[engineering mission]

1. **Deep space maneuver** to perform Earth swingby and trajectory change to target an asteroid flyby
2. **High-res observation of an asteroid during close (<30km) and fast (~10km/s) flyby**
   - Optical navigation and guidance to an asteroid
   - Automatic Line-of-sight image-feedback control to track asteroid direction during close flyby

[scientific mission]

1. **Wide-view observation of geocorona** with **Lyα imager** from a vantage point outside of the Earth's geocorona distribution

Current mission status

- **Demonstration of deep space bus system**
  → success!
- **Scientific mission** (geocorona observation)
  → success!
- All the mission were successful excluding **the long-time deep space maneuver** and the subsequent **asteroid flyby**
  (because of a trouble of ion propulsion system)

Demonstrated **the capability of this class of spacecraft to perform deep space mission by itself** and it can be a useful tool of deep space exploration

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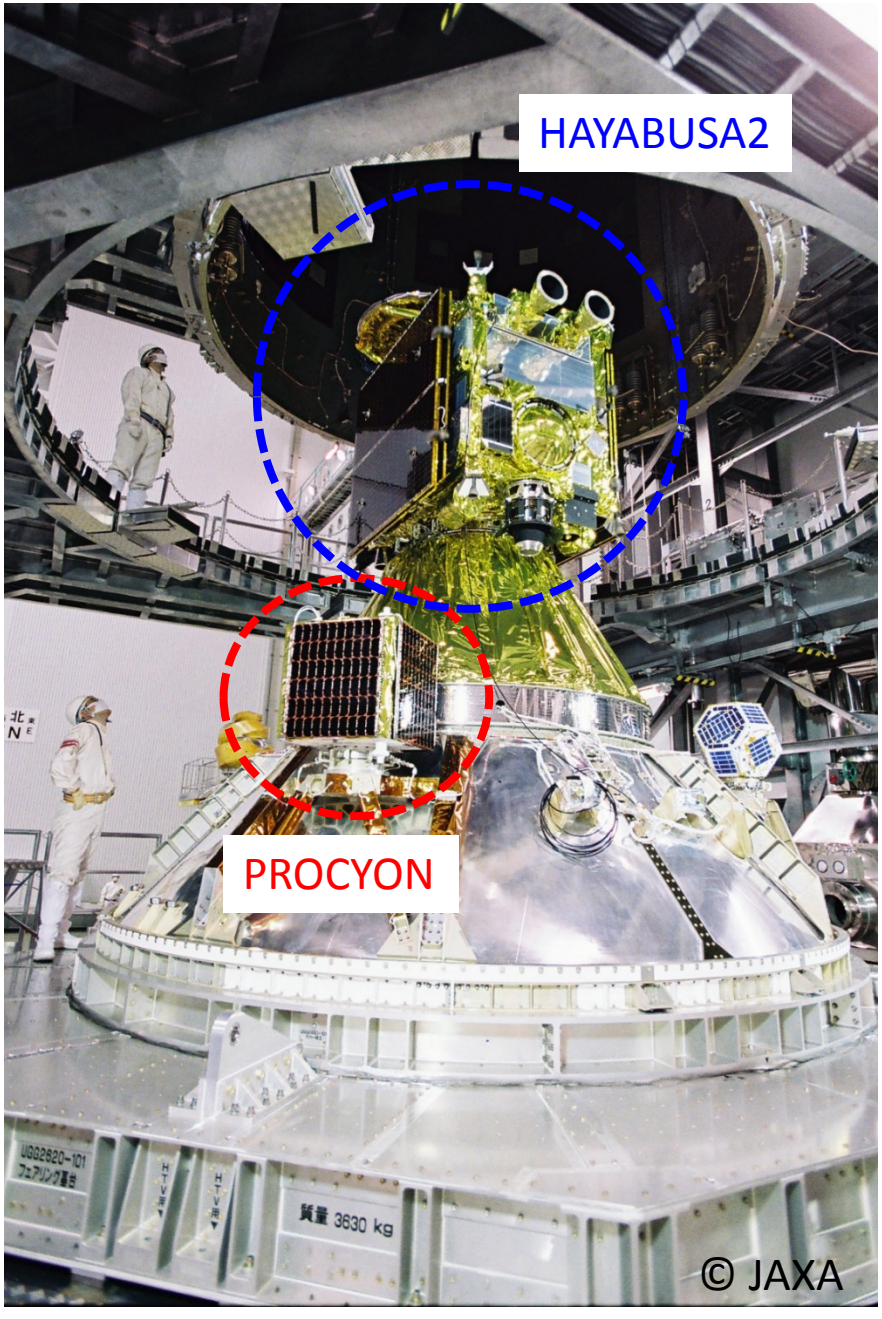
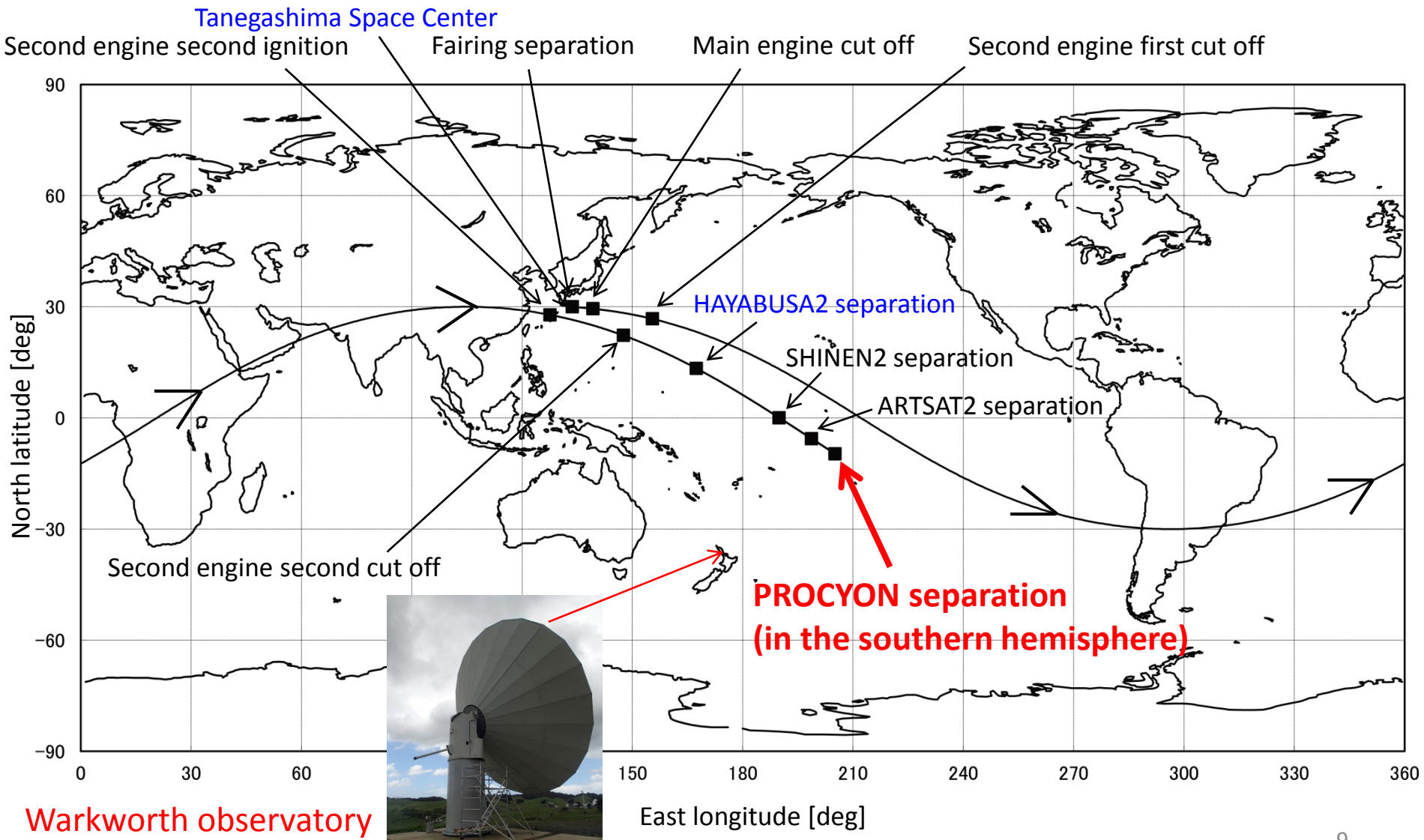

HAYABUSA2
PROCYON
質量 3630 kg
© JAXA


H-IIA rocket
NIPPON
© JAXA

Trajectory of H-IIA rocket



Warkworth observatory
12m antenna

Initial acquisition at Warkworth observatory

- PROCYON separation: in the southern hemisphere

- The first opportunity to track PROCYON
  - Japan: (UTC)10:10:16
  - New Zealand: (UTC)6:24:19 (about 3.5 hours earlier) Movie

