Planetary atmospheric monitoring with the Tohoku University Haleakala telescopes: current status and future plan

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We are conducting an international collaboration for the 1.8-m aperture off-axis telescope project PLANETS. In this presentation, we focus on the current status of PLANETS project and future plans to promote planetary/exoplanetary sciences. PLANETS is characterized by low-scattering and high-contrast optics with off-axis mirror system, and also by monitoring observation. We mainly concern variations in planetary atmospheres, faint gases produced from satellites, exoplanetary atmosphere, and also welcome other targets that match to the advantages of PLANETS. Continuous monitoring is essential to understanding the planetary atmospheric phenomena, and therefore, own facility with even small-telescope and own instruments are important as we demonstrated with T40 and T60 telescopes at the summit of Haleakala, Hawaii (3050m).
To achieve precise spectroscopy and polarimetry for faint emissions/absorption in planetary/exoplanetary atmospheres and satellites, PLANET's a 1.8-m aperture with low-scattered light optics is necessary. PLANETS project is managed by the PLANETS Foundation (www.planets.life), which is an internationally organized entity whose board members are from several institutes in Japan, USA, Germany, Brazil, and France. This off-axis optical system brings us unrivaled high-dynamic range scientific capabilities on coronagraphy and polarimetry. It will have a Gregoian focus with a FOV of 6' (Fno=13) with diffraction limited image with a diameter of approximately 1'. The main mirror is Clearceram Z-HS with a diameter of 1850 mm, which is now on the final polishing process. We are designing mechanical structure of telescope for both cases of equatorial mount and azimuthal-elevation mount. We are also designing a mirror support structure in two ways, active support and passive support. We are aiming to get first light with PLANETS telescope within next several years.

Symposium on Planetary Sciences 2019 (SPS2019),
Sendai, Japan, 18-21 Feb., 2019.
P10

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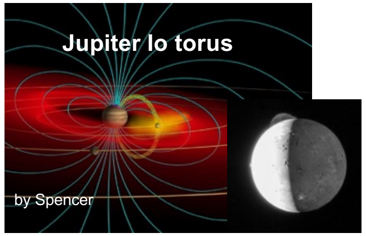
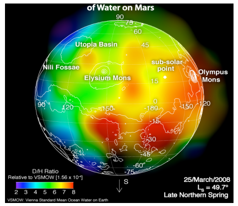


Aim and Goals
(1) Faint emissions surrounding a bright body

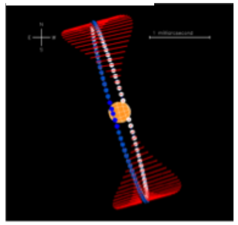
High-dynamc range, high-spectral resolution

- ✓ Satellite-related gas, such as Io torus and Enceladus torus, and planetary exosphere
- ✓ Rayleigh scattering
- ✓ Resonance and fluoresce scattering
- ✓ Electron impact excitation

Mars HDO/H_2O map



Exoplanet



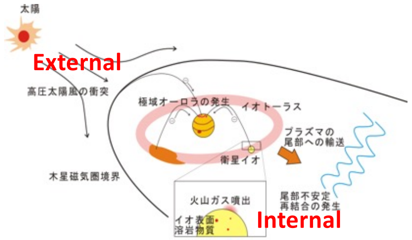
- Brightness of planetary disk is roughly 10^{-5}～10^{-7} times greater than that of targets.

→ coronagraphy
→ high-resolution spectroscopy

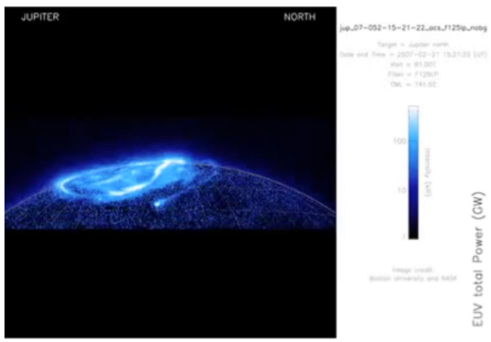
Aim and Goals
(2) Continuous monitoring of planets

- ✓ **Difficult to distinguish auroral variations from apparent geometrical effect due to Jovian rotation**
- ✓ **HST has high spatial resolutions, but continuous measurement was rare.**
- ✓ **HISAKI only measure UV total flux, but can monitor its time variation.**

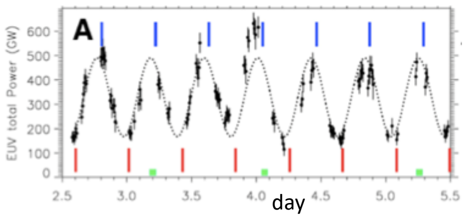
→Monitoring is essential to understanding planetary variation.



