Life-environmentology, Astronomy, and Planetary Ultraviolet Telescope Assembly (LAPUTA)

惑星科学、生命圏科学、および天文学に向けた紫外線宇宙望遠鏡計画

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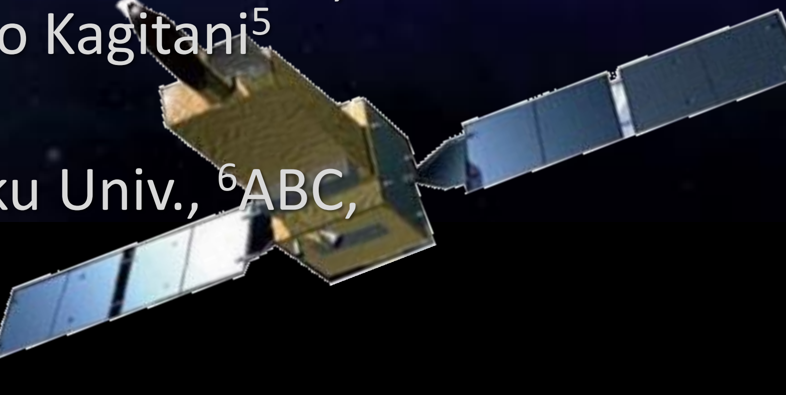
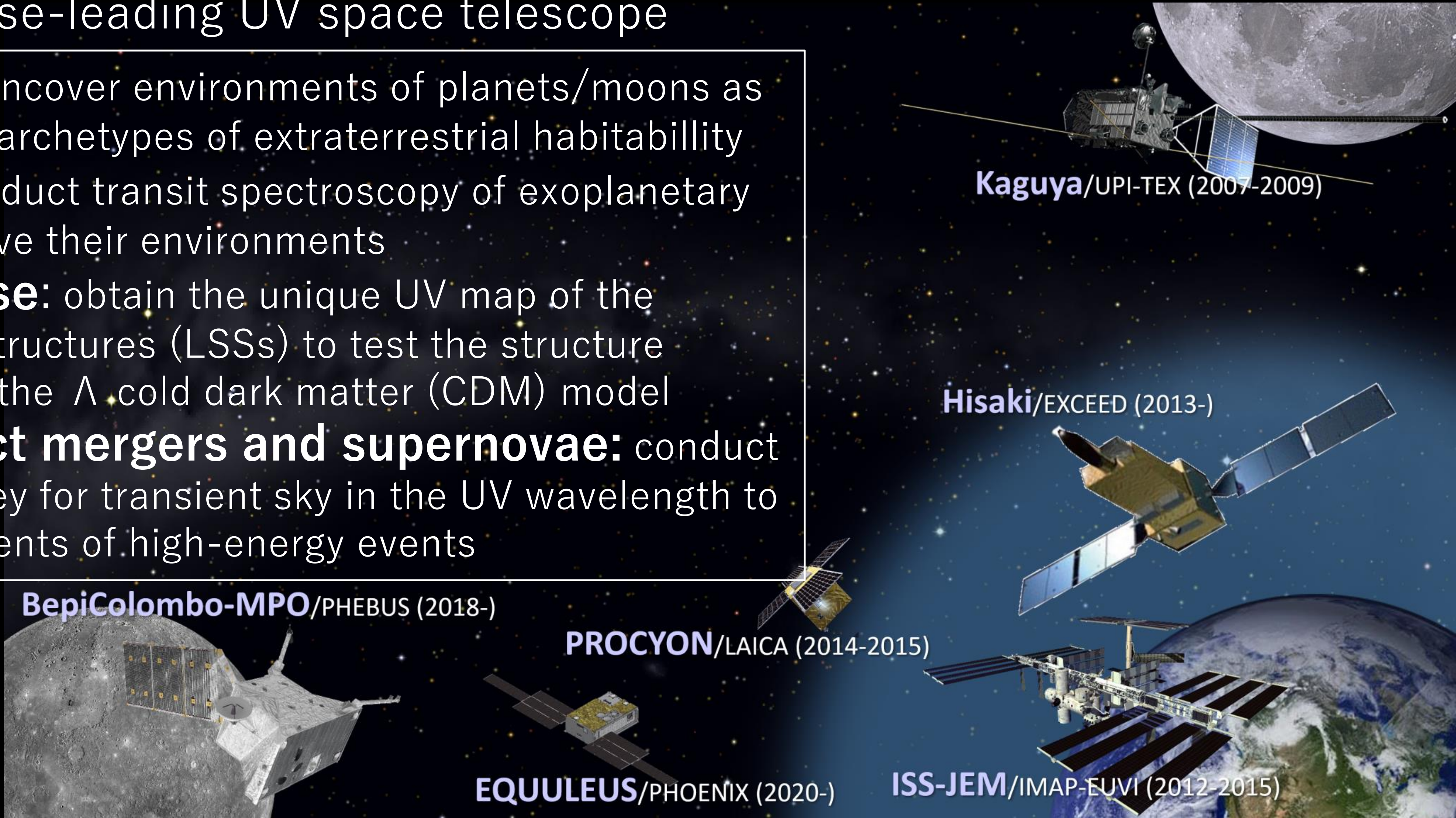


UV technique: powerful tool with many heritages

Ultraviolet observation technique can cover wide science fields from planetary science to astronomy

LAPUTA: a Japanese-leading UV space telescope

1) **Solar system**: uncover environments of planets/moons as the most quantifiable archetypes of extraterrestrial habitabillity
2) **Exoplanets**: conduct transit spectroscopy of exoplanetary atmospheres to observe their environments
3) **Nearby Universe**: obtain the unique UV map of the gaseous large-scale structures (LSSs) to test the structure formation scenario of the Λ cold dark matter (CDM) model
4) **Compact-object mergers and supernovae:** conduct the time-domain survey for transient sky in the UV wavelength to witness the first moments of high-energy events



Goal 1: Solar system bodies

Led by Fuminori Tsuchiya and Tomoki Kimura

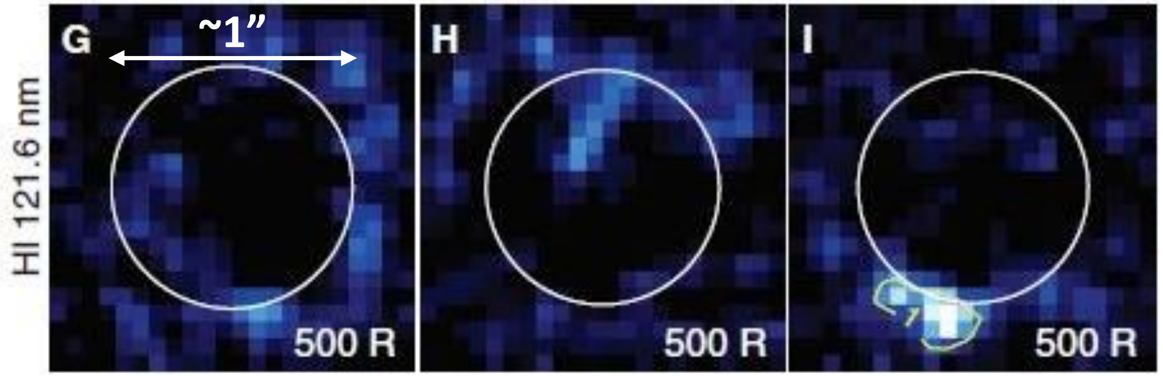
(1) First-ever continuous monitoring of the water plumes erupted from icy moons

(2) Long-term monitoring of energy flows in gas giants' magnetosphere

➔ High sensitivity and high spatial resolution UV spectroscopy by Japan's "own" telescope

