

Future ultraviolet space telescope mission LOPYUTA

**Fuminori Tsuchiya¹, Go Murakami², Atsushi Yamazaki², Shingo Kameda³, Masato Kagitani¹, Kazuo Yoshioka⁴, Ryoichi Koga⁵, Jun Kimura⁶, Tomoki Kimura⁷, Chihiro Tao⁸, Kei Masunaga⁹, Shotaro Sakai¹, Akifumi Nakayama³, Masahiro Ikoma¹⁰, Norio Narita⁴, Masami Ouchi^{4,10}, Masaomi Tanaka¹, Masaki Kuwabara³, Shin Toriumi², Yuta Notsu¹¹, Kosuke Namekata¹²
LOPYUTA JAXA pre-project team*

1. Tohoku Univ., 2. ISAS/JAXA, 3. Rikkyo Univ., 4. The Univ. Tokyo, 5. Nagoya City Univ., 6. Osaka Univ., 7. Tokyo Univ. Science, 8. NICT, 9. Yamagata Univ., 10. NAOJ, 11. Colorado Univ., 12. Kyoto Univ.

- Science goals & objectives*
- Instrument*
- Sensitivity*
- Key technologies*
- Toward HWO*

- Current status*
One of JAXA M-class candidates
Down selection will be planned
- Target launch year*
Early 2030s

LAPYUTA Science goals & objectives

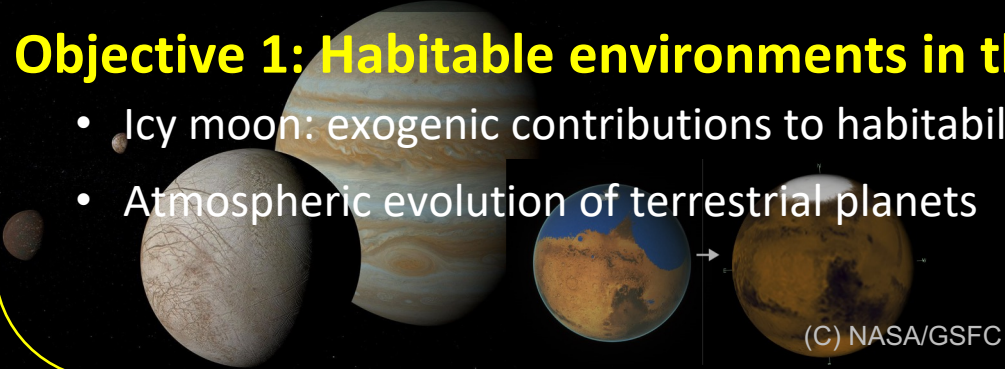
Goal1: habitable environments in the universe

Elements for the habitable environment

Hydrogen, Oxygen, Carbon → Advantage of UV spectroscopy

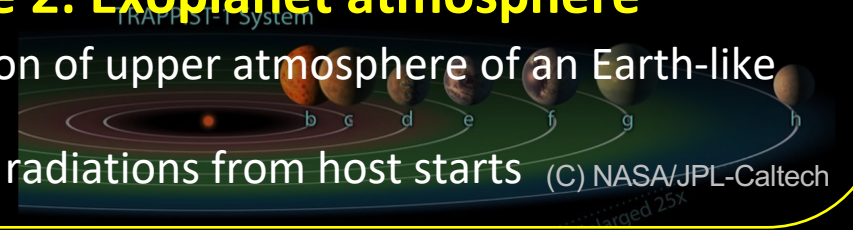
Objective 1: Habitable environments in the solar system

- Icy moon: exogenic contributions to habitability
- Atmospheric evolution of terrestrial planets



Objective 2: Exoplanet atmosphere

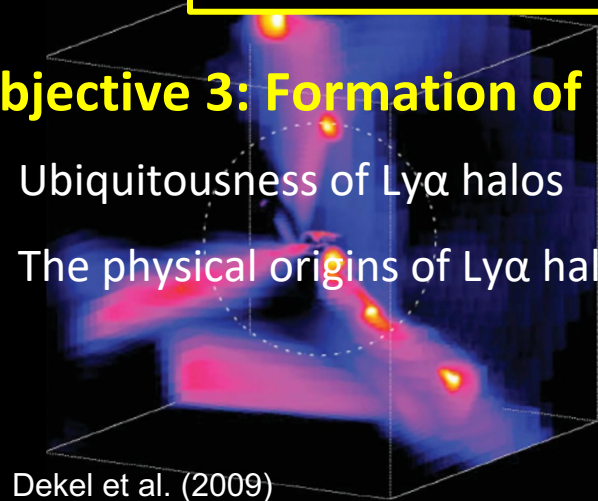
- First detection of upper atmosphere of an Earth-like exoplanet
- High energy radiations from host stars



Goal2: the origin of matter and space in the universe

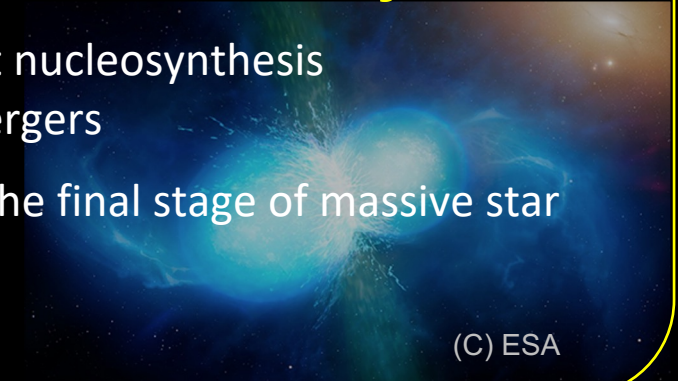
Objective 3: Formation of present-day galaxy

- Ubiquitousness of Ly α halos
- The physical origins of Ly α halos (the Cold Streams)



Objective 4: Origin of the heavy element

- The heavy element nucleosynthesis by neutron star mergers
- Understanding of the final stage of massive star evolution



UV astronomy

Science Investigations(habitable environments in the universe)

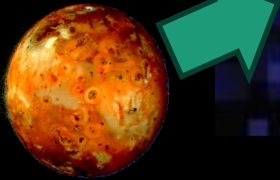
[1-1] Icy moons of giant planets: a second habitable environment

Potential exogenic contributions

- Transport of chemical species from Io
- Production of oxidants by hot plasma irradiation
- Tidal process on icy moons

Water plume on Europa

(Roth et al. 2014)

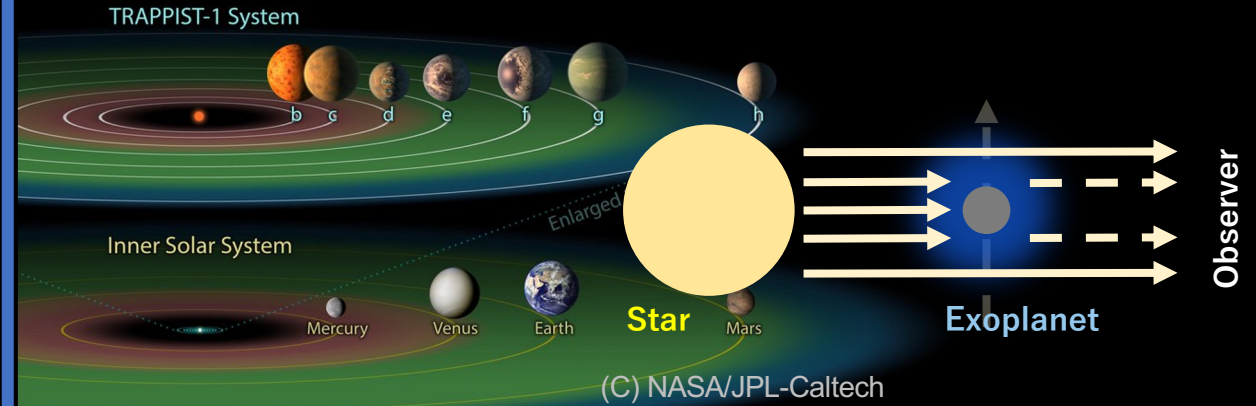


[1-2] Atmospheric escape of Venus & Mars: Atmospheric evolution

Global observations of H, O, and C

Ongoing atmospheric escape
& response to Sun and atmospheric variability

[2] Exoplanetary Atmospheres: Planets in the habitable zone Earth-like?



Transit observation with Ultraviolet Spectroscopy: Detection of upper atmosphere of terrestrial planets

- (1) First detection of expanded upper atmospheres (**O, C**)
→ Discovery of habitable planet candidates
- (2) First detection of a large outflow atmosphere (**H**)
→ understanding of planetary evolution (runaway greenhouse, etc.)
- (3) High-energy radiation from central stars (stellar flares, CME, etc.)
→ understanding of direct effects on atmospheres

Science Investigations(origin of matter and space in the universe)

[3] Formation of present-day galaxy

Ubiquitousness of the Galactic Ly α Halo

- Presence of the Ly α halo in galaxies today?