HST observation of Jovian UV aurora

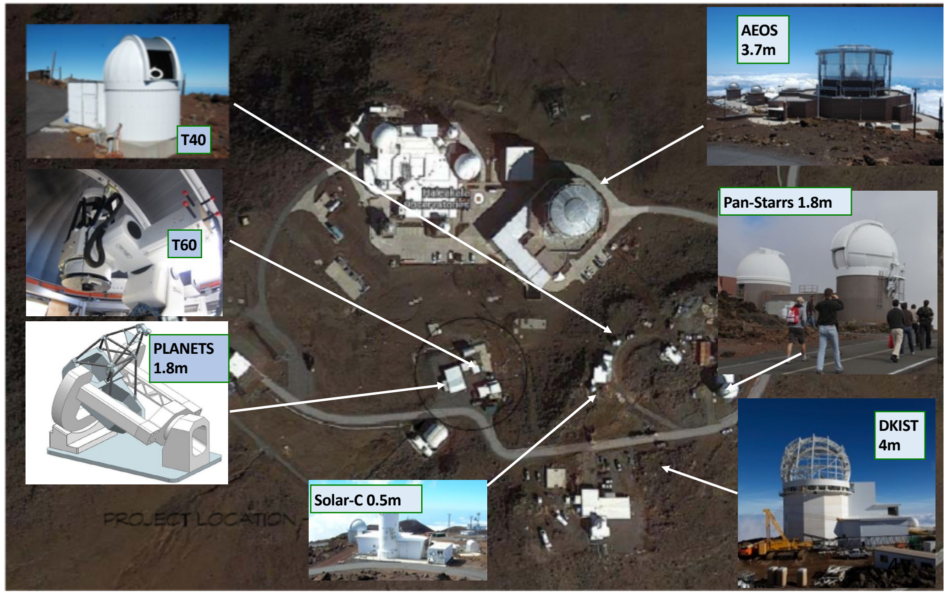


HISAKI observation of Jovian UV aurora



Site: Haleakala observatories

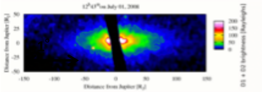
GLAT=20° 42.5’ N, GLON=203° 44.5’ W, ALT=3040m



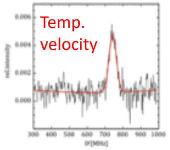
Tohoku telescopes at Haleakala, Maui

- Continuous monitoring of planets
- Flexible and timely coordination with other instrument
- Unique instruments

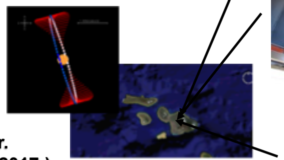
Wide-FOV imager, Io sodium nebula (1998-)

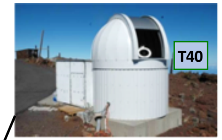


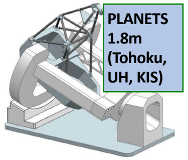
MILAHI: Mid-infrared heterodyne spectr, Venus and Mars CO2 non-LTE emission (2015-)



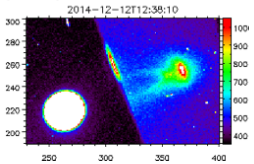
DIPOL-2: Exoplanetary polarization (2014-) [KIS, U.Turku]



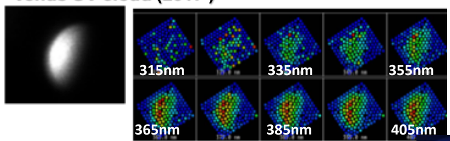




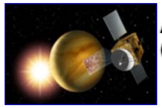
Vispec: Visible echelle, Io plasma (S+) torus (2006-)