- Initial acquisition at Warkworth observatory
  - Significant to confirm the initial condition of PROCYON

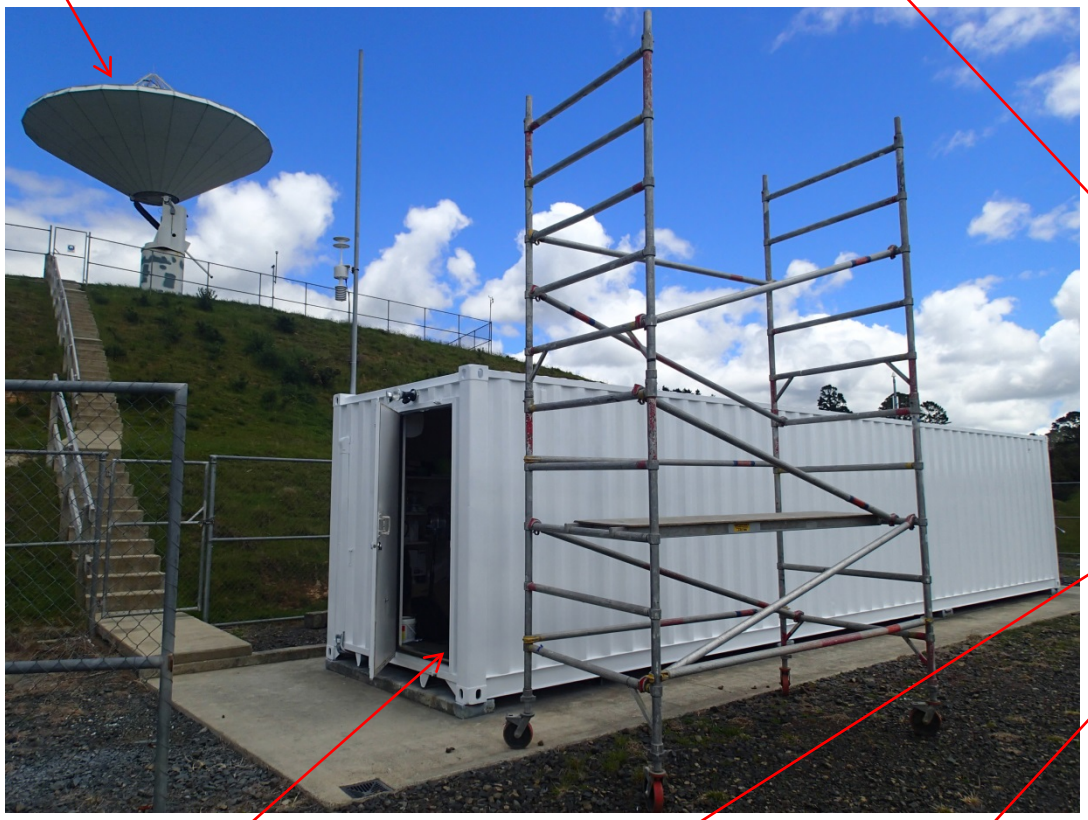
- Carrier monitoring system
  - Realized by the kind support from the AUT (Auckland University of Technology)

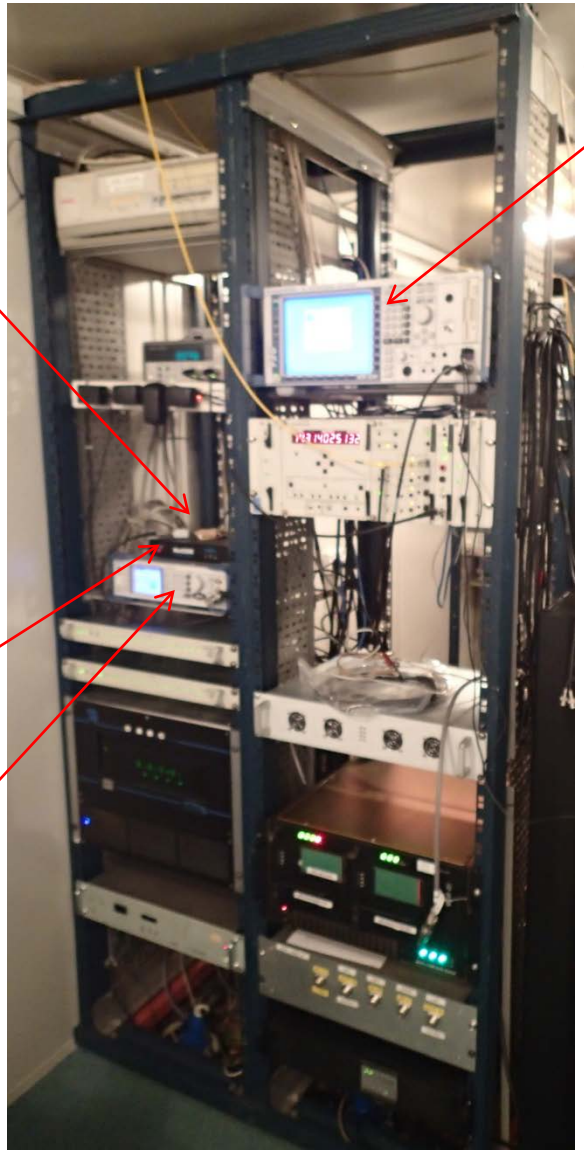
Carrier monitoring system
at Warkworth observatory 12m antenna