Large-Scale Structure of the Universe

~First Detection of "Cold Streams" in Galaxies

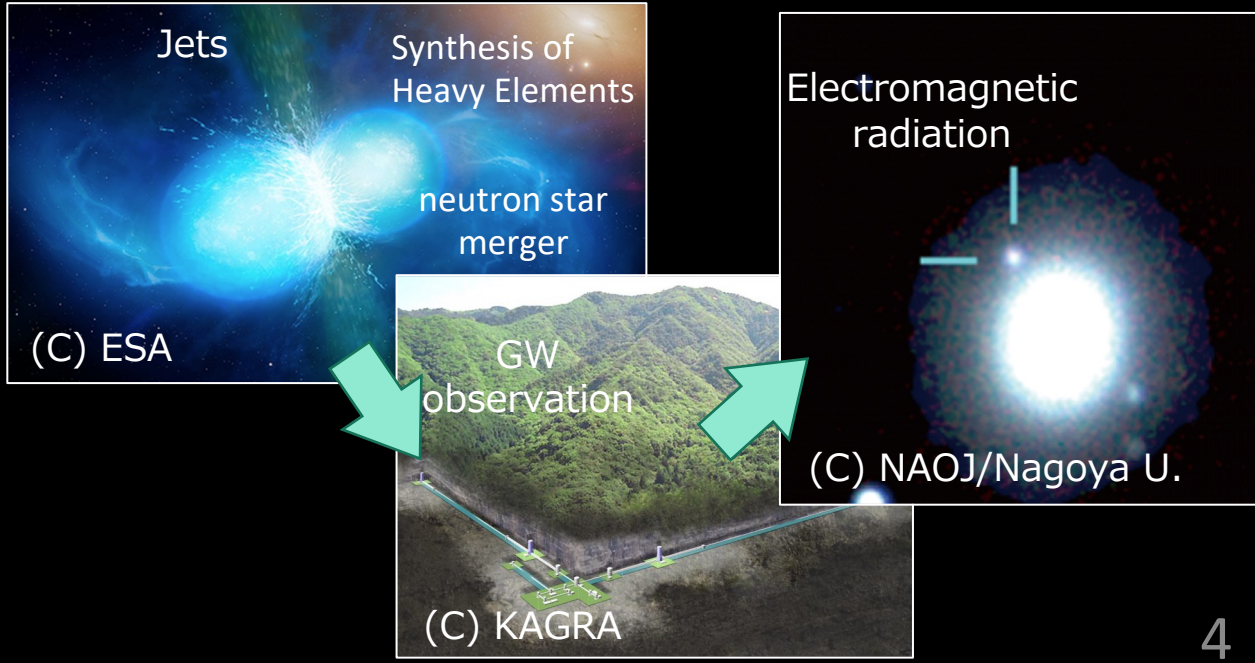
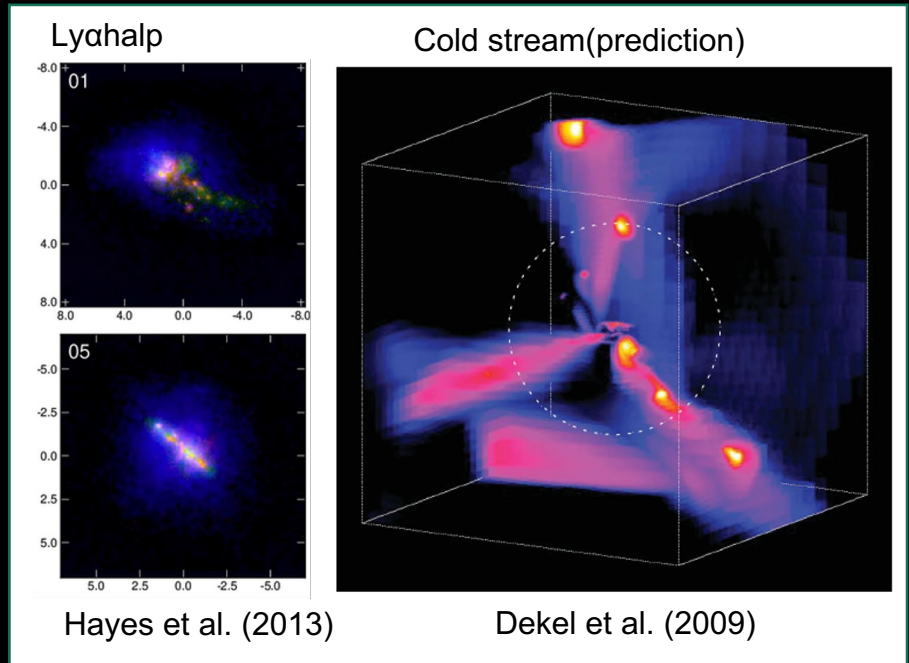
- Physical origin of the galactic Ly α halo.
- Basic structure of the material around galaxies.
- Verification of the galaxy formation process.
- Obtain ultraviolet atlas of galaxies.

[4] Origin of The heavy element

Era of "Multi-messenger Astronomy"

Observation of total spectral distribution of the radiation and its time evolution from neutron star mergers (within 3 hours from discovery)

- Understanding the Origin of Heavy Elements
- Overall Picture of the Synthesis of Heavy Elements



Instruments : Specification



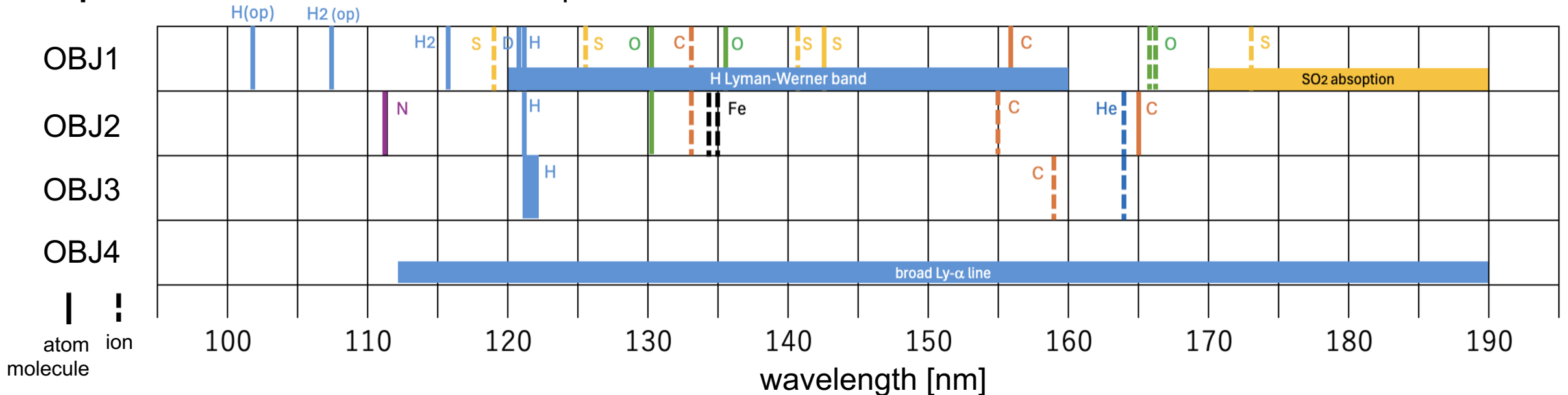
Spectrograph data

	Mid-dispersion	High-dispersion
• FOV	100 arcsec	13.5 arcsec
• Spectral range	110-190 nm	110-170nm
• Spatial resolution	0.1 arcsec	0.6 arcsec
• Spectral resolution	0.02 nm (6,500)	0.003 nm (43,000)

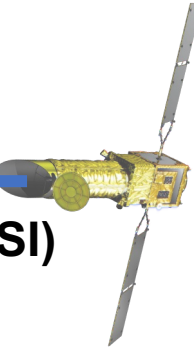
Imaging data

- FOV : **180 arcsec**
- Spectral range : 110-190 nm
Six bands selectable with filter wheel
- Spatial resolution : **0.2 arcsec**

Spectral lines in 110nm-190nm (option : >100nm)