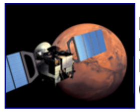
Fiber-array spectr. Venus UV cloud (2017-)



- Collaborations with space missions



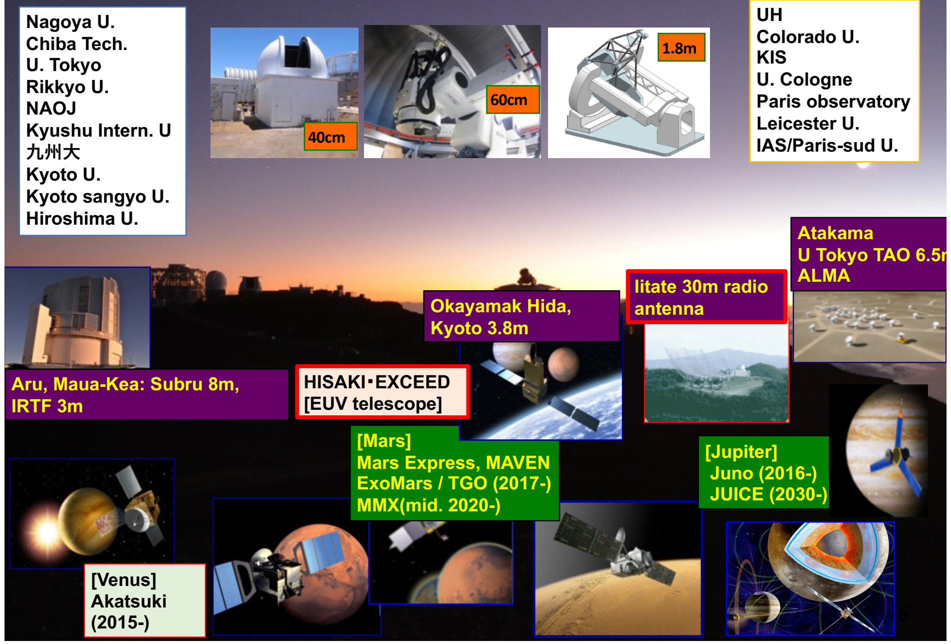
Akatsuki (Venus)



MEX MAVEN ExoMars (Mars)

Hisaki HST Juno (Jupiter)

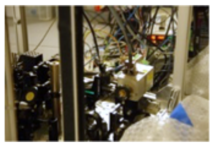
Collaborations



T60

- Advantages
  (1) High-res. Spectroscopy (Coude)
  (2) German equatorial mount (Polarimetry)
  (3) Remote-automatic operation system

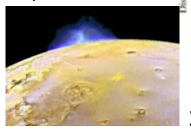
Instrument *Cou: Coude, Cas: Cassegrain	Spec.
Cou: Vispec(Visible Imager and Spectrograph with Coronagrpahy)	0.4-0.9mm, FOV~10' / R~50000,3000
Cou: MILAHI (Mid-infrared laser heterodyne spectrometer)	7-11nm, R ~ $10^{6\text{-}7}$
Cas: DiPOL-2 (Polarization imager) (KIS)	B, V, R polarimetry (DoLP ~ $10^{-5\sim6}$)
Cas: DMD Variable Occultation Mask Imager	Variable mask + Cronagraph
Cou: Integral Field NUV Spectrograph (Chiba-tech. U)	IFU, R~125
Cou: RGB and NIR camera (Kyushu Intern. U)	RGB+2NIR, high-speed imaging

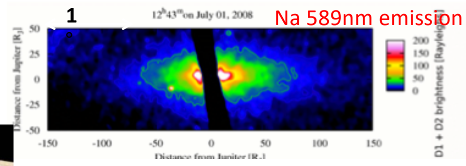


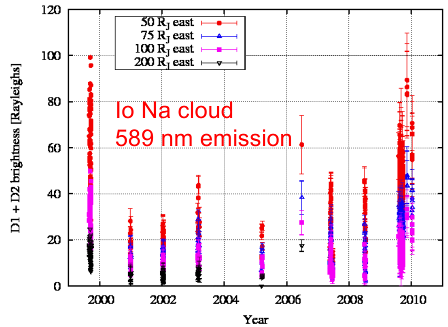
[On-going or potential guest
NIR(1-4um) Echelle spectrograph (ESPRIT)
λ/dλ ~ 20,000
Mid-IR (7-12um) Echelle spectrograph (GIGMICS) Nagoya U.
λ/dλ ~ 40,000