12m antenna

Divider, LPF, Mixer, and BPF

Spectrum analyzer





Antenna control room

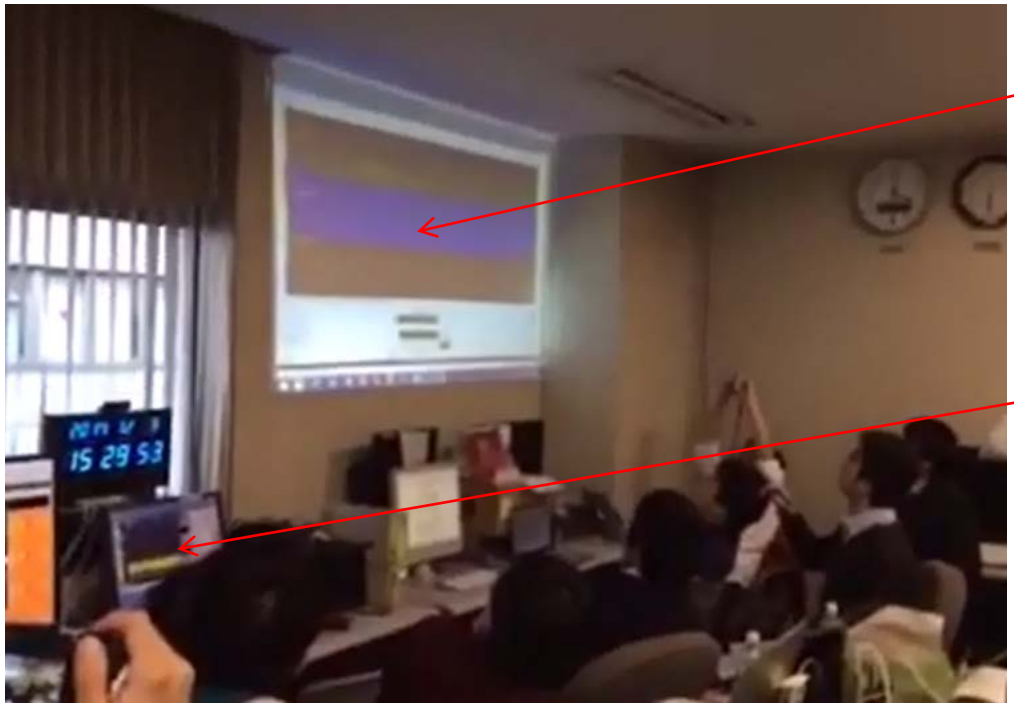
Signal generator

NetSDR

High performance 16 bit Software Defined Radio on the network

Flight operation results

- The carrier monitoring system successfully worked
  - Using Azimuth/Elevation antenna prediction data
  - Checking the initial condition (Detecting the first voice from PROYCON)
  - Confirming the deployment of solar array panels by using 1-bit communication (using the duration of modulated signal)



Operation room in JAXA on the launch day

Movie

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X-band DOR experiments

- X-band DOR technologies achieved in PROCYON mission
  - The world's first demonstration of Chirp DOR
  - The world's first DOR experiment between two space probes (HAYABUSA2 and PROCYON)
  - The world's widest tone bandwidth