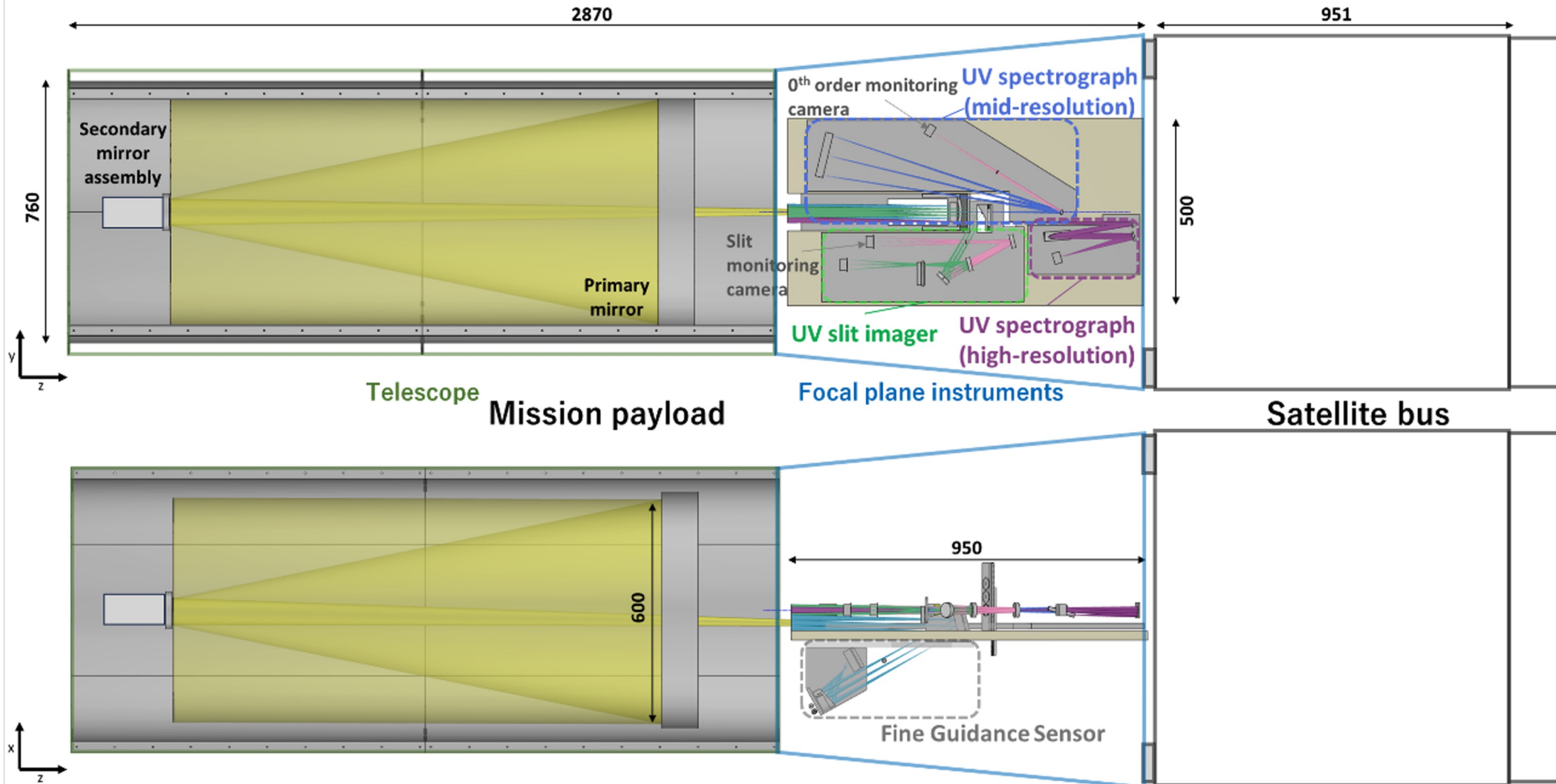
Instruments : Telescope



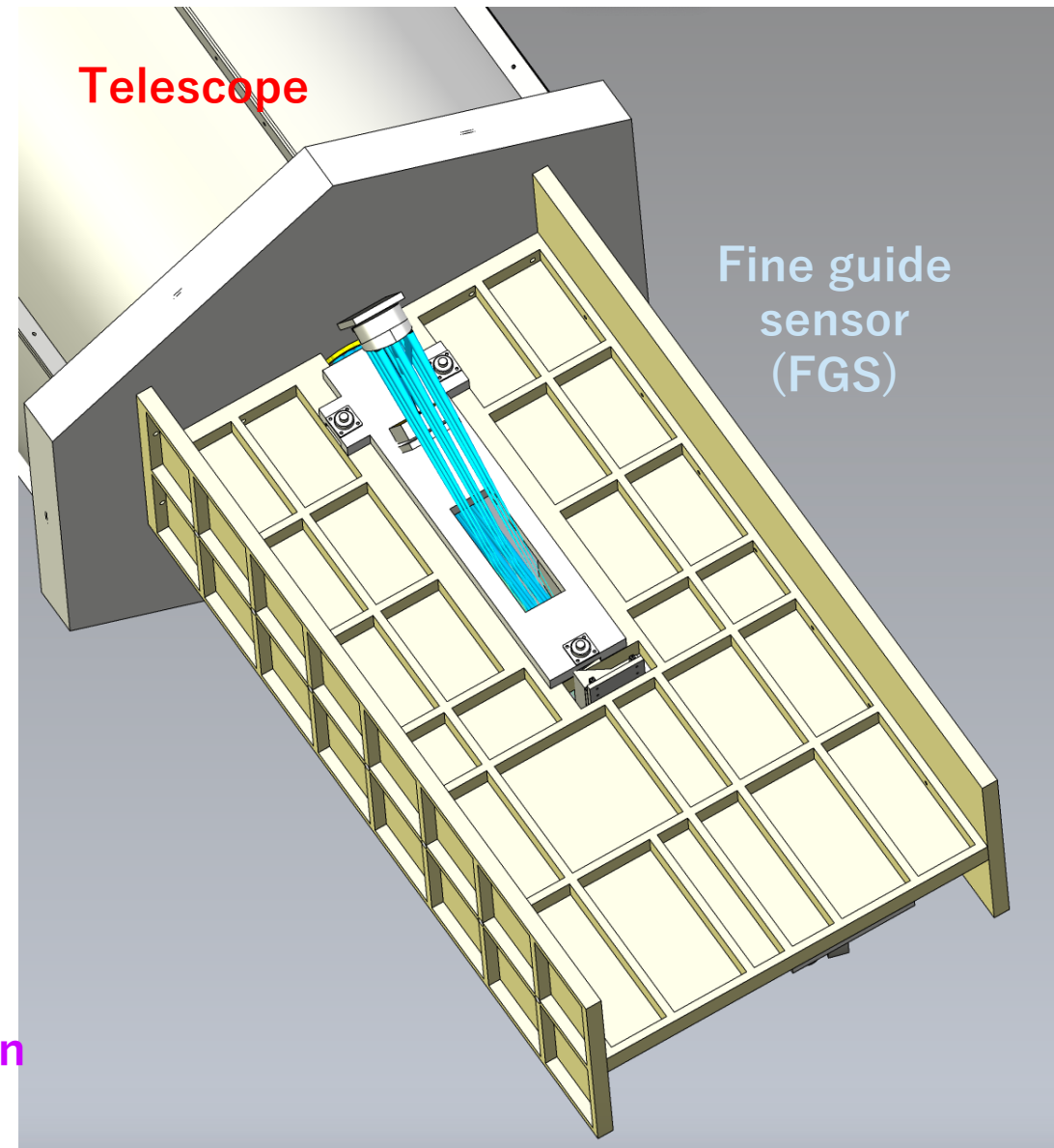
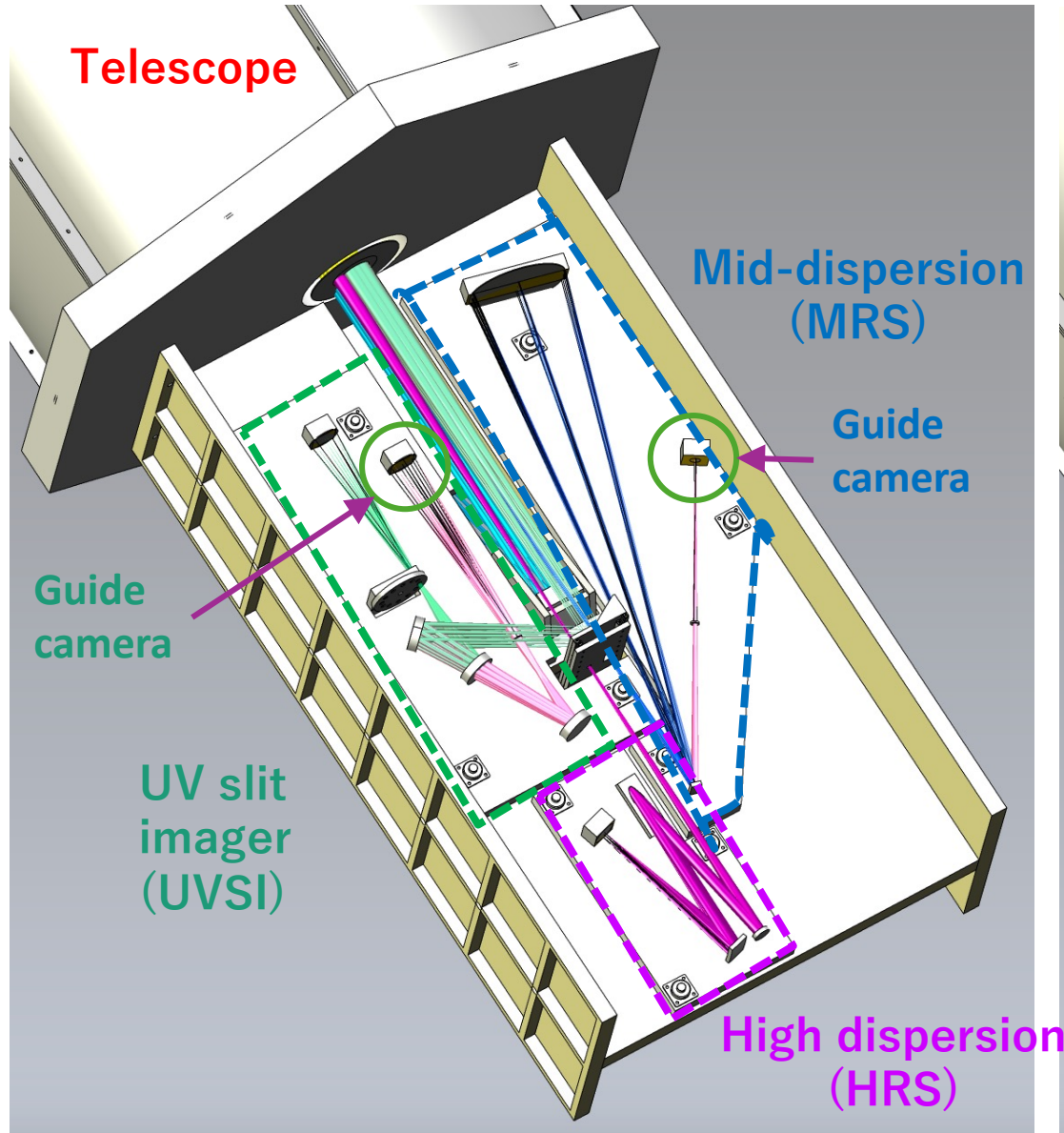
Mission payload:

A telescope + focal plane instruments

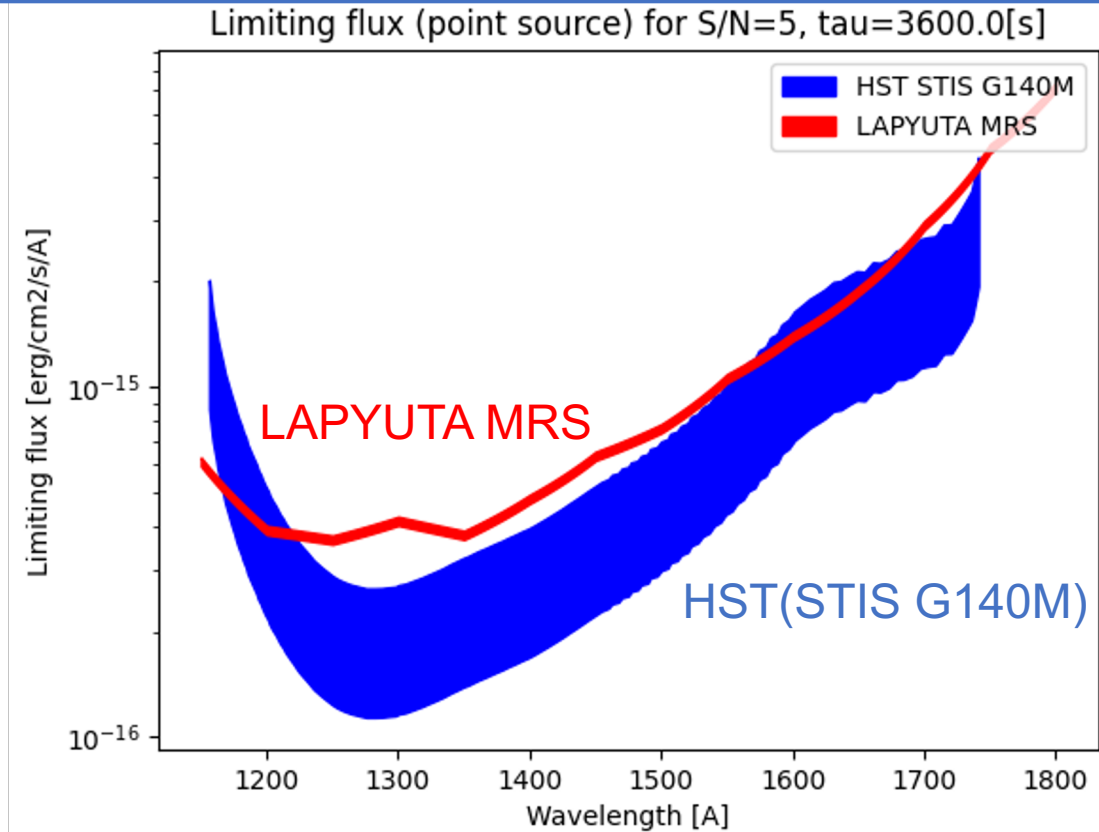
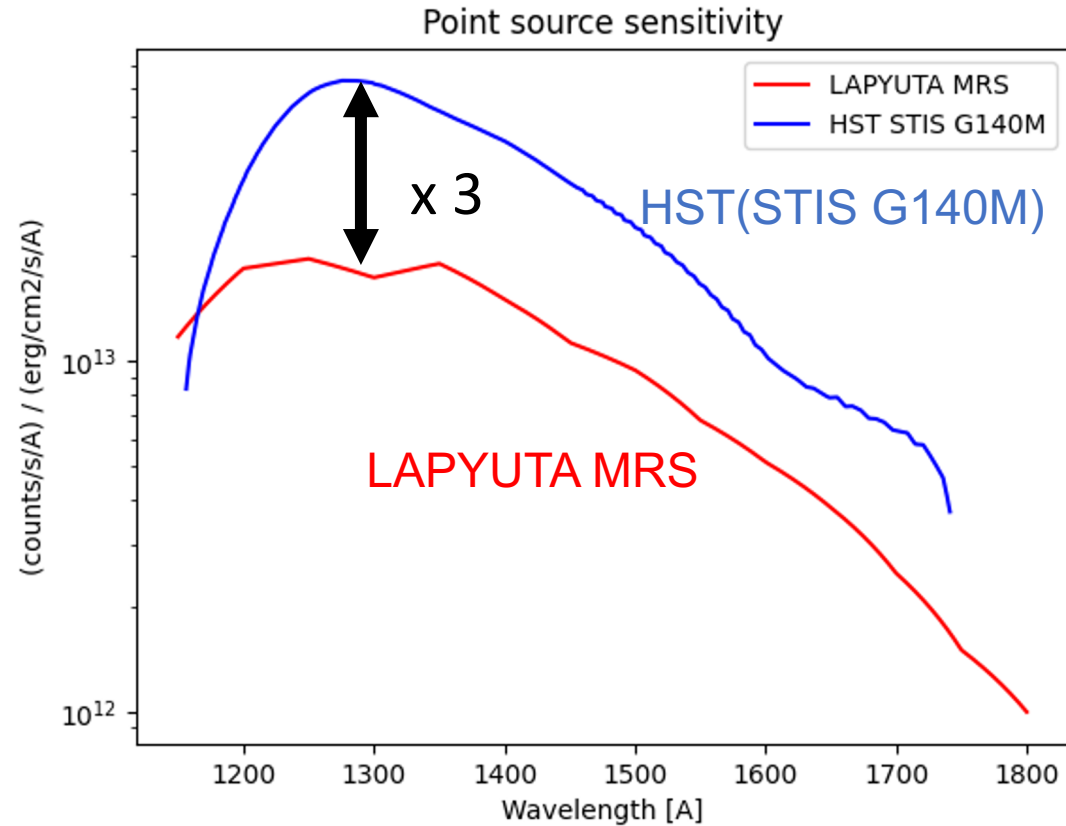
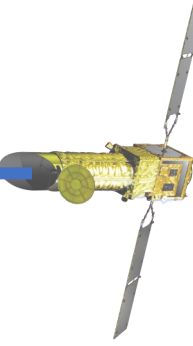
- Mid-resolution spectrograph (MRS)
- High-resolution spectrograph (HRS)
- UV slit imager (UVSI)