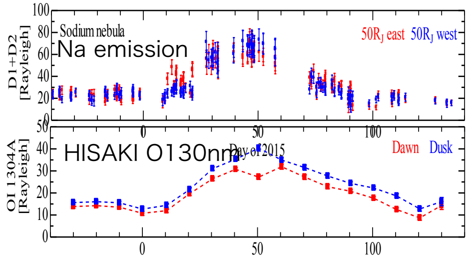
Jupiter and Io system

Sodium imager + HISAKI
(Kagitani, Tsuchiya, Yoneda)

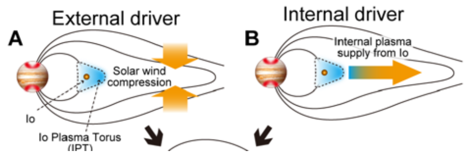






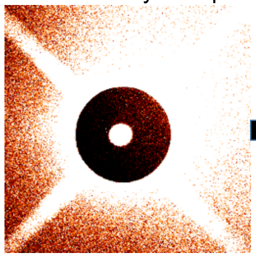


Day of 2015

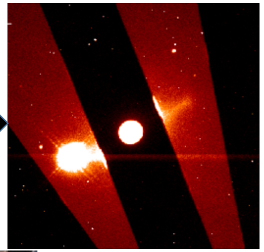


(1) Virspec: a strip-shaped mask coronagraph

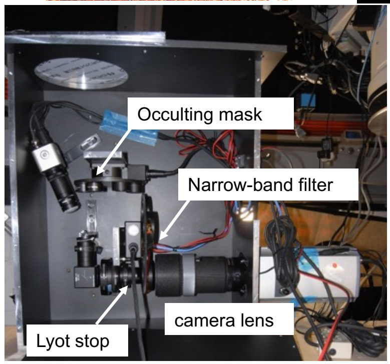
Without Lyot stop

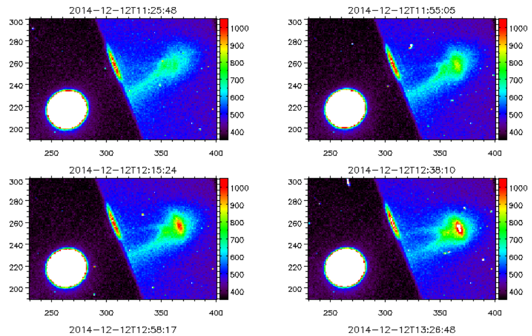


With Lyot stop



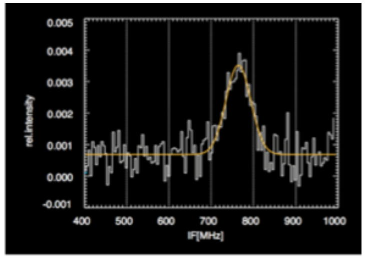
Io plasma (S+) torus emission at 671.6nm





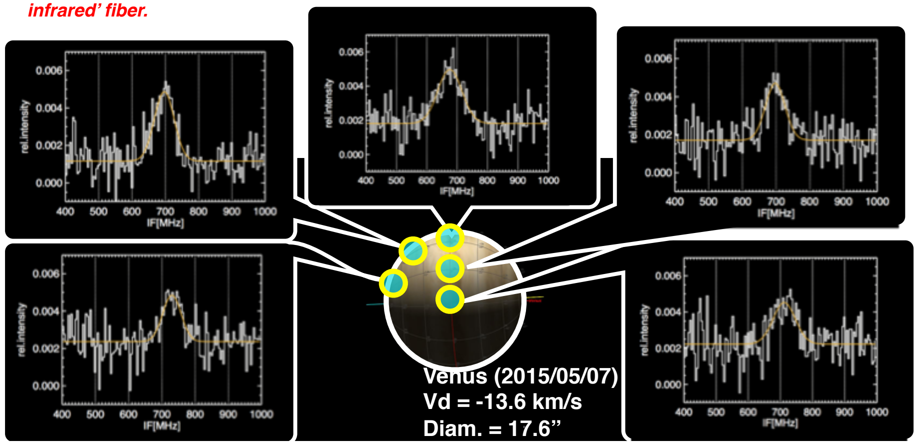
(2) MILAHI: mid-infrared heterodyne spectrometer