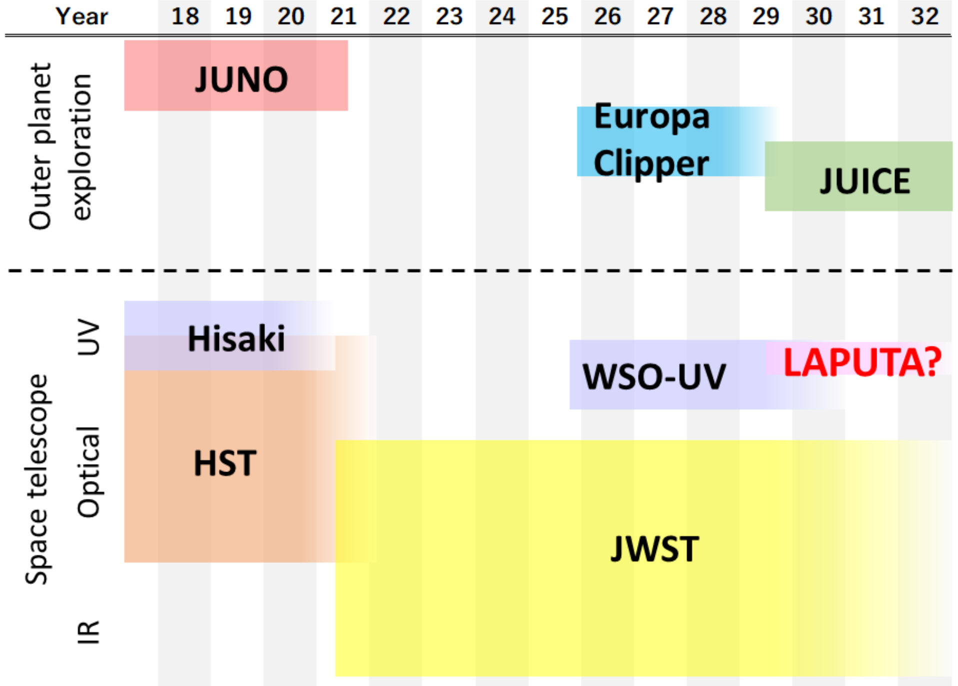
Europa Water plumes: When? How often? -> **Key information on sub-surface ocean**

Oct 1999 **Nov 2012** **Dec 2012**

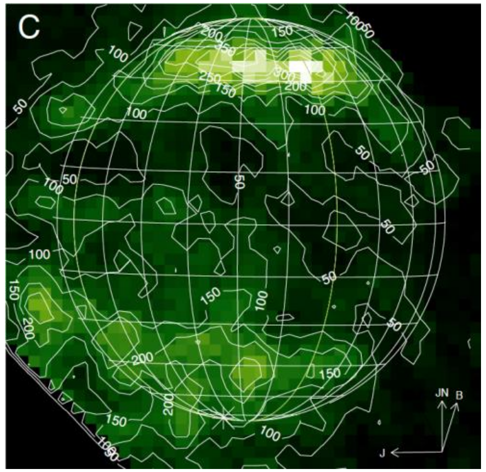


[Roth et al., 2014]

Continuous and long-term monitoring is **missing**

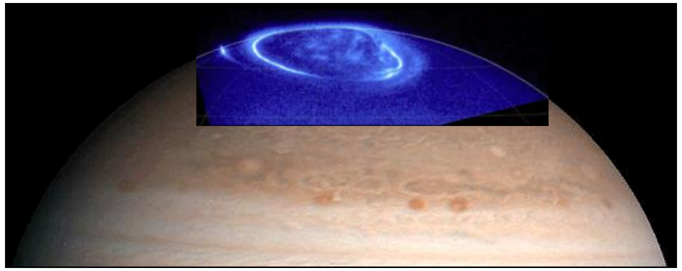


Ganymede



[Feldman et al., 2002]

Jupiter



Auroral morphology reflects magnetospheric dynamics

-> Energy flows to icy moons

-Spectral range: 120-160nm with <1nm resolution

-Spatial resolution: 0.1 arc-sec

-Effective area: >200cm2

-Field of view: >320 arc-sec

Goal 1: Solar system bodies

Led by Kei Masunaga

(3) How is atmospheric escape from terrestrial planets controlled by solar wind and solar UV flux?

➔ Long-term monitoring of atmospheric escape from Mars and Venus in a global view

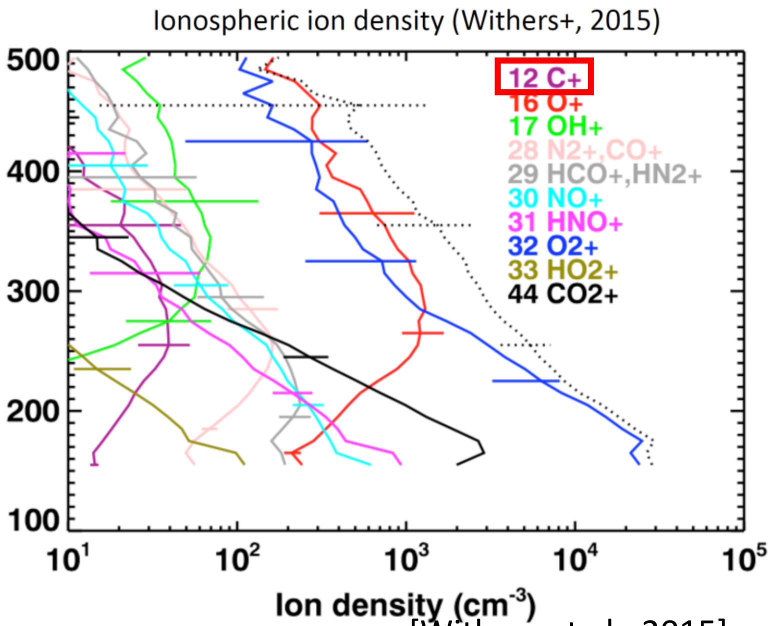
Test the upper atmosphere and escape models with solar system observations

-> **Close link to Goal 2 (exoplanetary environment)**

Exosphere (O and H) and ion escape (C+ and N+) can play a key role

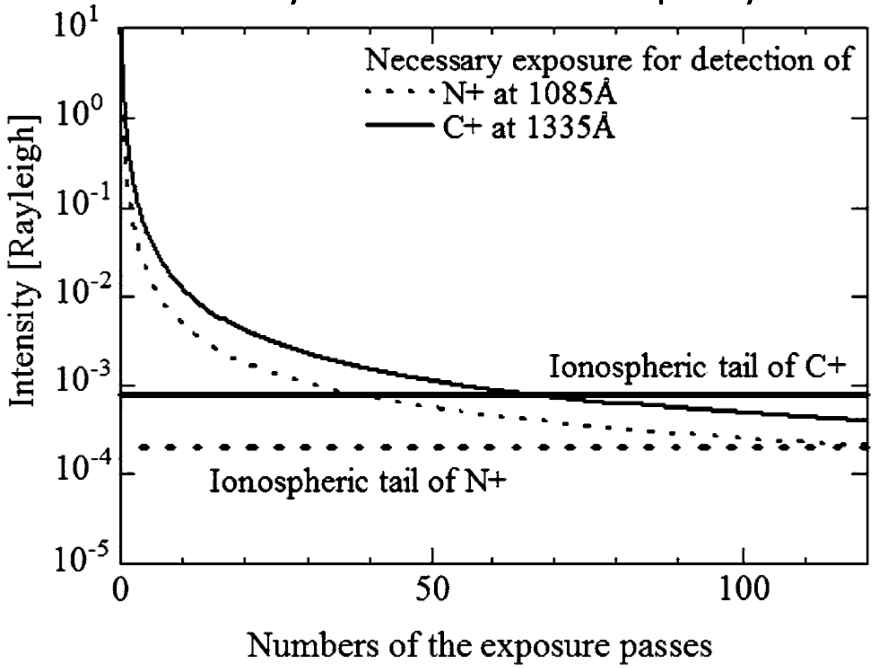
- -Spectral range: 105-140 nm with <1nm resolution
- -Spatial resolution: ~1 arc-sec
- -Effective area: >200cm2
- -Field of view: >200 arc-sec

Mars (Maven observation)



[Withers et al., 2015]

Detection feasibility of Venus ion escape by Hisaki



[Yoshikawa et al., 2014]