Instruments : Focal plane instruments



Instruments : Sensitivity (vs. HST)



HST (STIS G140M) vs. LAPYUTA (MRS)

- Primary mirror diameter
HST: 2.4m, LAPYUTA: 0.6m (x1/16)
- Throughput
HST (STIS G140M): 2%, LAPYUTA (MRS): 12% (x 6)

Comparable with the current HST/STIS performance

- Dark noise
 - HST/STIS 1.1 – 96 counts/s/cm²
(STIS Instrument Handbook)
 - LAPYUTA 0.7 – 11 counts /s/cm²
(Hisaki heritage)

1. MCP detector for UV

High efficiency: **funnel-type MCP**

Large format (120 x 30 mm/8k x 2k) --- **A prototype (80 x 80mm) has been developed and is now under evaluation**

High dynamic range and resolution: **CMOS readout**

2. Mirror coating & grating

UV mirror coating

Base line: Al + MgF₂ Goal: >90% @130 nm / **90% at 130 nm achieved !**

Other coatings: Al + MgF₂ + XeF

Toroidal blazed holographic grating ~50% at 130 nm achieved

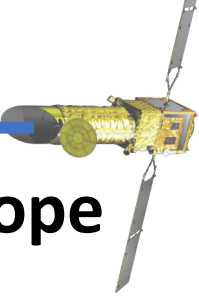
3. Pointing fluctuation cancelling system

Concept of pointing cancellation system

"Electronical image stabilization" onboard the mission system

- High-speed imaging of visible light & detection of UV photons
- Correction of the UV photon positions with reference to the centroid of the visible image.

Sciences & technologies toward HWO



Habitable Worlds Observatory : a 6-m class UV/VIS/near-IR space telescope (NASA)

Engineering participation to HWO

based on technologies developed for LAPYUTA

High sensitive detector

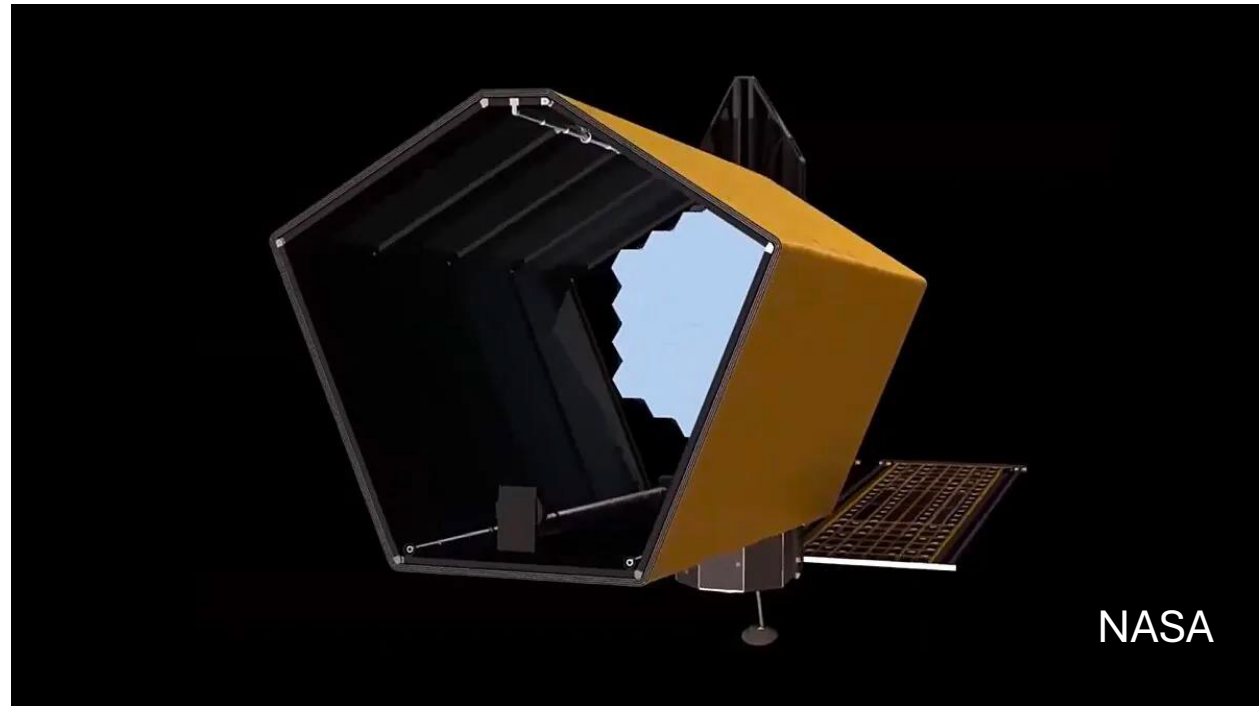
High reflectance mirror coating

Scientific participation to HWO

through LAPYUTA

Path finder to HWO

LAPYUTA will open a public observation slot 1-2 months/year
Proposals of UV observation are welcome.



The LAPYUTA mission



- **Four Scientific Objectives**
 - (1) Habitable environments in the solar system
 - (2) Exoplanet atmosphere
 - (3) Formation of present-day galaxy
 - (4) Origin of the heavy element
- Key technology development, conceptual study of the telescope are on going.
- **Schedule**
 - A pre-project candidate of JAXA's M-class mission
 - The next milestone: down selection in 2026 (TBD)
 - Target launch year for the LAPYUTA team: 2033 (TBD)

Observation time allocation plan



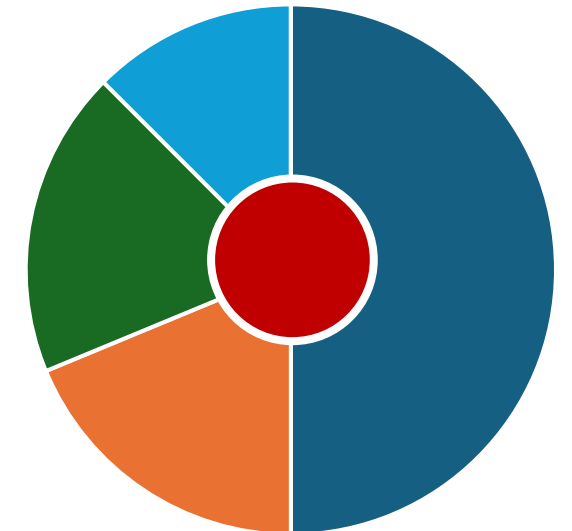
Baseline

- **Solar system bodies:** optimized by solar separation angle
 - Jupiter & Mars: around oppositions
 - Venus: around maximum solar elongation angle
- **Exoplanets & Near-by Galaxies**
 - Unsuitable periods for the solar system bodies
- **Neutron star mergers, Supernova & Stellar flares**
"Target of Opportunity"
with 24-hour operation campaign (3 months/year)
- **Public slot** (1-2 months/year)

Primary mission period : 3 years

The mission period will be extended up to 9 years

Time allocation plan



- Solar system bodies
- Exoplanets
- Near-by Galaxies
- Public slot
- ToO

Originality and international competitiveness

<High sensitivity>

12% end-to-end throughput (@130 nm)

<Fine angular & spectral resolutions>

- 0.1 arcsec (diffraction limit) angular resolution with "pointing fluctuation cancelling system"

- $\lambda/\Delta\lambda = 6,000$ or $43,000$ @ 130nm



With the high sensitivity and high resolutions comparable sensitivity with HST, LAPYUTA enables

- **Dedicated platform for selected targets** with enough observation time (OBJ 1-3)
- **Time of opportunity (ToO) operation** (within 3 hours from trigger signals) (OBJ 4)