7-11nm, $\lambda/\triangle\lambda \sim 10^{6-7}$



Venus mesospheric MIR CO_2 non-LTE emission

- ✓ ***First detection by T60 at 971.532 cm^{-1} (2MHz res.) on 28 Mar. 2015***
- ✓ ***Currently, we are developing a detection system with 'mid-infrared' fiber.***

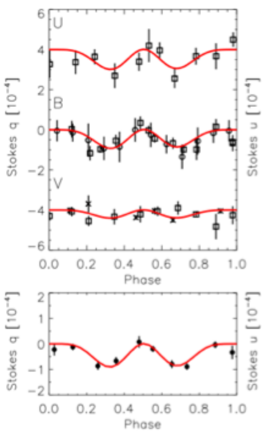


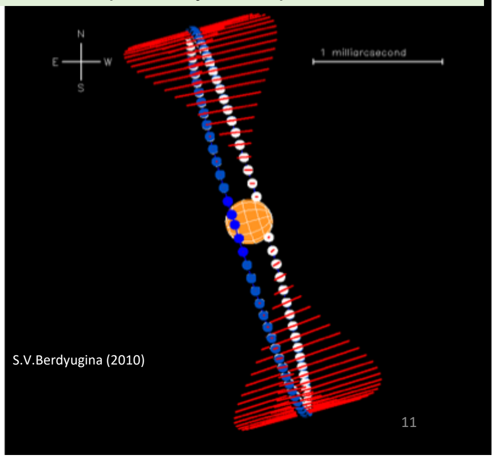
(3) Polarimetry of exoplanet

(A. V. Berdyugin, S. Berdyugina, Vilppu Piirola, Kagitani)

HD189733b Hot Jupiter: period=2.2d, a = 0.03AU, R~1.5R$_J$ [star: 7.7mag(V), K0/M4]

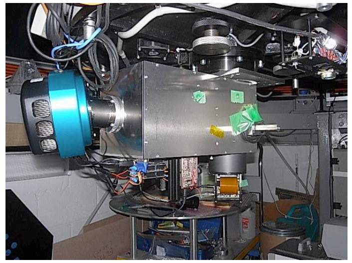
Multispectral Polarization at B,V, R band
Degree of Linear Polarization =10^{-4} order
Consistent with Rayleigh scattering model in exoplanetary atmosphere



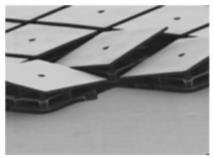


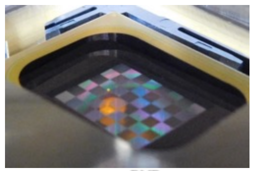
(4) DMD variable mask coronagraph

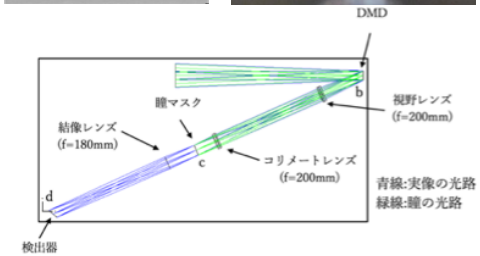
Variable mask for multi-targets
Useful for Io and Enceladus torus, exoplanets, etc,...
Reduction rate ~ 10^{-5} to 10^{-6}