World's first demonstration: Chirp DOR

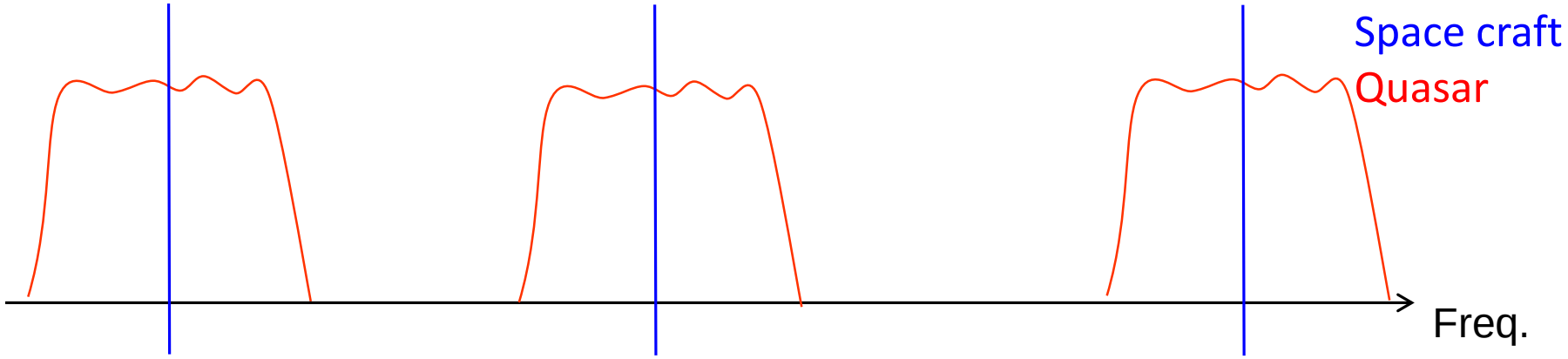
Conventional Delta-DOR measurement

Space craft : Tone (CW) signal
Phase detection: using a certain frequency

Quasar : Continuous spectrum
Phase detection: averaging in a certain bandwidth

Resulting in systematic error due to phase ripple in the band

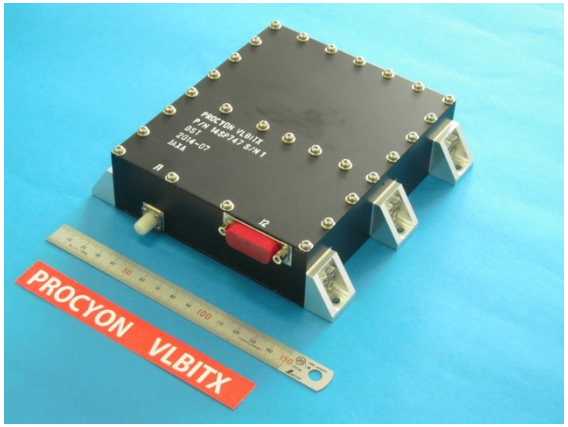
The principle limit of previous Delta-DOR measurement