HST

Proposal-based observatory

Limited capability for H Ly- α observation & ToO

UVEX

Survey type telescope

Wide field
H Ly- α (only spectroscopy)
ToO capability

LAPYUTA

Dedicated platform for selected targets

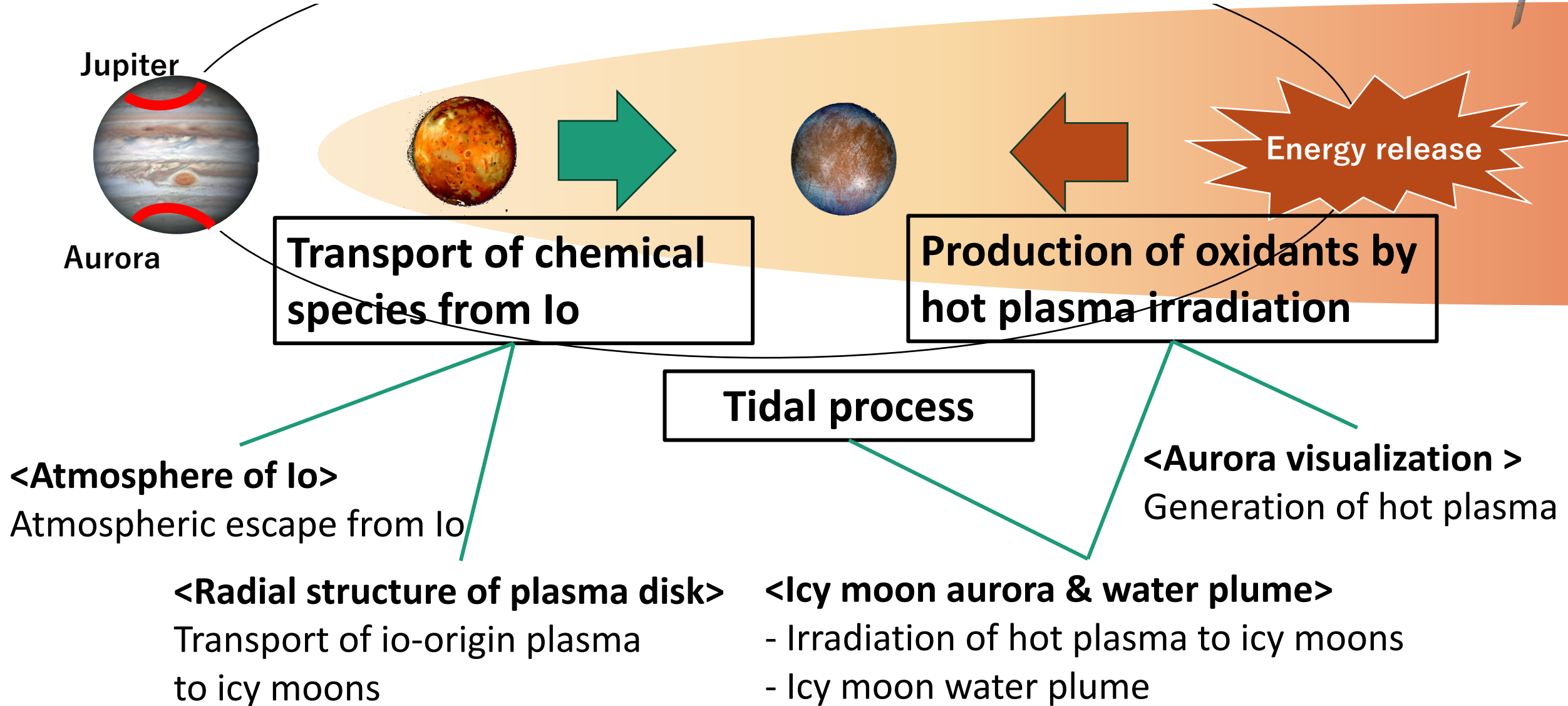
High resolutions (spatial & spectral)
Monitoring capability
H Ly- α
ToO capability

Beyond LAPYUTA → HWO

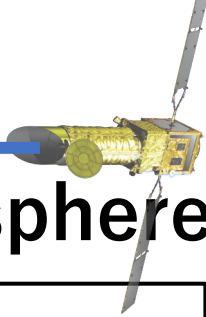
Key technologies developed by LAPYUTA (large format detector, grating, & mirror coating for UV) will be applied for HWO.

Habitable environment in the solar system

Potential exogenic contributions to habitability of icy moon



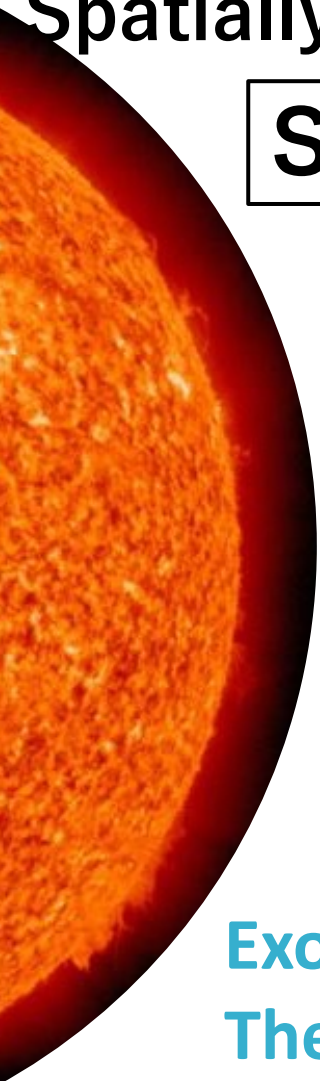
Habitable environment in the solar system



Spatially resolved monitoring → Time variability of upper atmosphere

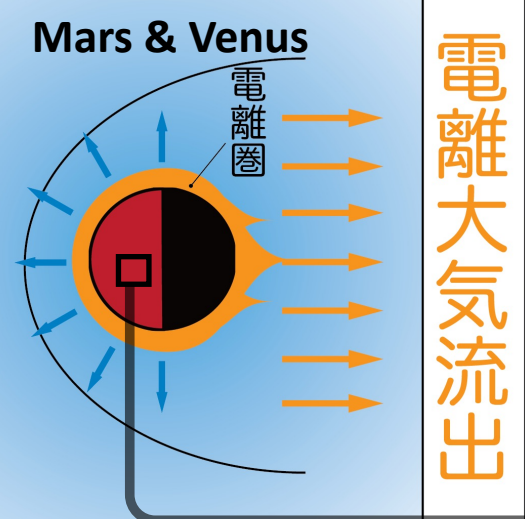
Solar drivers

Atmospheric drivers

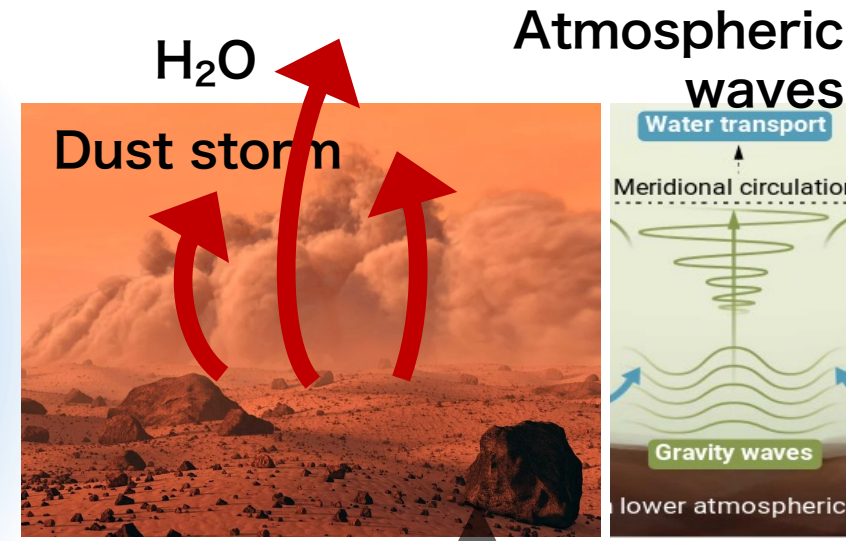


Solar wind
Solar radiation

中性大氣流出



電離大氣流出



Exosphere
Thermosphere

H, O, C, H₂,
D/H (under study)

~~H⁺, O⁺, C⁺~~ Too dim

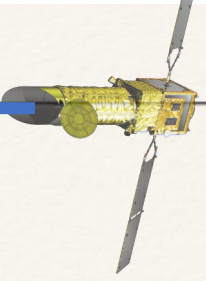
C⁺

dose not represent ionosphere

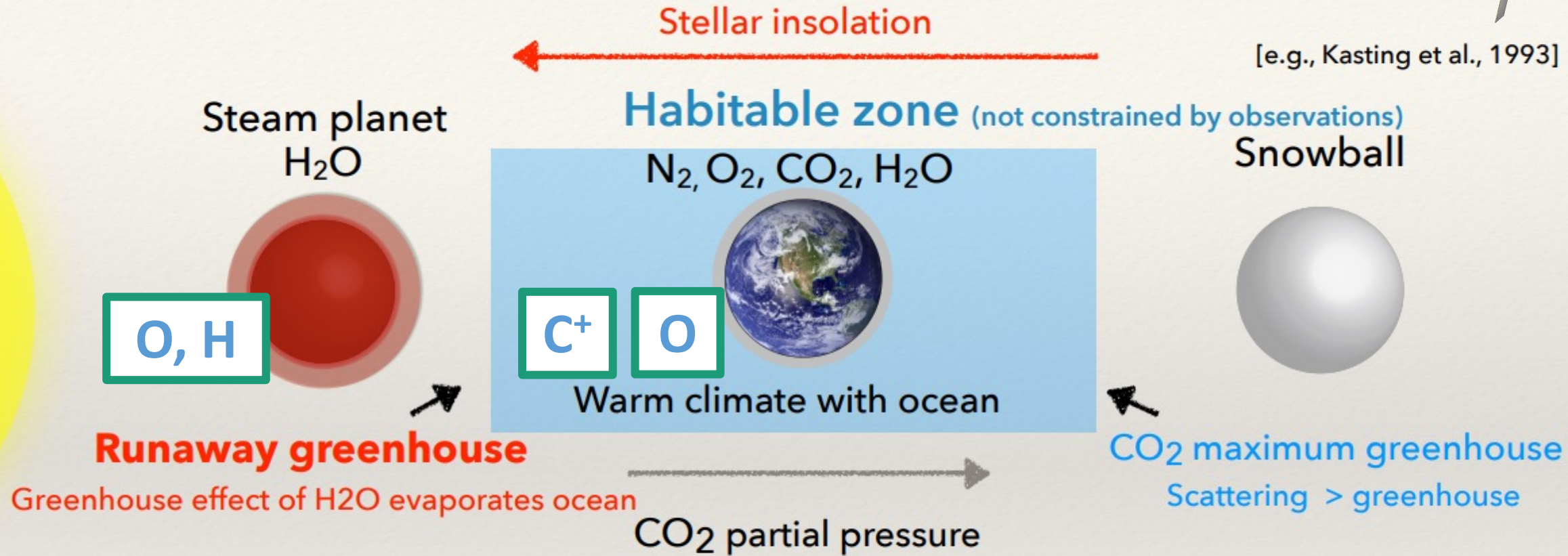
C, O

Suprathermal e⁻? (Sakai et al.)
Aurora ?