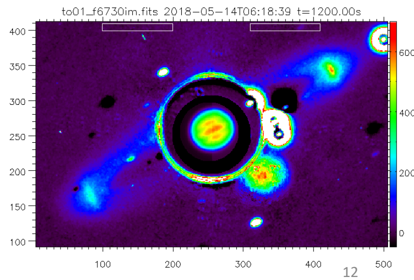
DMD array







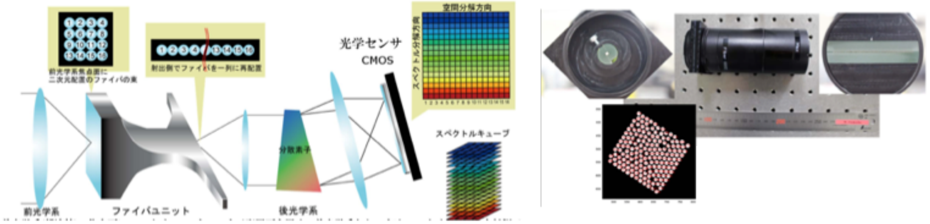
Io S+ 671.6+673.1 nm torus



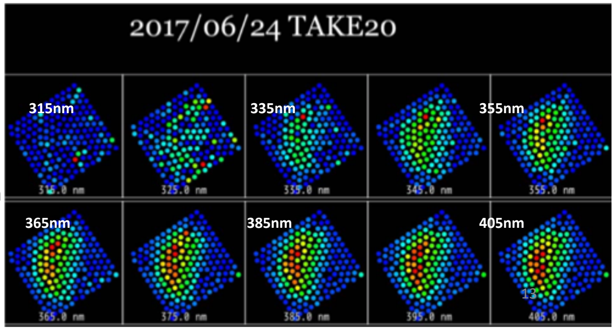
(5) Integral Field Spectrograph

(Kagitani, Yamada, Yamazaki)

IFU with fiber array



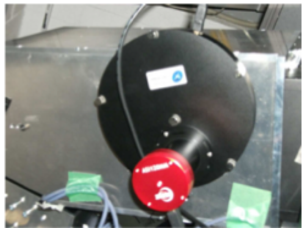
- **Spatial resolution: 1.86 ″/fiber**
- **Fiber array number: 164**
- **Fiber pitch: 0.13mm**
- **Dispersion: 0.46nm/pixel**
- **Image FWHM ~ 7pix = 3.2nm**
- **Spectral res. λ/Δλ = 125**

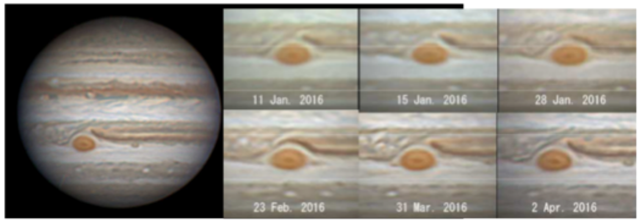


(6) RGB+IR imager(Asada, Kagitani Sakanoi)

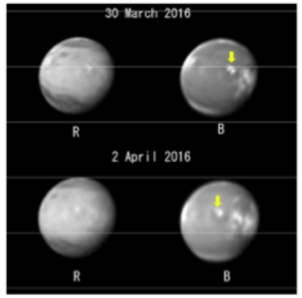
Filter: RGB + 750nm(IR continuum) + 893 nm methane band
3 measurements per night, 100 min interval
- 2800 RGB images for 2 min
- 130 IR images for 2min
- 24 methane band images for 2min

Analysis: Averaging -> wavelet trans. -> Max. entropy method





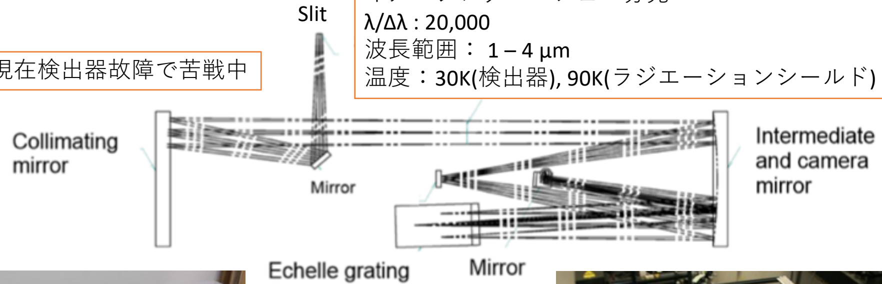
	待機日数	撮像日数	確率
2015年12月	15	7	46.7%
2016年1月	31	29	93.5%
2016年2月	29	26	89.7%
2016年3月	31	25	80.6%
2016年4月	11	9	81.8%
2016年5月	24	16	66.7%
計	141	112	79.4%