Goal 2: Characterization of exoplanetary environments

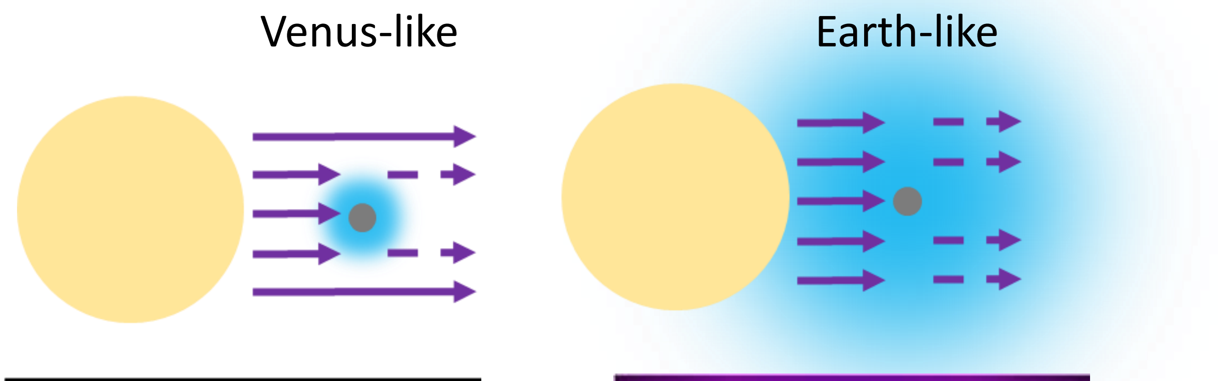
Led by Shingo Kameda

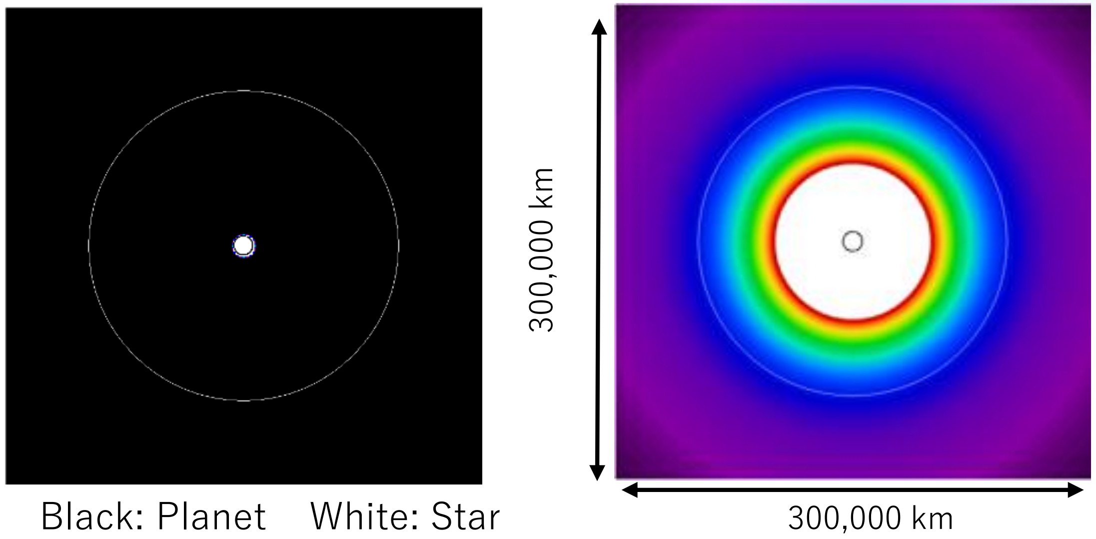
UV transit observation to detect extremely expanded Oxygen and Hydrogen exosphere

➔ (1) Distinguish Earth-like planets from Mars-/Venus-like planets

➔ (2) Distinguish super-Earths (w/o hydrogen atmosphere) from mini-Neptunes (with hydrogen atmosphere)

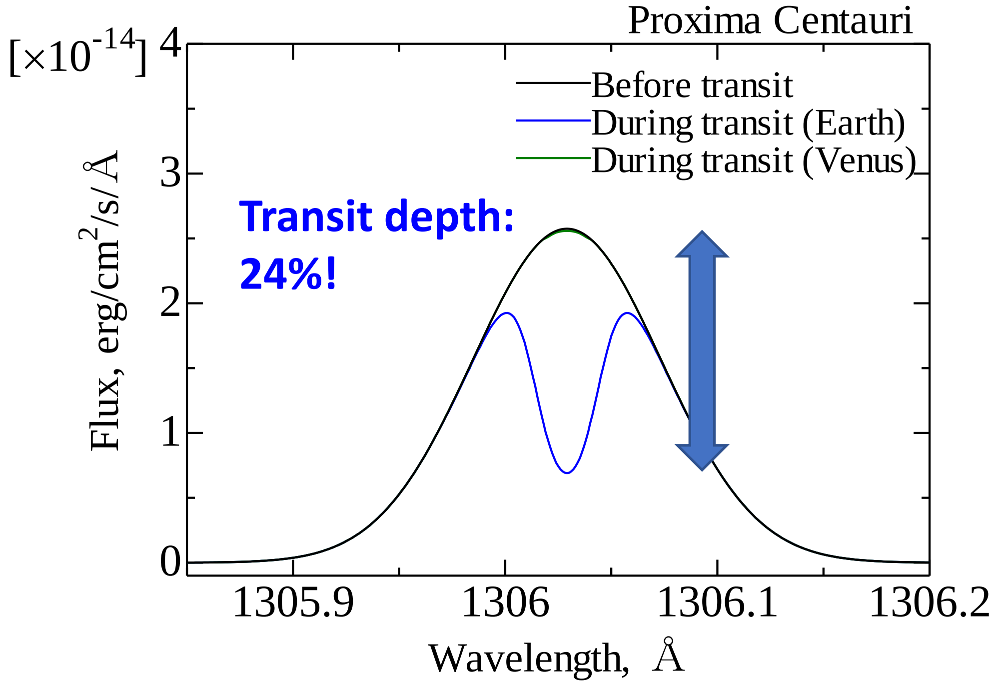
HZ of cool star: close to star -> High UV irradiation (> x10)





Black: Planet White: Star

The Earth-like planet has extended oxygen corona



-Spectral range from <120nm to >135nm
(H Ly-α: 122nm, OI: 130nm)
-Spectral resolution: <0.3nm
-Sensitivity stability: <1%

Participation to Russian UV space telescope WSO-UV is on-going -> Goal 2 will be updated

Goal 3: First Atlas of Gaseous Large-Scale Structures

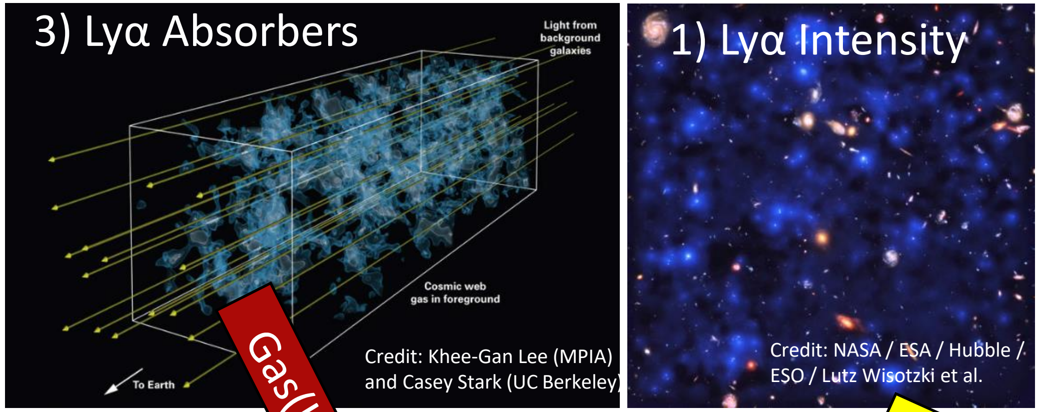
Led by Masami Ouchi

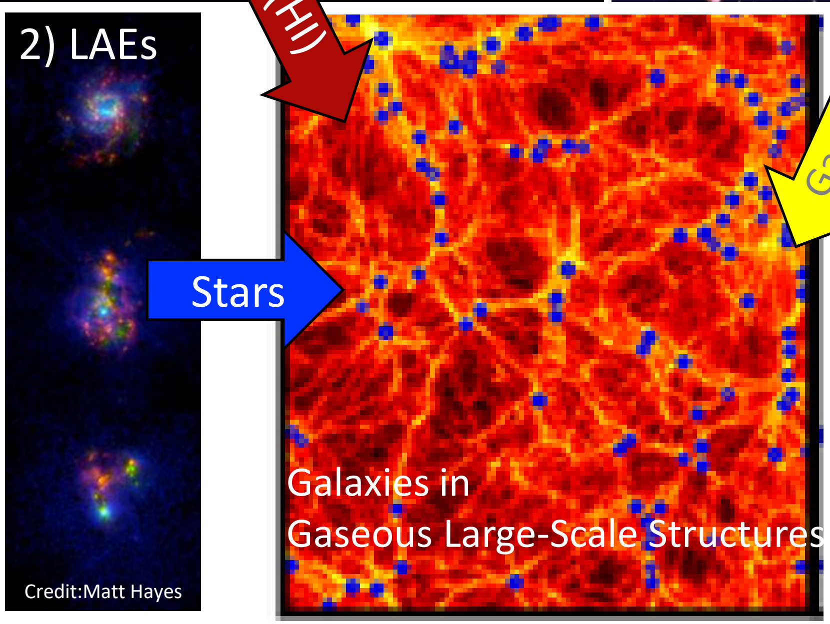
(1) What is the nature of dark matter?: the long-standing “missing satellite problem”