Exoplanetary science targets



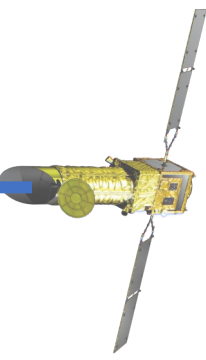
Steam planets and potentially habitable planets



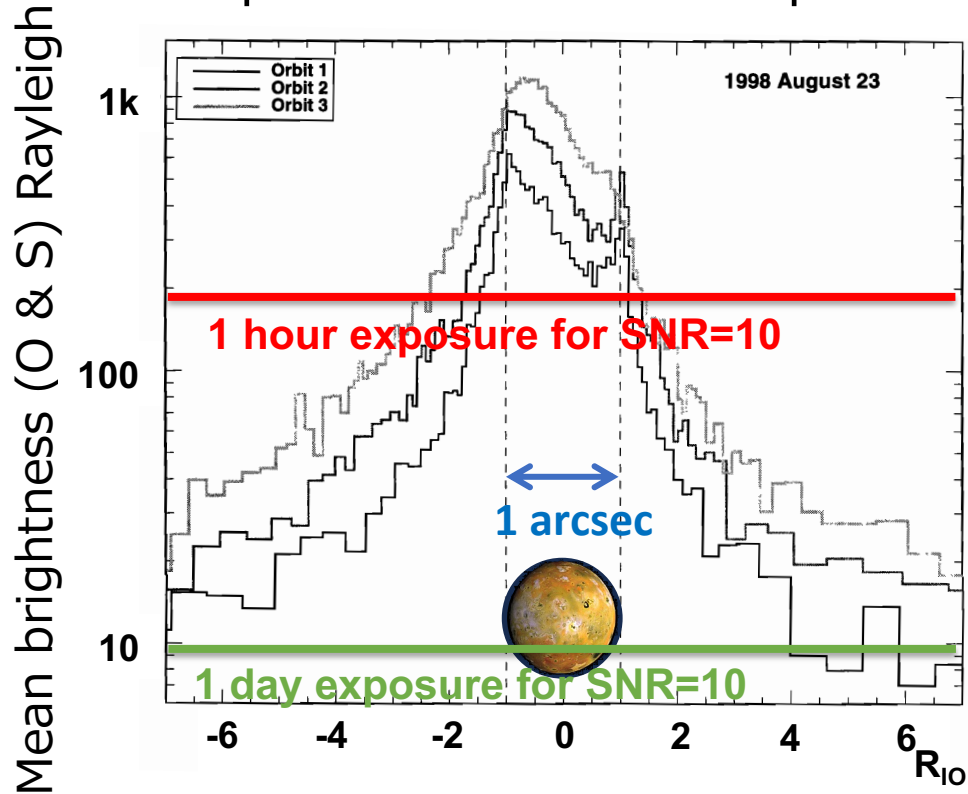
We observationally access the habitable zone and atmosphere of terrestrial planets

- First detection of upper atmosphere of **steam** and **habitable** planets (H, C, O)
- Stability of atmosphere in high-XUV conditions

Examples of feasibility study

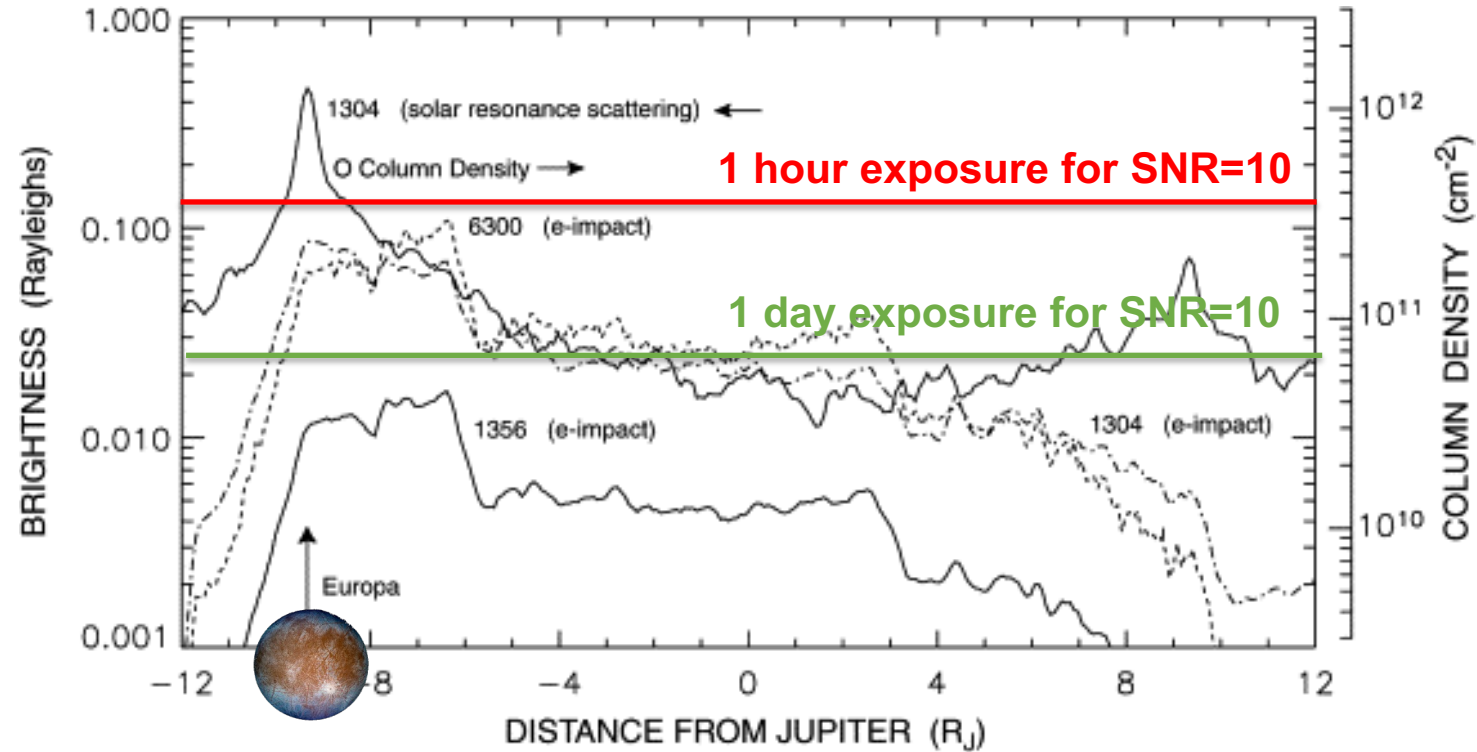


Io's exosphere ($\Delta\theta=0.2\text{arcsec}$)
 Important for neutral escape



HST observations of O & S corona around Io (Wolven et al., 2001)

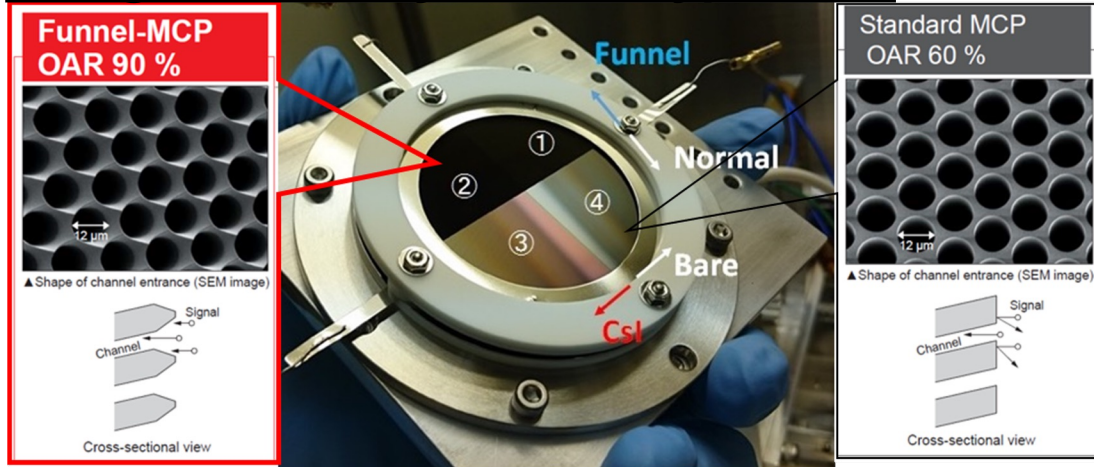
Europa's oxygen neutral cloud
 Model prediction, never been observed yet



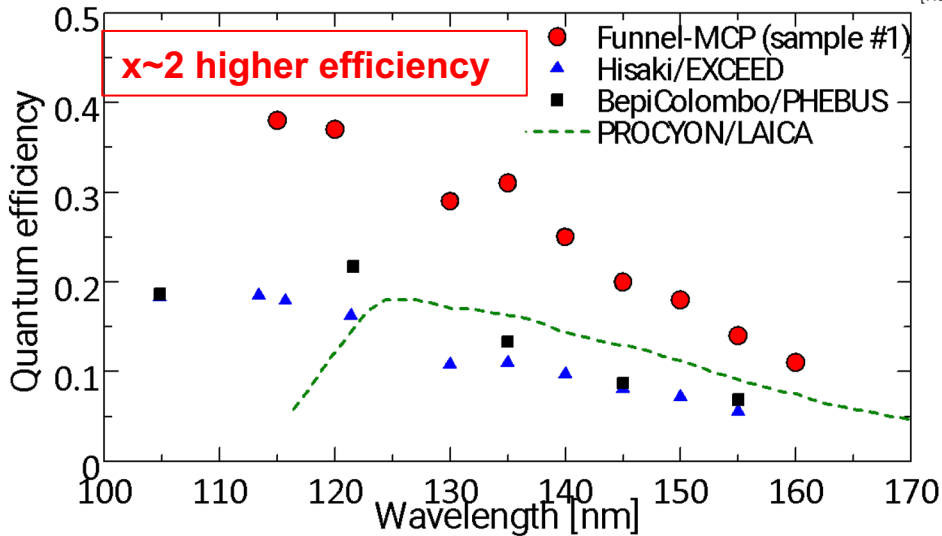
Model prediction of Europa's oxygen neutral cloud, (Smyth & Marconi, 2006)

Key technologies: MCP detector for UV

1. High efficiency: funnel-type MCP



[Hamamatsu Photonics K.K.]