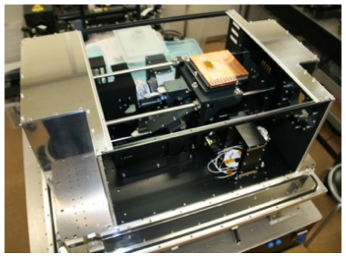


[進行中] 赤外エシェル分光器ESPRITの開発[坂野井、鍵谷、平原、市川]

現在検出器故障で苦戦中

検出器：レイセオンInSb 256x256
イメージング＋エシェル分光
λ/Δλ : 20,000
波長範囲： 1 – 4 μm
温度：30K(検出器), 90K(ラジエーションシールド)





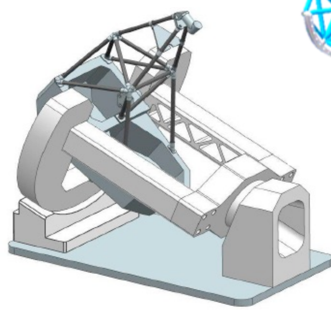
PLANETS JapanHawaiiEuropeTelescope

PLANETS 1.8-m off-axis telescope

https://www.planets.life/

- ✓ Mid-size low-scattering light telescope
- ✓ Continuous monitoring observation of planetary and exoplanetary targets

The PLANETS telescope project is promoted and will be operated by the PLANETS foundation consists of Tohoku Univ., IfA/UH, KIS, Brazil, France etc.



Aim and strategy

- Mid-sized telescope with low-scattering optical system
- Dedicated to specific target

→ Monitoring science by lots of time allocation

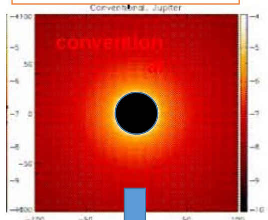
→ Faint target near bight object

Technical issues : AO + occulting mask

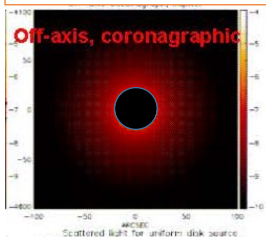
- Targets in the solar system: plume on Enceladus and Europa, Io's volcano, atmospheric escape from Mars and Venus
- Potential targets: Variations in active objects in astronomy, satellite volcanism, satellite geology, exoplanetary atmosphere, astrobiology (water vapor, minor tracer gas), etc.

Advantage of off-axis telescope

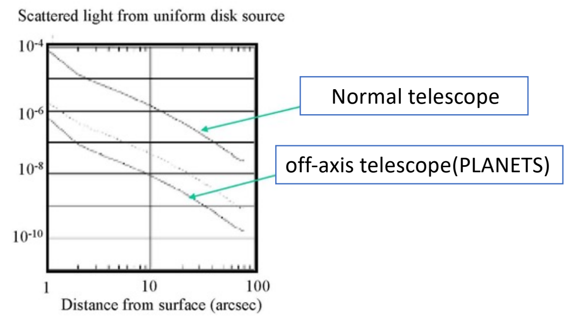
Normal telescope



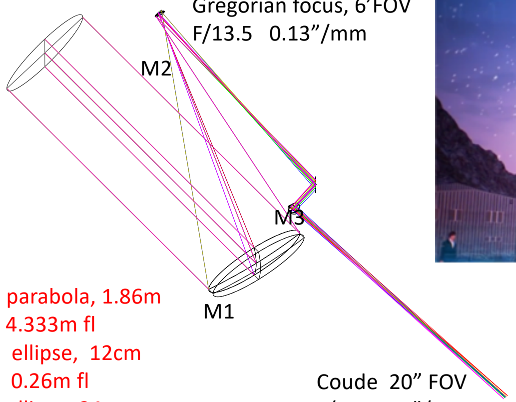
off-axis telescope(PLANETS)



- Off axis system contributes to low-scattering light inside optics, and therefore we can obtain the faint light data near a very bright object, such as emission and absorption in exoplanetary atmosphere.



PLANETS optics



M1: parabola, 1.86m
4.333m fl
M2: ellipse, 12cm
0.26m fl
M3: ellipse, 24cm

Probably, the world biggest (*nighttime) off-axis telescope.
(* DKIST is a 4m off-axis solar telescope.)