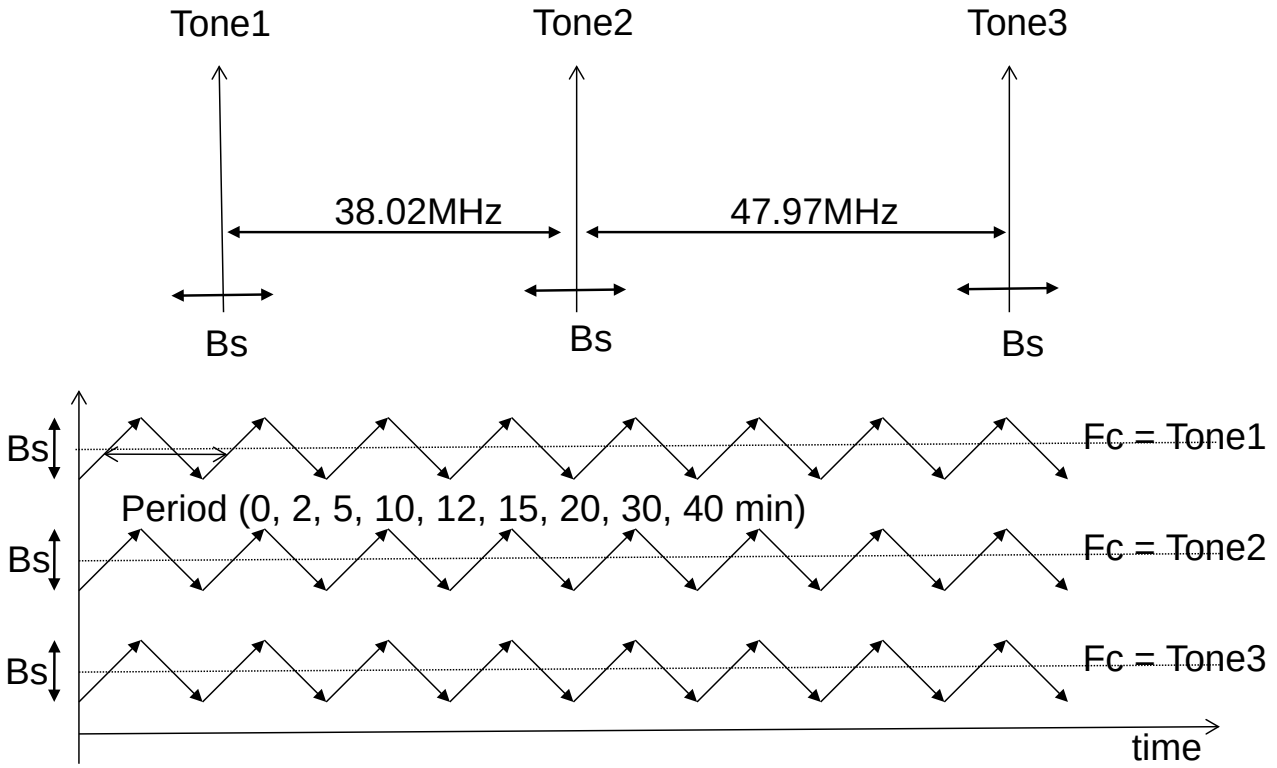


Chirp-DOR Space craft : sweep signal

Enable to cancel the systematic error with the aid of the equal bandwidth between space craft and quasar