(2) What is the baryonic structure of the universe today?: the baryon physics/galaxy formation issue

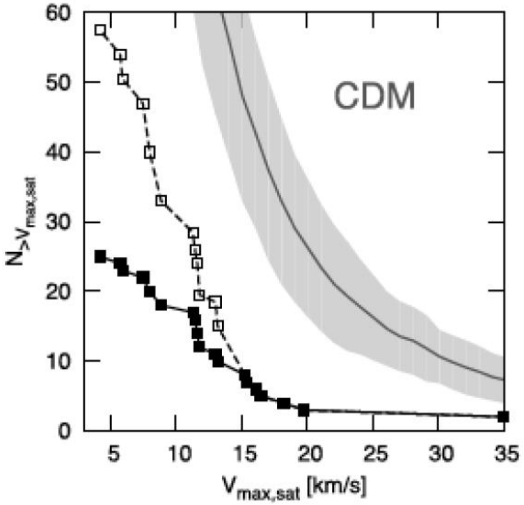
➔ Key: the large-scale structures of hydrogen gas in the nearby Universe via Lyα emission and absorption

---Cosmology and Galaxy Formation Astronomy---





Gas (HII+HI)



Milky way satellites expected by the Cold Dark Matter model are about an order of magnitude higher than those identified by the observations

[Boehm et al., 2014]

- -Complement to SPHEREx
- -HI tomography map
- -Comparing with SDSS, LSST, Roman/EUCLID

c)http://spherex.caltech.edu/Science.html#Inflation

Specification requirements <To be updated>

Baseline survey: >100 deg^2 to ~24 mag

FoV: >0.1 deg^2, Spectral range: 120–190 nm

1) Lyα Intensity

- Imaging with a spatial res. of ≲ 10”

2) Lyα emitters (LAEs)

- Imaging/slitless spec (≲ 4” & R ≳10)

3) Lyα Absorbers

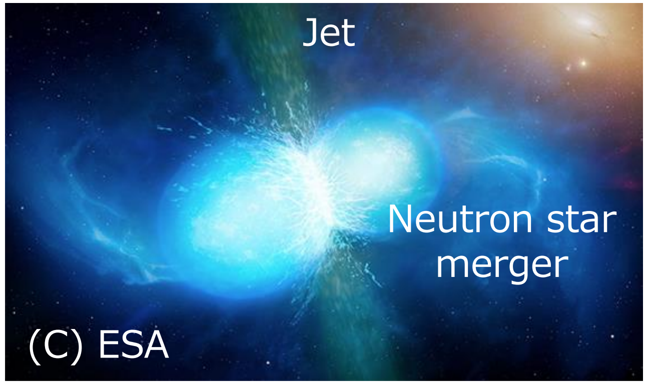
- Slitless/target spec (R ≳10/100)

Goal 4: Time-domain astronomy

Led by Masaomi Tanaka

(1) How are relativistic jets formed in extreme physical environment?: neutron star merger
(2) What happens in the last 10 years of stellar evolution?: supernovae
➔ Detecting the first 1 hour of explosive transients in UV

First emit electromagnetic signals: in the UV wavelength range
-> **Missing!**

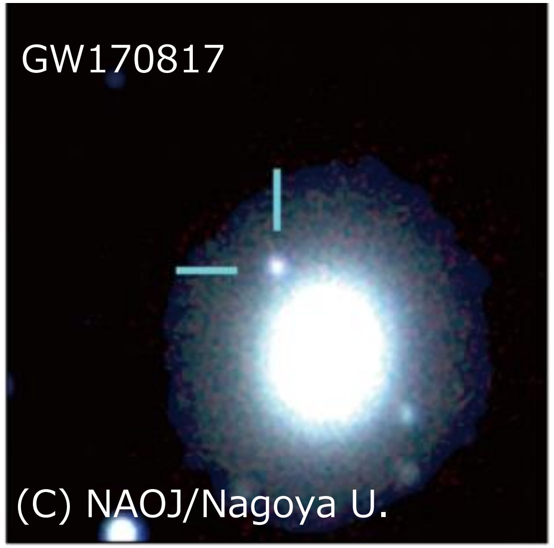


Gravitational Wave (GW)

Alert

Multi-messenger astronomy

(1) UV survey for GW source
- 23 mag (AB) depth for 10 deg^2 within 1 hour
- Rapid data transfer to the ground



(2) UV survey for supernovae
- 23 mag (AB) depth for 10 deg^2 -> 500 Mpc
- 1 hour cadence

Future plans and roadmaps

-Analyze each requirement

-Concept study of the telescope system and instruments

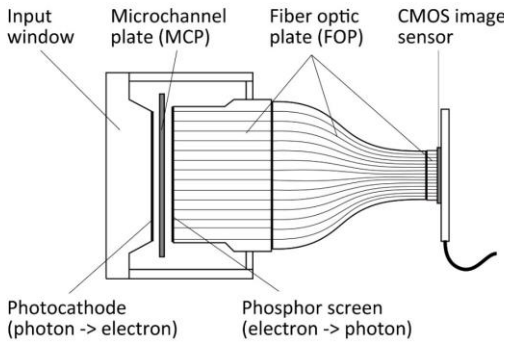
  -Two designs: for S-class and M-class

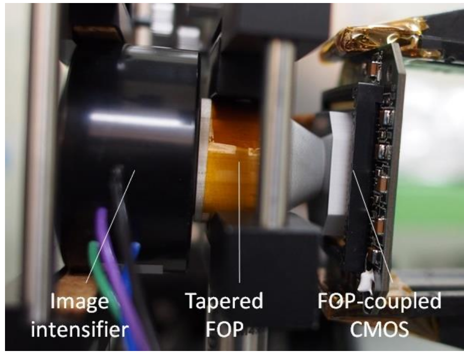
-Clarify the key techniques for this mission and future

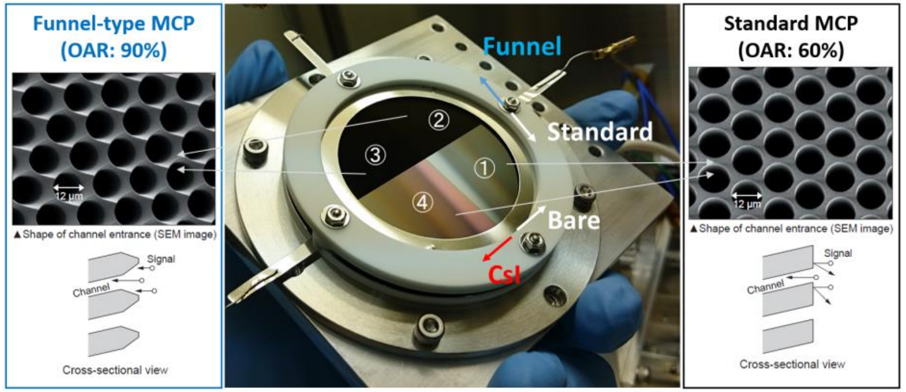
Target	Goal 1	Goal 2	Goal 3	Goal 4
	Icy moons	Exoplanets	Gal/Cosmology	GW/supernovae
Mode	Slitless spectroscopy (/Imaging)	Spectroscopy	Imaging/ slitless spectroscopy	Imaging
Spectral range	120-160nm	120-135nm	120-190nm	<300nm?
Spectral resolution	<1nm	<0.3nm	<1nm	TBD
Spatial resolution	<0.2"	-	<4"	TBD
Field of view	>320 arc-sec	-	>0.3 deg2	100 deg2, 23 Mag(AB) in 1h
Effective area (Sensitivity)	>200 cm2	>200 cm2	24 Mag	