1.85-m main mirror (M1)

Ohara Clearceram Z-HS (same as TMT)

Φ = 1850mm, t=100mm

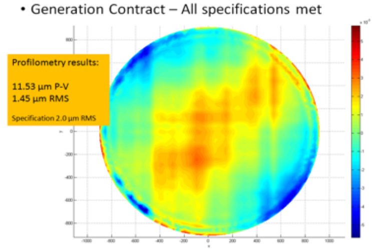
Melting (Dec. 2010)

Blank reached to L.A. (May 2011)

Grinding at Harris/EXELIS (July 2012)

Metrology Assessment

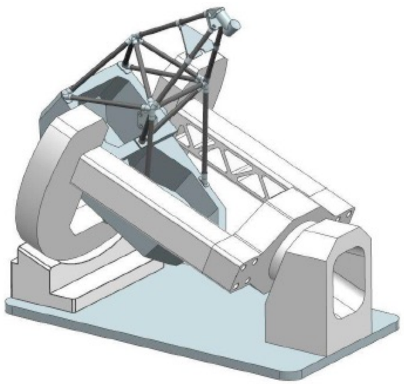
- Average of 2 Orientations Clipped to CA
- Generation Contract – All specifications met



Arrived in Maui (June 2017)

Mount and mirror support structure

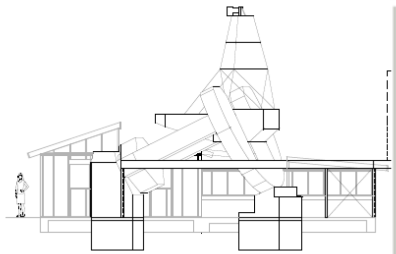
- ✓ We are discussing the horse shoe equatorial mount (left) and azimuthal-elevation mount (right).
- ✓ For the mirror support structure, we are discussing traditional whiffle-tree system and active support (e.g., air cylinder, balancer with motor).

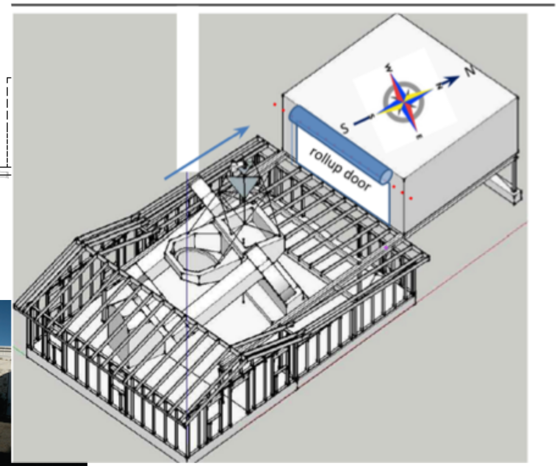


Building construction

PLANETS JapanHawaiiEuropeTelescope

We already got the Land Use and Construction Permit which determined the construction period within coming 3 years.





Issues and Current status of development

1. **M1 (1.8-m mirror) final polish: mostly funded. This will be done by the end of 2018 (Tohoku U and UH)**
2. **Building construction: partially funded Got the land use permit of Hawaii. (KIS/Germany, Brazil and UH)**
3. **Mount and support: will be funded. We completed rough design, and detailed design is proceeded. (UH and potentially Tohoku U).**
4. **Secondary mirror: Adoptive secondary mirror is discussed by France and Tohoku U.**
5. **Instruments: Polarization imager, High- and lo—res. Spectrometer, Near- infrared spectrograph, Mid-infrared heterodyne spectrometer.**

Concluding remarks

Any collaboration is welcome!

Mid- and small-size telescopes
-> planetary, and solar-system target
-> exoplanetary and star formation field

Haleakala telescopes (T60 and T40): Current achievement

- ✓ **High-resolution spectroscopy with coronagraphy, and polarimetry**
- ✓ **Continuous monitoring of planetary atmosphere**
- ✓ **Collaboration with space missions and big telescopes**

1.8-m off-axis PLANETS telescope will expand planetary science with:

- ✓ **Low-scattering light and high-contrast imaging**
- ✓ **Precise coronagraphy with adaptive optics**
- ✓ **Planetary and exoplanetary monitoring**
- ✓ **Polarimetry**