Special VLBI transmitter

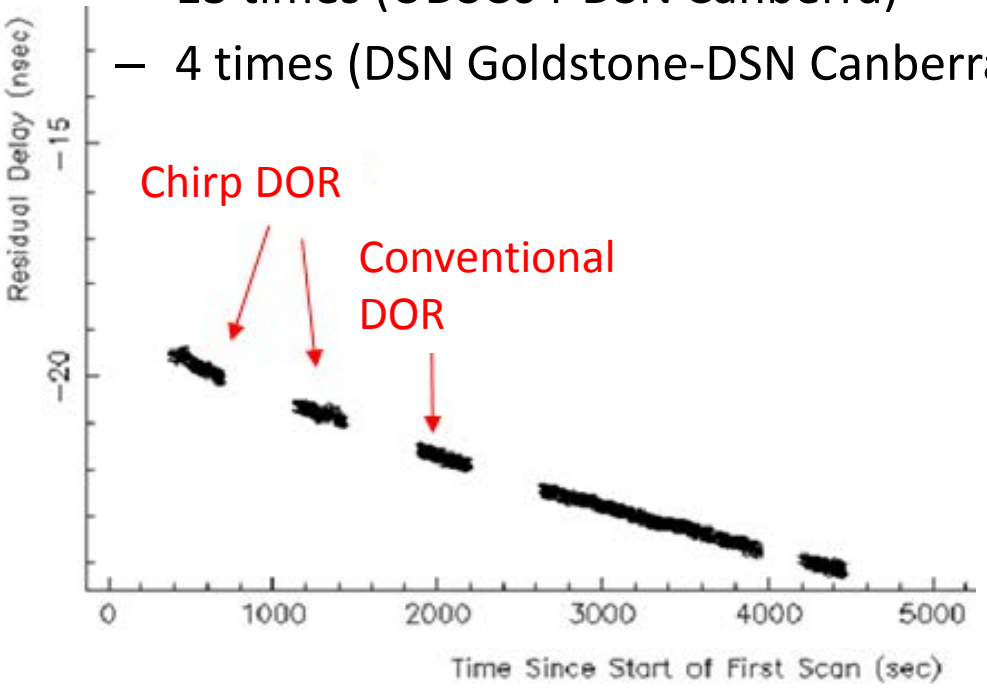


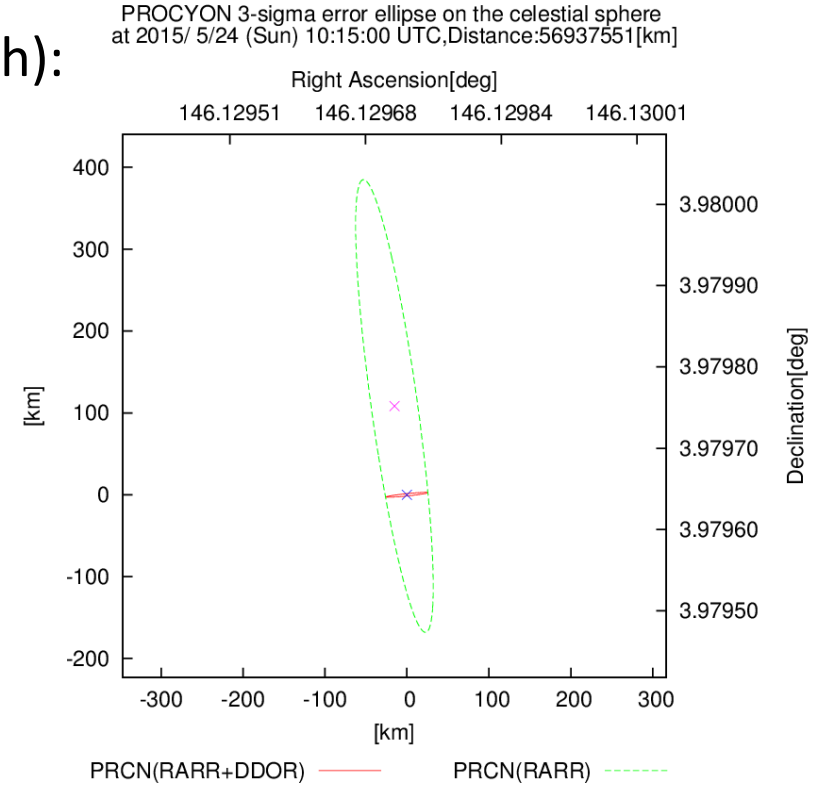


- Generating 3-synchronized tones the frequencies of which can be swept
  - The maximum sweep width: 7.9 MHz
  - Sweep time: between 2 and 40 minutes
- The bandwidth between Tone1 and Tone3 reached 86 MHz
  - The widest bandwidth of all previous X-band onboard VLBI transmitters

Flight demonstration results of DDOR experiments

- Chirp DOR experiment: 9 times
- DOR between HAYABUSA2 and PROCYON: 8 times
- DDOR experiments (the widest bandwidth):
  - 13 times (UDSC64-DSN Canberra)
  - 4 times (DSN Goldstone-DSN Canberra)





RARR only: σ = 93.0 km, 15.7 cm/s

RARR+DDOR: σ = 8.5 km, 5.5 cm/s

- Succeeding in acquisition of excellent data
- Developing and updating a software to analyze the data (Chirp DOR, two probes)
- Confirming the effectivity of the wideband DDOR

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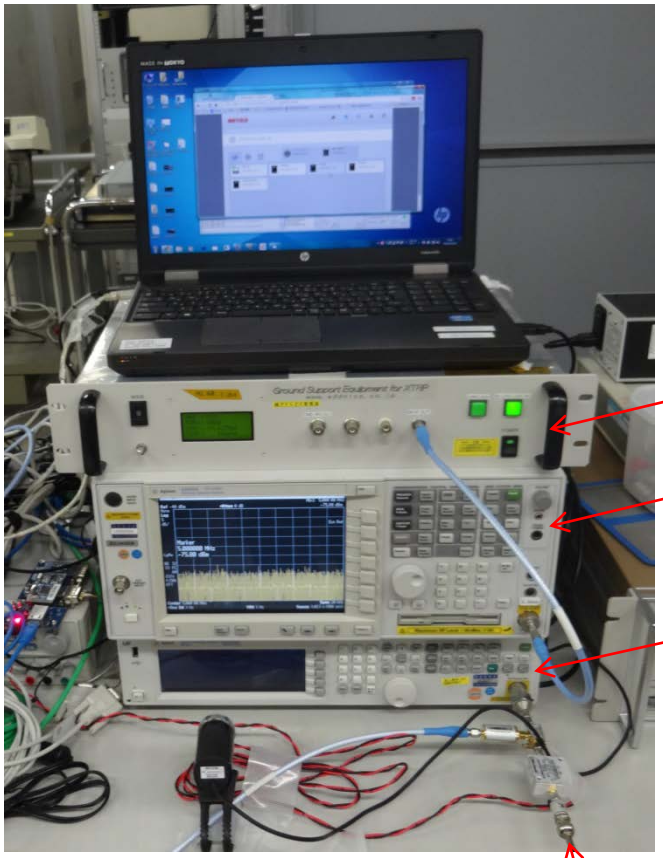
Remote telemetry demodulation system