<Key techniques>

-Detector







-Lightweight mirror

-Tip-tilt/defocusing mechanism

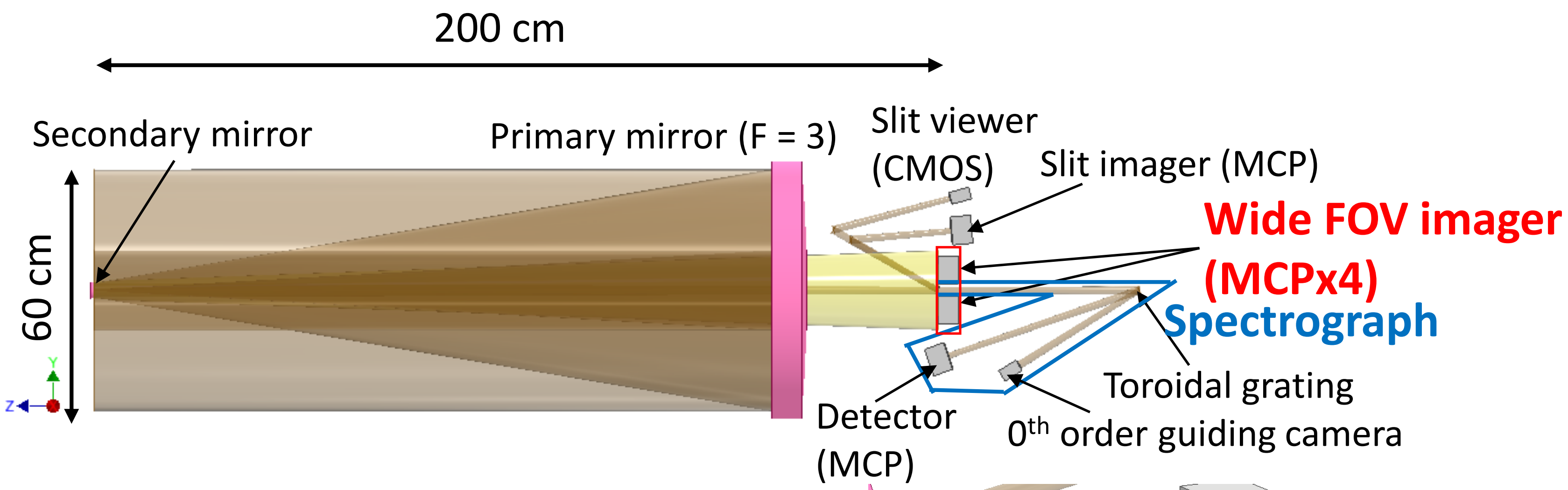
UV space telescope with high sensitivity (>1m class)

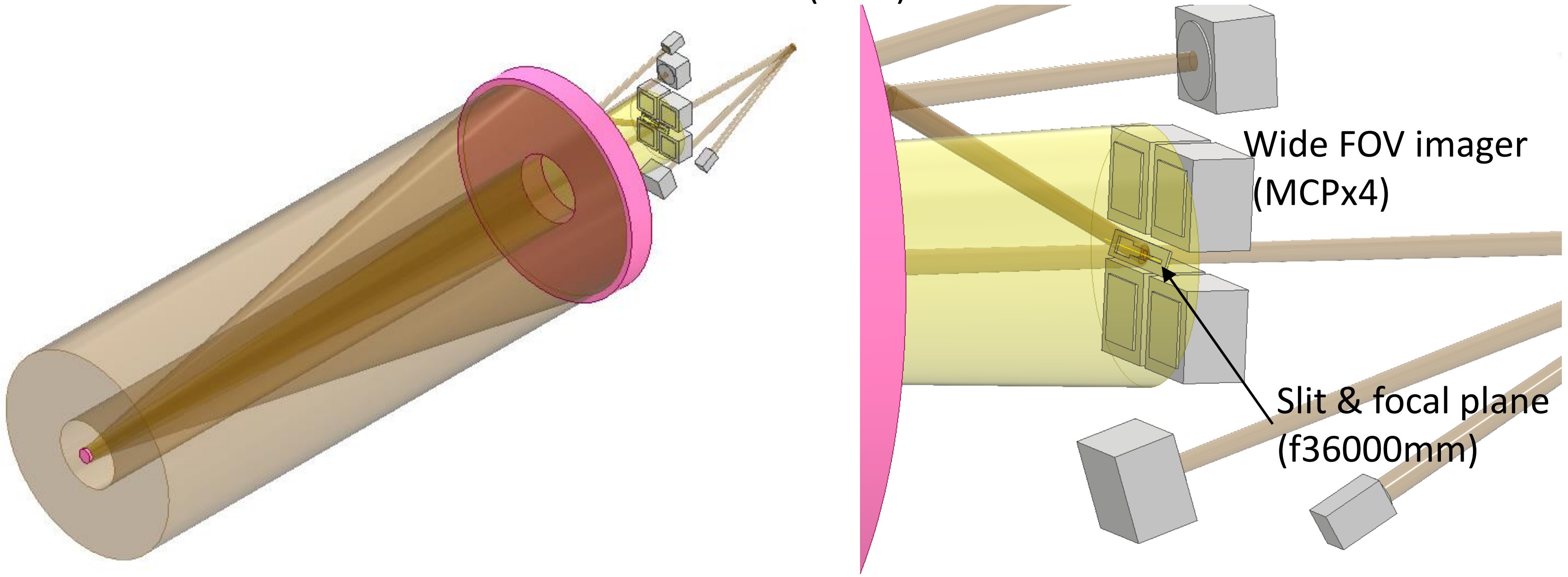
→ **Demonstrations for Japan's space telescope design/development**

Participations to large missions (LUVOIR/HabEx)

Specifications and preliminary design

Cassegrain telescope: D = 60 cm, effective f = 3600 cm





Science instruments

1. Spectrograph

Slit + Toroidal grating + MCP detector

Data type	2D spectral image (wavelength vs space)
Effective area	125-350 cm2 (at 130 nm)
Spectral range	115-190 nm
Spectral resolution	<0.02 nm (at the slit center)
Field of view	100" x 1-50"
Spatial resolution	0.1" (at the slit center)

2. Wide FOV imager

Large-format MCP array (4 detectors)