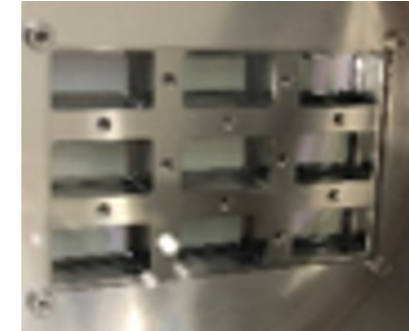
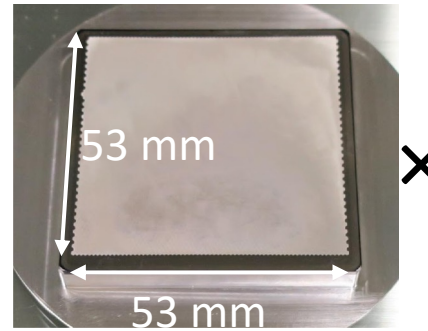


- Test model ($\phi 40\text{mm}$) achieved ~ 2 times higher efficiency
- UVSPEX will use this funnel-MCP technique**

2. Large format (120 x 30 mm/8k x 2k)

53 x 53 mm funnel MCP

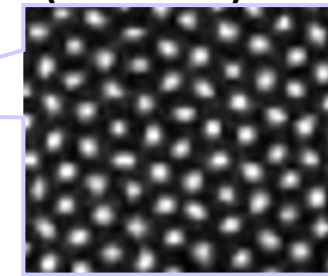
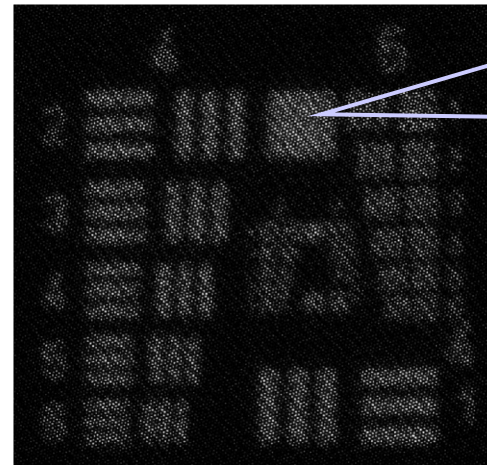
3x3 MCP array (Gap: 6.5mm)



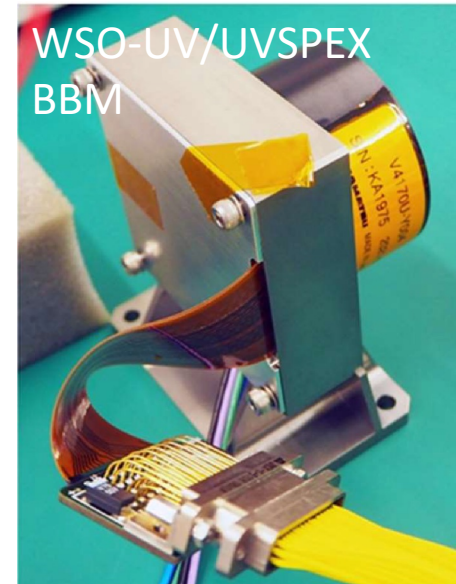
Goal for HWO:
3 x 3 array with $\square 70 \times 70$ mm funnel MCPs
to achieve $> 200 \times 200$ mm format

3. High dynamic range and resolution: CMOS readout

- MCP + FOP + CMOS coupled detector
- Test model achieved dynamic range of $> 10^{11}$ and MCP-channel resolution (6 μm)
- UVSPEX first apply this technique**
- CMOS: CMOSIS CMV4000 (baseline)



Channel size: 6 μm



Key technology: mirror coating & grating

UV mirror coating: Al + MgF2

Improvement/optimization of evaporation process

- Optimized MgF2 thickness for $\lambda = 130$ nm
- Evaporation method
- Substrate temperature
- Evaporation rate

Goal: >90% @130 nm

-> 88% at 130 nm achieved

Other coatings:

Al + LiF, Al + AlF3

- On-going study
- Thickness of LiF and AlF3 should be modified (Optical constants to be updated)

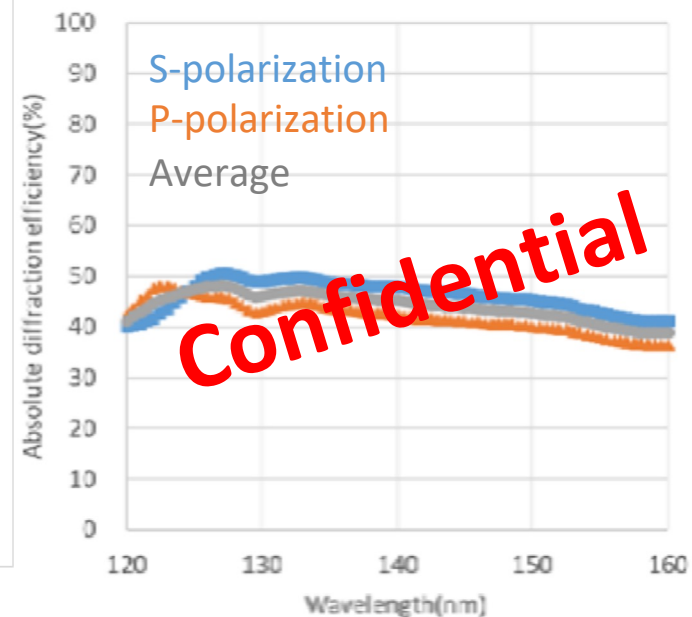
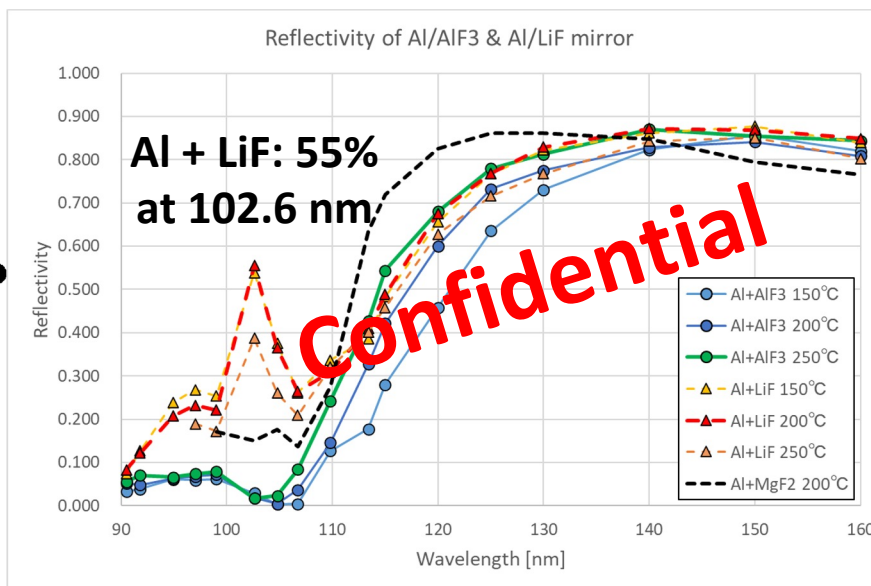
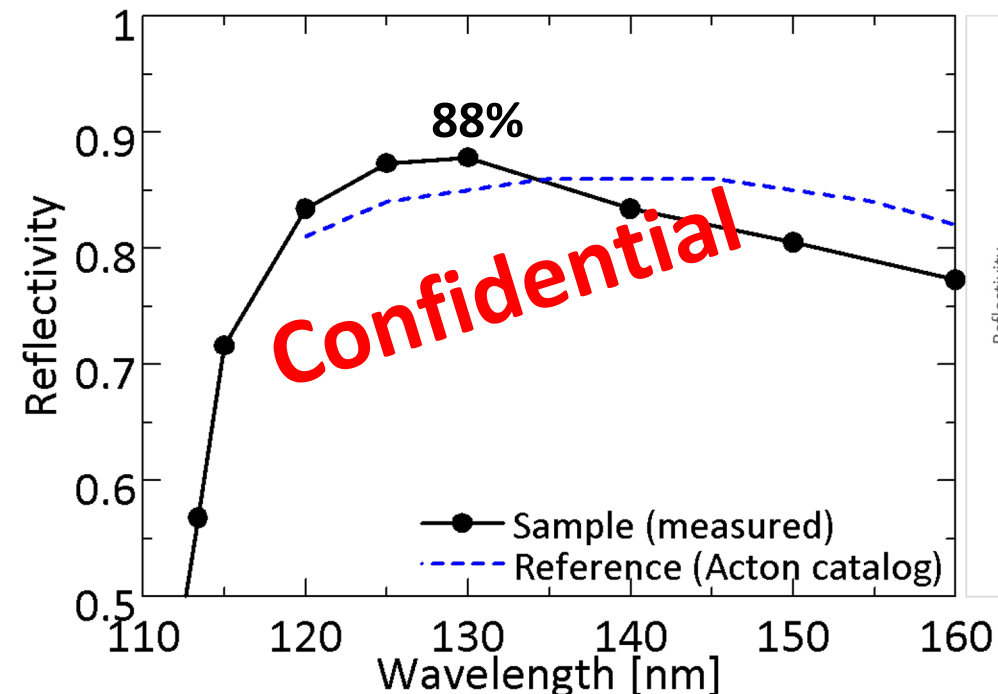
Toroidal blazed holographic grating

WSO-UV/UVSPEX (EM)

- 32 (W) x 30 (H)
- 2400 lines/mm
- Coating: Al + MgF2



-> ~50% at 130 nm achieved



Pointing fluctuation cancelling system onboard the Hisaki satellite

(Yamazaki et al. 2013 Space Sci. Review)

(1) A target object into a FOV of a monitoring camera

Target objects are introduced into the field of view of a monitoring camera by attitude control of the bus system.

The target image is taken by the camera and the image centroid position is calculated by the MDP (every 3 seconds).