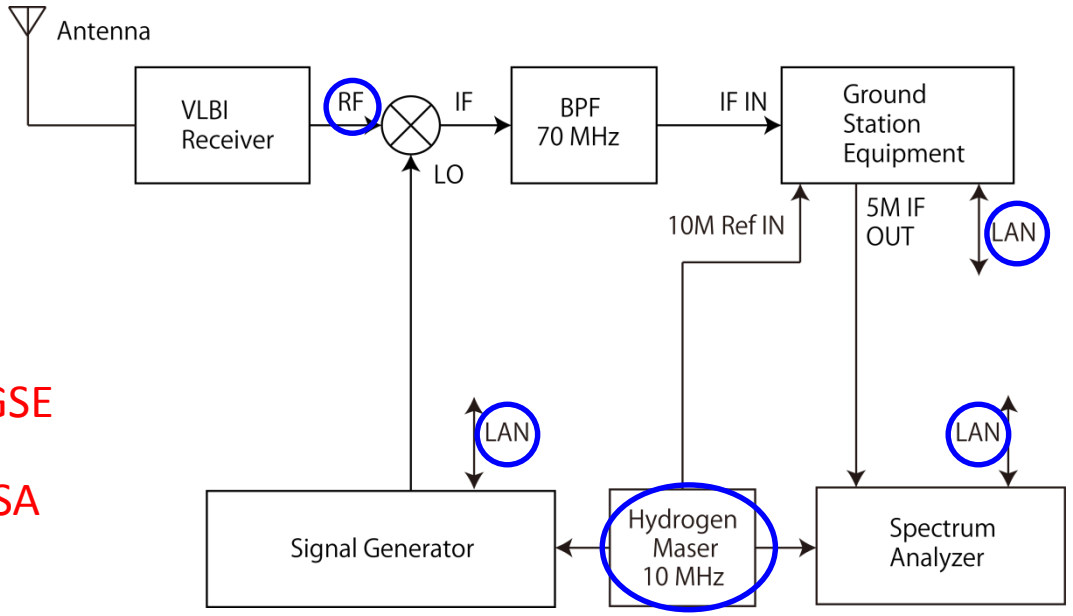
- PROCYON: Sub payload (Main payload: HAYABUSA2)
  - Having less opportunity to use deep-space centers compared with main mission
    - Mission priority: Sub mission << Main mission
    - Project budget: Sub payload << Main payload

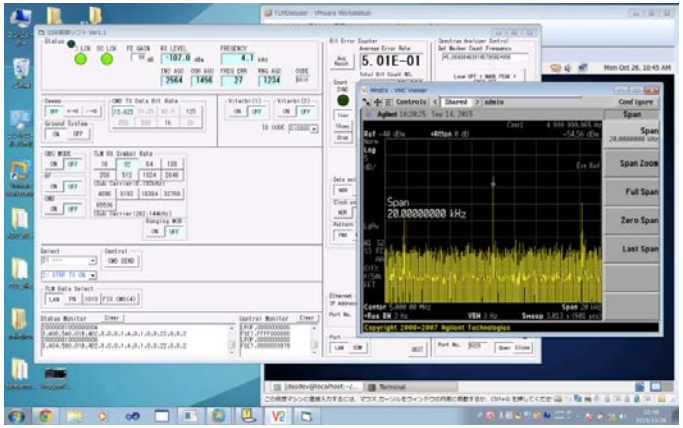
- For the future growth of ultra-small deep-space explorations
  - Great importance of collaborating with worldwide large antennas including telescopes so as to use as receiving antennas of deep-space probes as we did at the Warkworth observatory

- Remote telemetry demodulation system (not only carrier monitoring)
  - Developed a simple system to monitor demodulated telemetry data
  - Demonstrated at a 32m antenna of Yamaguchi Univ.
    - Using antenna prediction data appropriate for telescopes (ascension and declination)

Remote telemetry demodulation system







Succeeding in remote telemetry demodulation with a simple system
(Doppler-shifted signal could be tracked and demodulated)

Demodulation experiment at worldwide VLBI stations are welcome !!

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Summary

- PROCYON
  - the world's first ultra-small (50kg-class) deep-space probe
  - has been working successfully since it was launched (on 3 Dec. 2014)
- Flight demonstration results
  - succeeding in confirming initial condition just after the launch thanks to the kind support from the AUT (at Warkworth observatory)
  - demonstrating new X-band Delta-DOR technologies
    - the world's first Chirp-DOR experiment
    - the world's first DOR measurement between two space probes (HAYABUSA2 and PROCYON)
    - the world's widest tone bandwidth (86 MHz)
- For the future low-cost operation of ultra-small deep-space probes,
  - developing a simple and low-cost remote telemetry demodulation system
  - confirming the system works successfully at a 32m antenna in Japan
  - hoping some of the participants of this workshop will join us!!

Thank you for your kind attention.