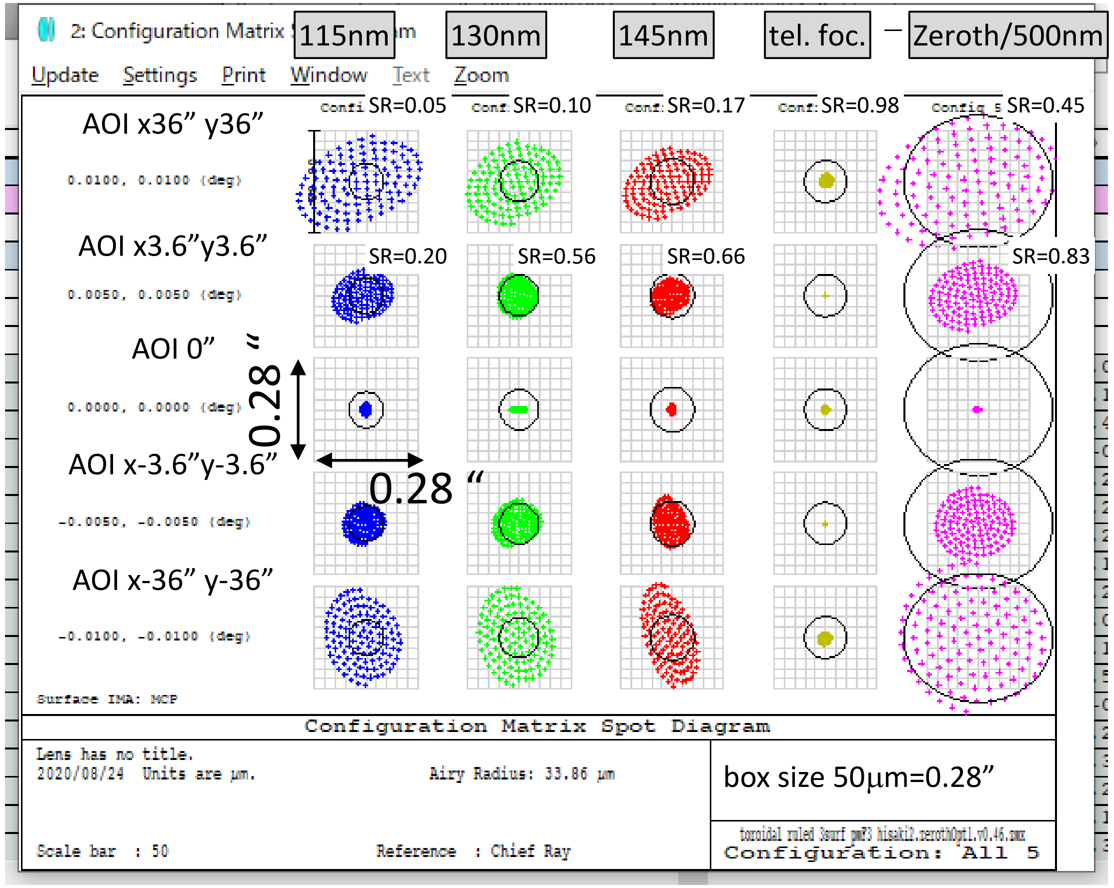
Data type	2D image
Effective area	320-880 cm2
Sensitive spectral range	115-190 nm
Field of view	10' x 10'
Spatial resolution	< 1"

Supporting/option instruments

- 0^{th} order guiding camera (VIS)
- Slit viewer (VIS)
- Slit imager (UV)
- H/D absorption cell

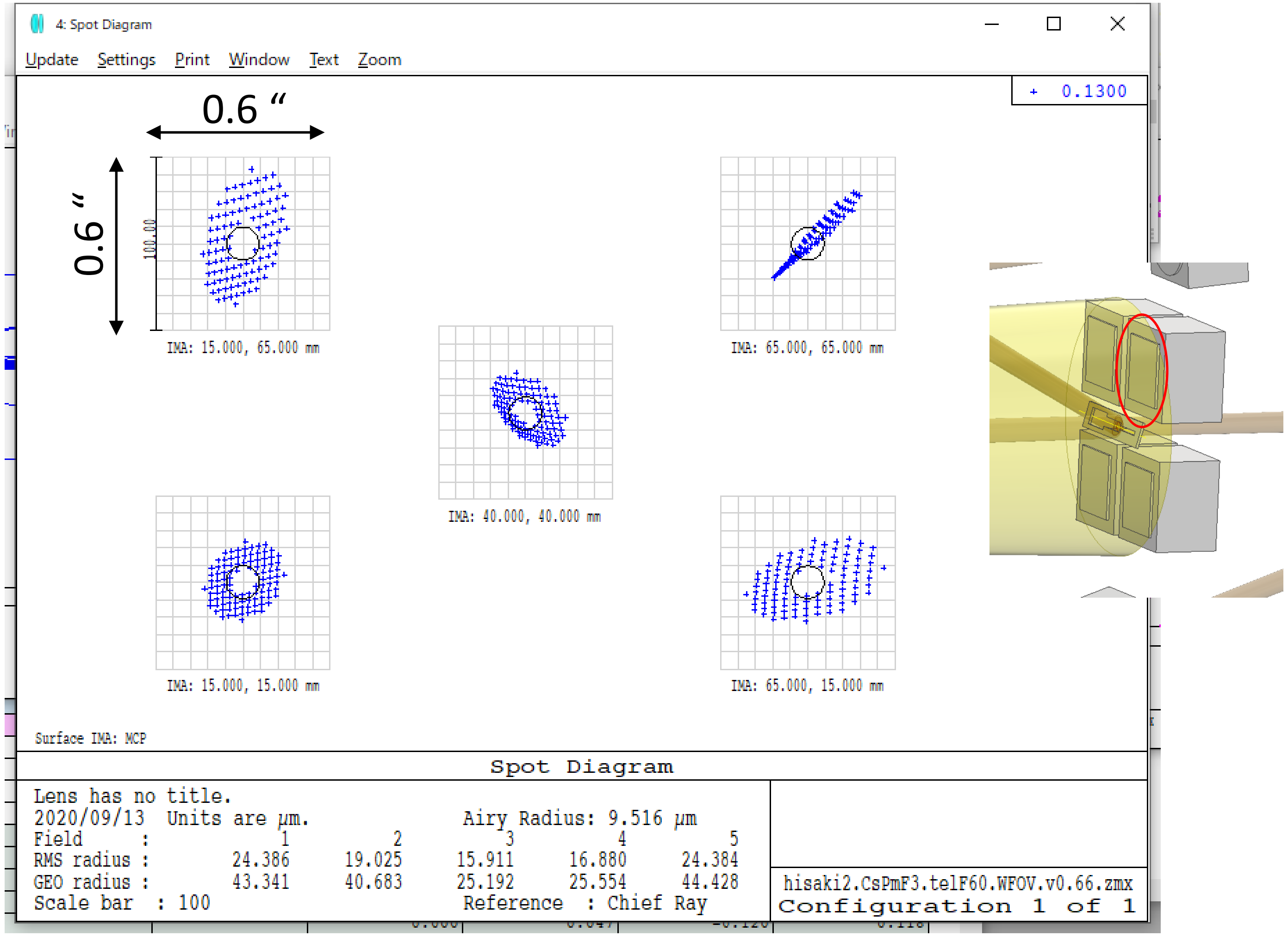
Specifications and preliminary design

Spectrograph



Resolution of 0.1” can be achieved at FOV center (±~3”)

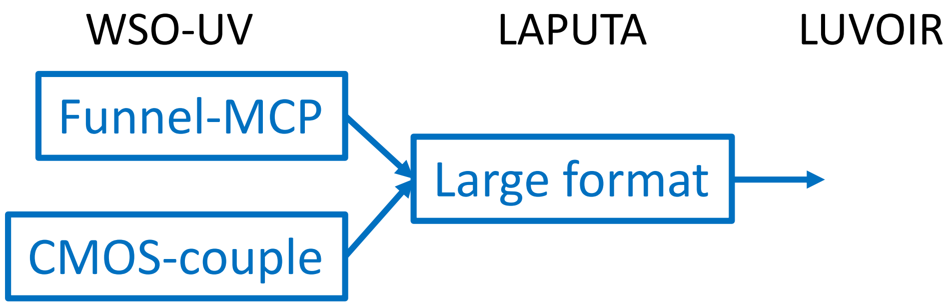
Wide FOV imager



Resolution of <0.6” can be achieved at all FOV

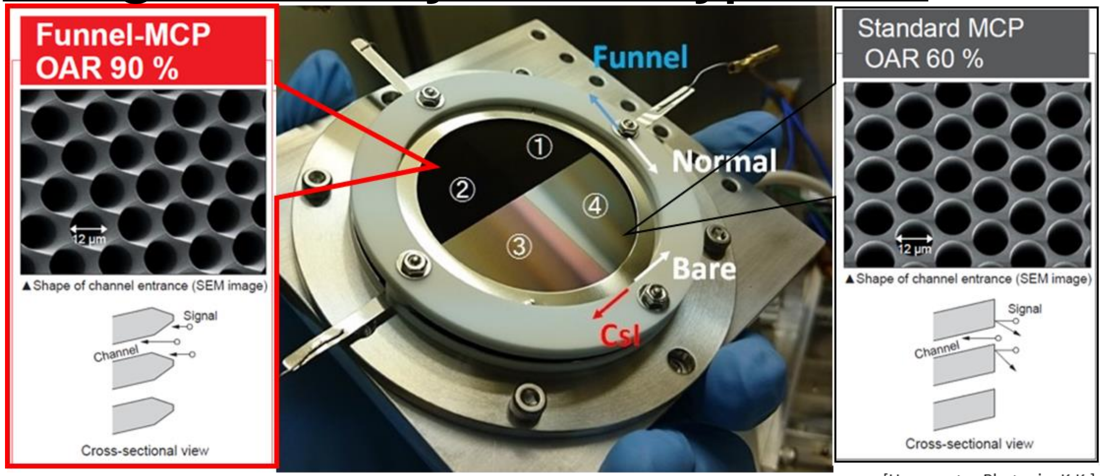
Key technologies

- **60 cm telescope on a small-class scientific satellite bus**
- **Grating 0th order guiding system in the spectrograph: new concept**
  - To achieve high accuracy pointing with a 0.1” resolution, a field of view monitoring camera is needed
  - To minimize the alignment differences between the camera and UV spectrograph detector, we plan to put the camera at the 0th-order position of the grating
- **High sensitivity detector**
  - Funnel-MCP will be used in WSO-UV/UVSPEX
- **High resolution detector**
  - CMOS-coupled MCP will be used in WSO-UV/UVSPEX
- **Large format detector**
  - Test model of large format (53 x 53 mm) funnel MCP is under evaluation
  - -> Array of large funnel MCPs coupled with CMOS will be tested