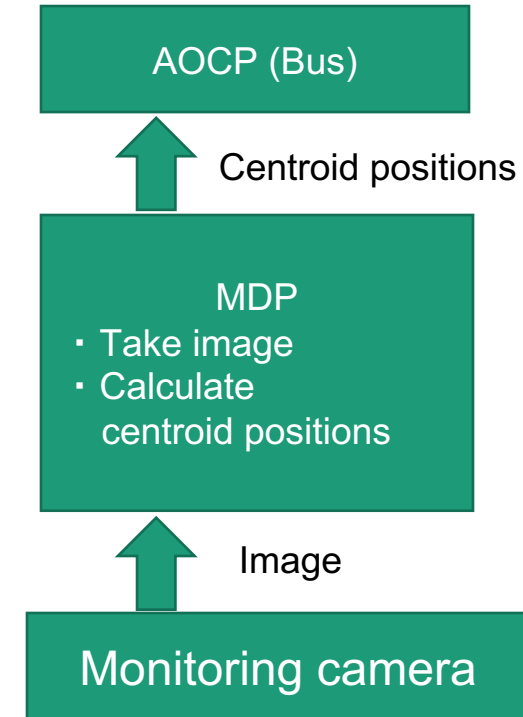
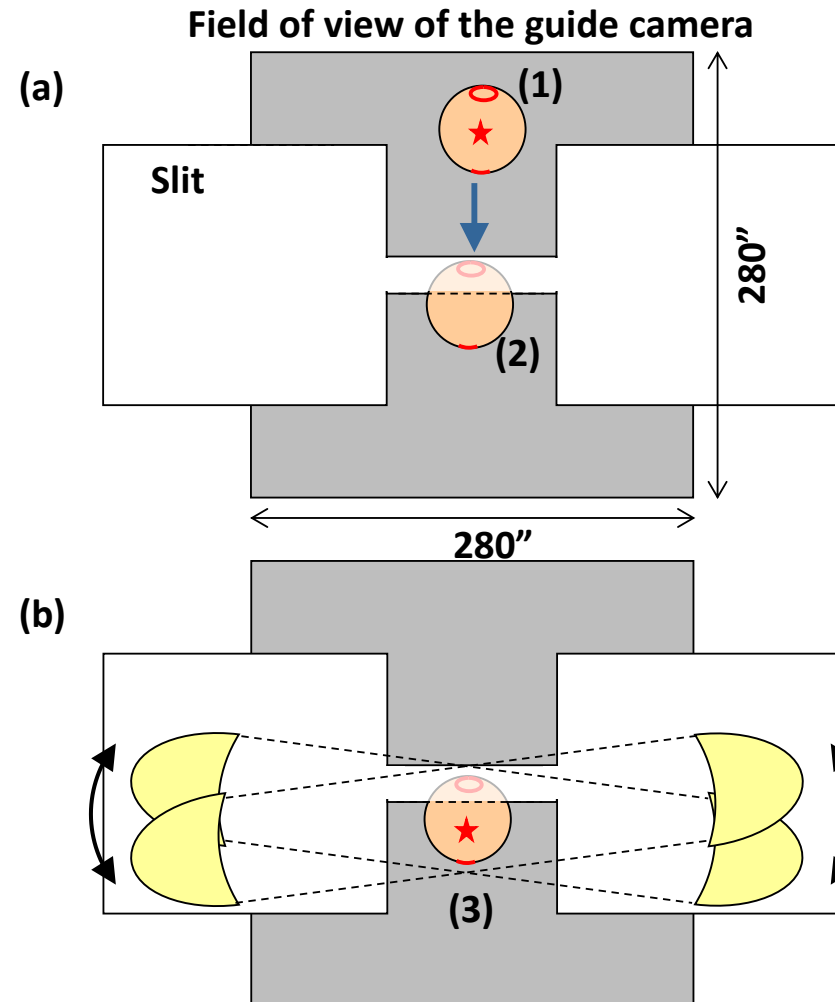
The image centroid position is transmitted to the attitude system of the bus system.

(2) The target object into the observation position

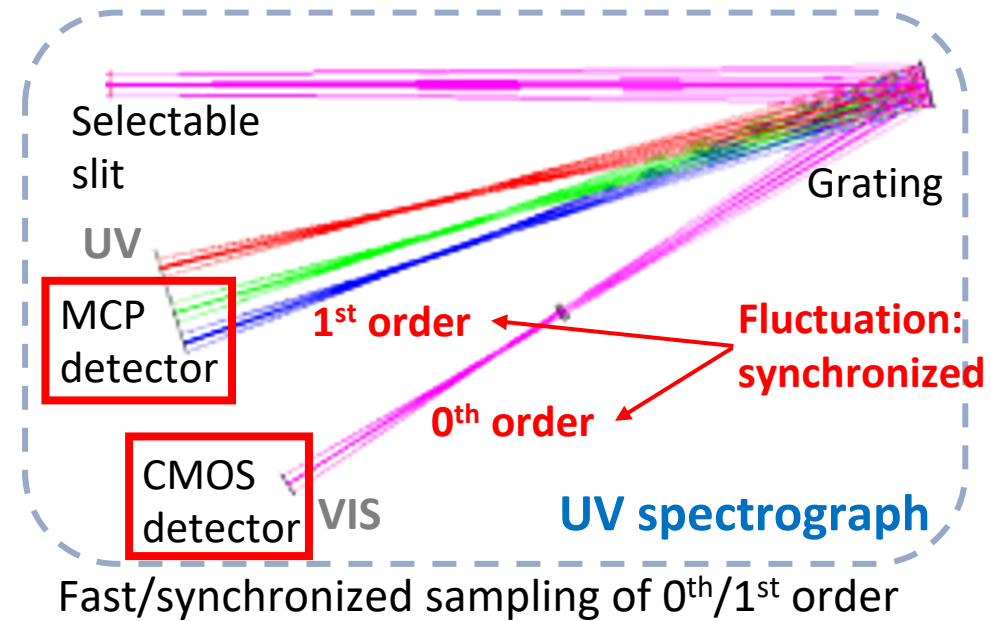
Maneuvers the satellite attitude so that the observed centroid position moves to the target centroid position (specified by command).

(3) Tracking of the target body

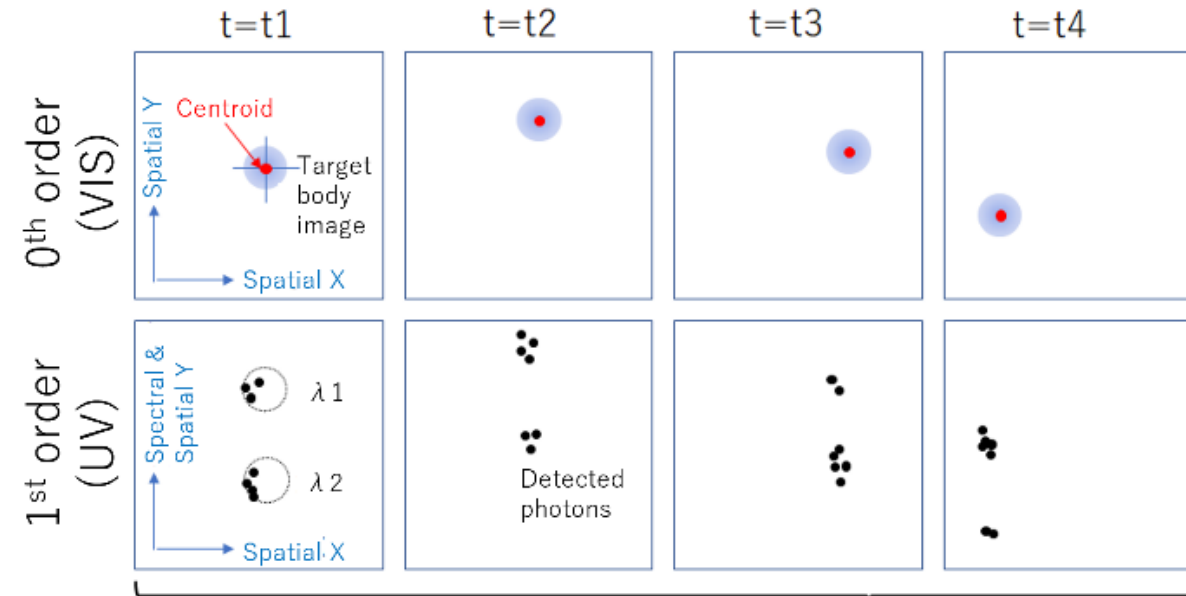
Continues attitude control so that the image centroid position is kept at the target centroid position.



Key technology: Pointing fluctuation cancelling system

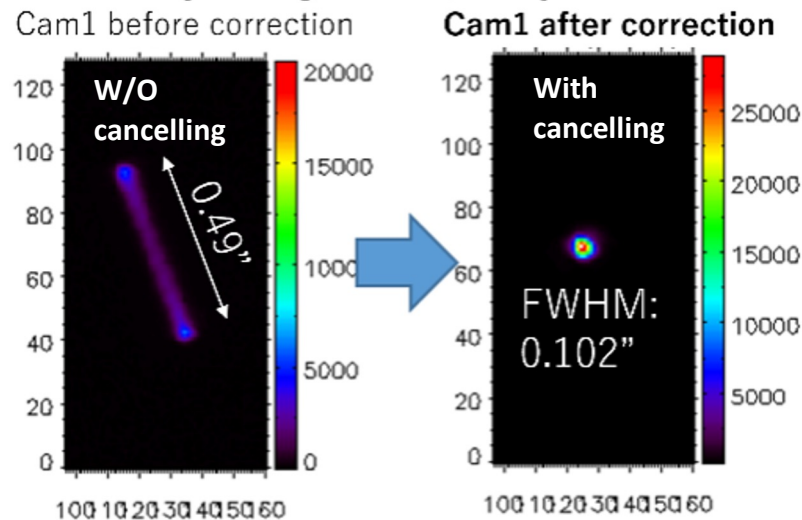


Concept of pointing fluctuation cancelling system

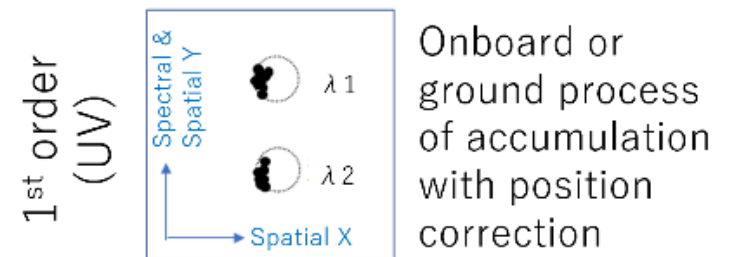
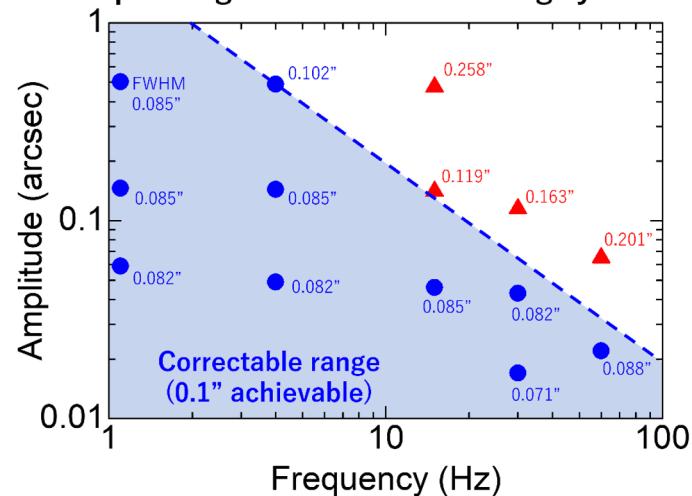


Lab-experiment: results

(a) Frequency: 4 Hz, amplitude: 0.49"



Demonstrated capability of the pointing fluctuation correcting system



We confirmed this system concept!