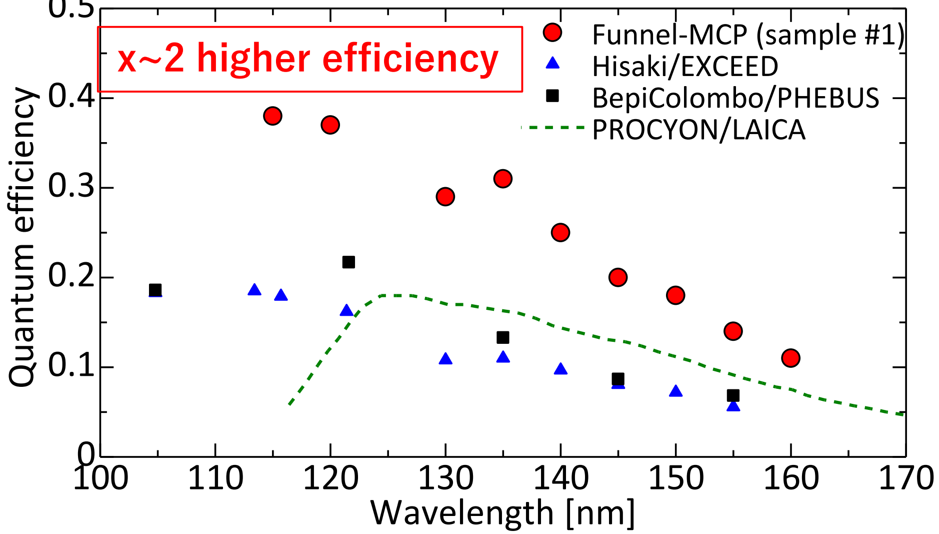


MCP detector for UV: fundamental developments

1. High efficiency: funnel-type MCP



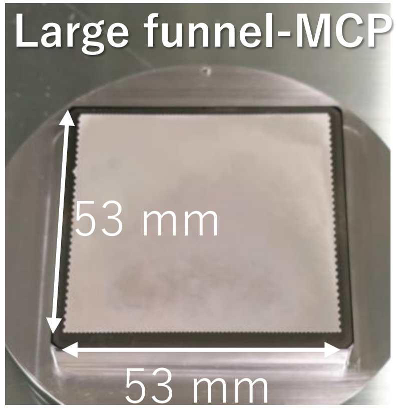
[Hamamatsu Photonics K.K.]



-Test model (ϕ40mm) achieved ~2 times higher efficiency

-**WSO-UV/UVSPEX will use this funnel-MCP technique**

2. Large format: MCP-array



-Test model is under evaluation

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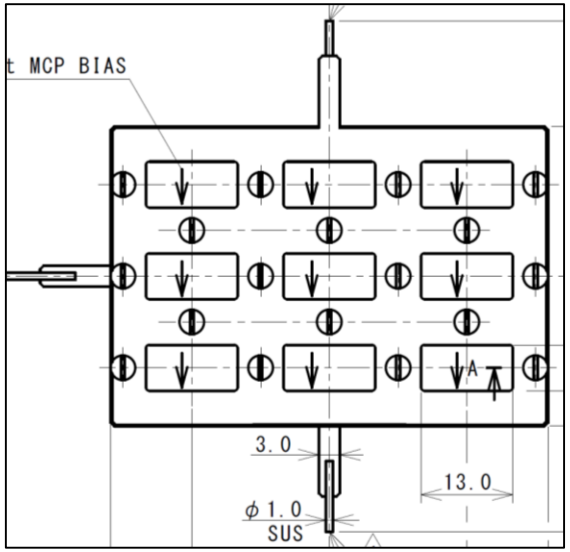


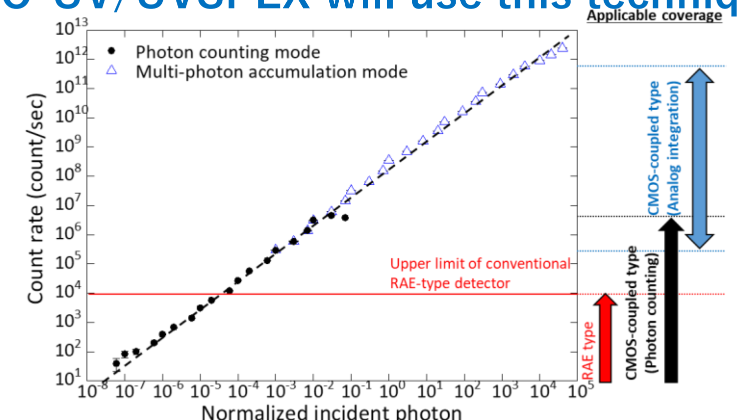
MCP-array with narrow (6.5 mm) gap

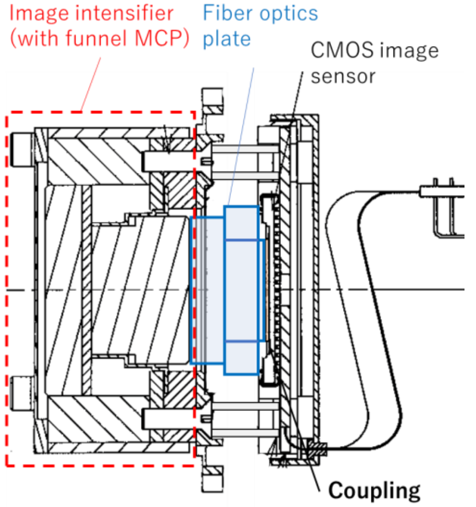
-Test model (3x3) with small MCPs is under manufacturing

3. High dynamic range and resolution: CMOS-coupled MCP

-Test model achieved dynamic range of $>10^{11}$ and MCP-channel resolution (6 um)

-**WSO-UV/UVSPEX will use this technique**

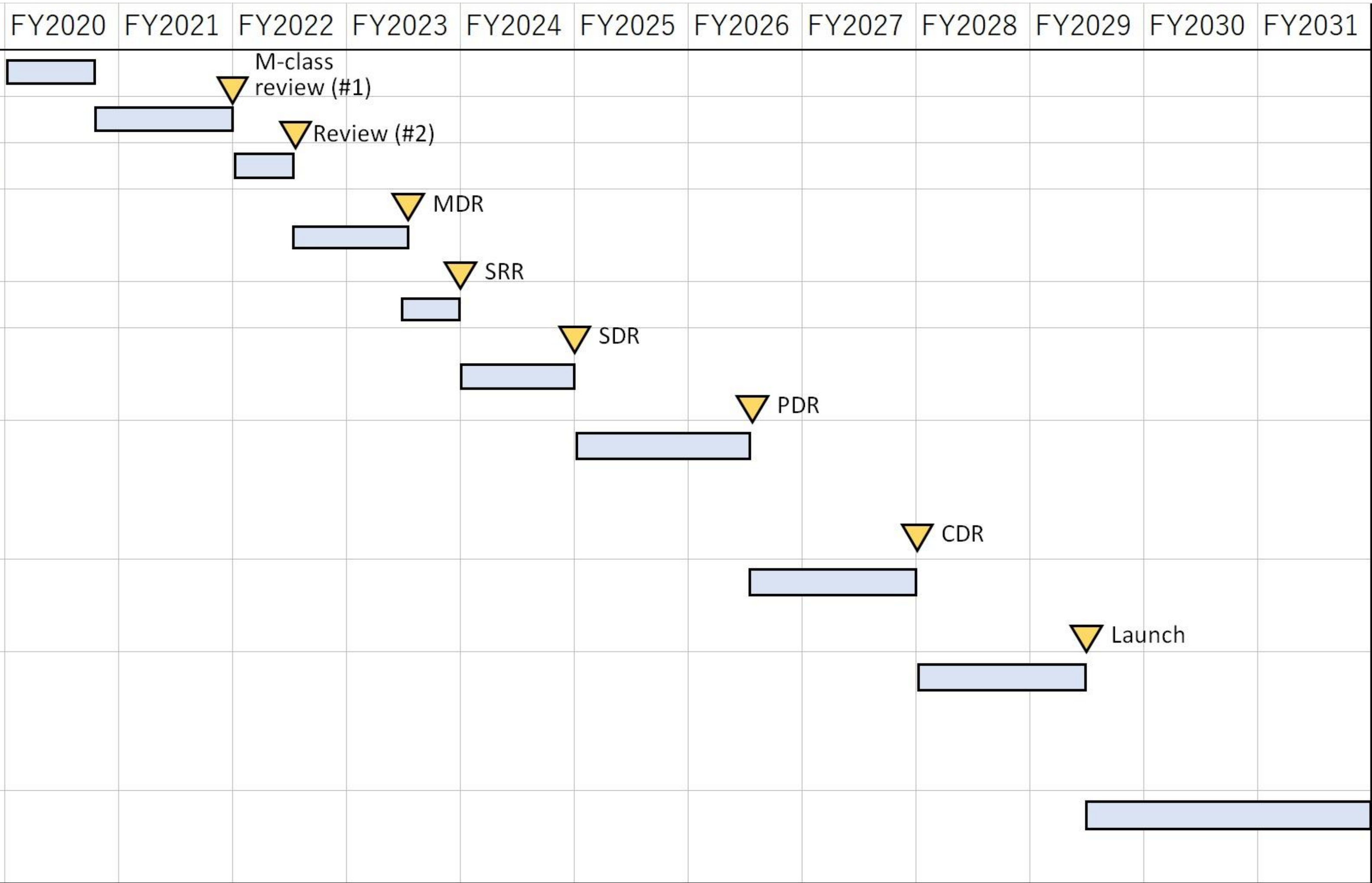




Schedule

- **Target class: JAXA M-class (公募型小型)**
- **Target launch: FY2029(-2030)**
- **-> We will apply to ISAS WG by the end of 2020**

Phase		Team	Activity
Mission consept study		RG study	Concept study
Pre-phase A	Pre-phase A1	WG study	Concept study
	Pre-phase A1b	WG + ISAS	Accereration process
	Pre-phase A2	Pre-project candidate	Mission defenition study
Phase A	Phase A1	Pre-project	Concept design
	Phase A2	Pre-project + industory	Project definition
Phase B		Project	Preliminary design and technology completion
Phase C		Project	Final design and fabrication
Phase D		Project	System assembly, integration, and test, launch
Phase E		Project	Initial and nominal operations



White Paper 評価結果：総評

本計画は、紫外線宇宙望遠鏡による、宇宙における生命をキーワードとした、**惑星科学から天文学にまたがる学際的な研究計画**である。それゆえ、**その独自性については高い評価が得られている**ものの、**個々の科学的価値については更なる検討が必要**という評価が多かった。**特に先行して打ち上げられるWSO-UV との差別化や優位性の検討が必要である。**また、惑星科学や生命科学を含む学際的な科学目標を掲げているため、評価ができないというコメントも多かった。これは、本計画が学際的であるがゆえであるため、**ネガティブに捉える必要はないと思われるが、一方で、従来の天文学コミュニティに対して、本計画への理解を広める活動の必要性を示している**とも言える。実現性については、「**ひさき**」**の実績を評価する声がある一方で、コミュニティの小ささを指摘する声もある。**「ひさき」の実績や学際性を活かし、本計画を担えるだけの**大きく強いコミュニティを作り上げていく活動が必要であろう。**

White Paper 評価結果：総評への回答

- 個々の科学的価値の追加検討、特に**WSO-UV** との差別化や優位性の検討が必要
  - 系外惑星大気はWSO-UV/UVSPEXの主目的であり明確な差別化を検討中
  - 太陽系内ターゲットに対する観測フィジビリティ（追尾など）を確認中
  - UV map、time domainについてはESCAPEなども含め他ミッションとの差別化・優位性を整理し、相補的な形を目指す
- 惑星科学や生命科学を含む学際的な科学目標については評価ができない、従来の天文学コミュニティに対して本計画への理解を広める活動が必要
  - 学会・研究会等での発表機会を増やしつつ、天文学コミュニティとの情報交換の場を設けていく
- 実現性について「ひさき」の実績を評価する一方で、コミュニティの小ささへの指摘もある。「ひさき」の実績や学際性を活かし、大きく強いコミュニティを作り上げていく活動が必要
  - 太陽グループとの連携・恒星サイエンス（フレア・CME、黒点）の追加
  - 太陽系内：月2回勉強会を実施し科学的価値の検討とともに体制強化
  - 系外惑星：惑星大気の専門家を検討メンバに加え他ミッションとの差別化を図る
  - 天文：目標仕様を広く共有しつつ、サイエンス・技術における連携強化を進める

惑星科学・天文・太陽の横通しにより、日本自前の宇宙望遠鏡を開発できる技術・経験・人材を継承・発展させたい

他ミッションとの差別化

	HST/ACS SBC	HST/WFC3 UVIS	HST/STIS	HST/COS	GALEX	Swift UVOT	ULTRASAT	WSO-UV	GUCI	CETUS	CASTOR	LAPUTA/ Spectrometer	LAPUTA/ Imager
Mirror size	2.5 m				0.5 m	0.3 m	0.5 m	1.7 m	0.13 m	1.5 m	1 m	**0.6-1 m**	
Sensitivity		~27 mag*			~22.5 mag*	~21 mag*	22 mag in 900 sec		20-21 mag In 300 sec	26-27 mag in 1 hour	25.8 mag		
Effective area (cm2)	~>1000	~>1000	250 @220 nm	2,000 @120 nm 500 @200 nm	36.8 @148 nm 61.7 @220 nm	~20 @200-[illegible] nm		1000	50	1000-2000		**125-350**	**320-880**
FOV	0.57′ x 0.5′	2.7′ x 2.7′	0.4′ x 0.4′	φ2.5″	φ1.2 deg	17′ x 17′	210 deg2	2′ x 2′ (F) 6′ x 6′ (N)	50 deg2	17′ x 17′	0.25 deg2	**1-50″ x 100″**	**10′ x 10′**
Spatial resolution	0.06″	0.08″	0.05″	0.06″	4-5″ PSF	1″ 2.5″ PSF	40″	0.16″ (F) 0.3″ (N)	40″ PSF	0.55″ (F) 0.33″ (N) PSF	0.15″ FWHM	**0.1″**	**0.2-1″**
Spectral range (nm)	115-170 (ACS up to 1000 nm)	200 - 1000	115-310 (STIS up to 1000 nm)	90-320	130-280	170-650	220-280	120-320	190-220 260-290	125-180 (F) 180-400 (N)	150-550	**115-190**	**115-190**
Spectral resolution R = λ/Δλ	R ~100 @150 nm prism	R ~ 180 @ 220 nm grism slitless	R ~ 30,000 – 114,000 Echelle	R =3000-20,000	R = 200 (F) R = 90 (N) grism	R~150 grism	None	R = 1,000 & 50,000	None	R = 12,000 -40,000	None	**R > 5000**	**None**
Period	2002-	2009-	1997-	2009-	2003-2013	2005-	2023?	2025	2025?	2030?	2026?	**2029**	

・ESCAPEを要追加

・各天文ミッション（WSO-UV含む）における太陽系内天体への観測フィジビリティを確認（特に追尾性、長期観測可能性）

・各科学ゴールに対し、観測フィジビリティ検討を進めつつ、できるだけ他ミッションと相補的な観測となるように装置仕様を工夫