# ULTRAVIOLET ASTRONOMY IN THE XXI CENTURY

## e-Workshop 2020 – October 27-29

JcUVa

# WSO-UV/UVSPEX for characterization of Earth-like exoplanets

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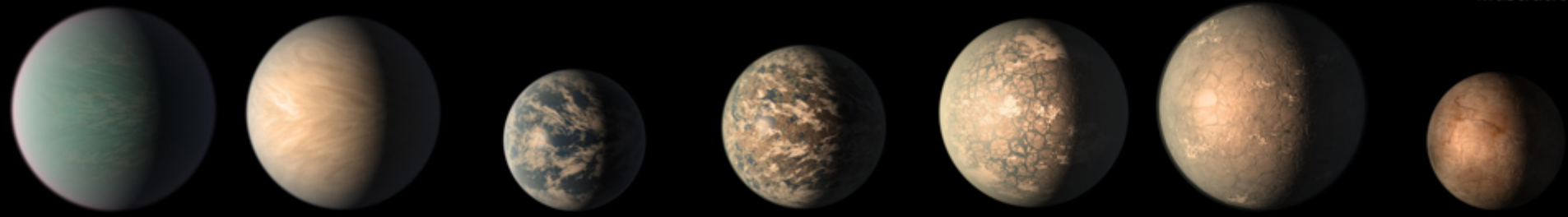
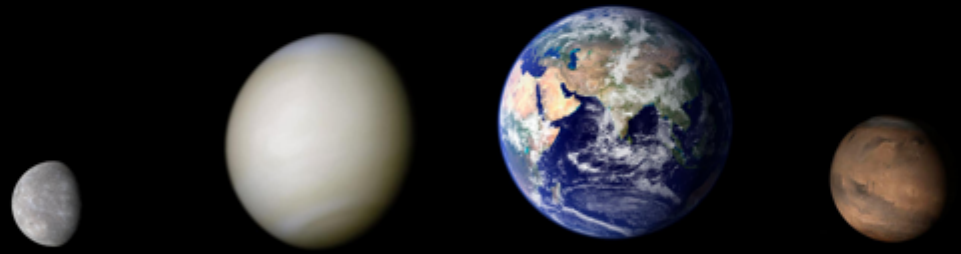
NASA

Illustrations



**TRAPPIST-1 System**
*Feb. 2018*

| | b | c | d | e | f | g | h |
|---|---|---|---|---|---|---|---|
| *Orbital Period* | 1.51 *days* | 2.42 *days* | 4.05 *days* | 6.10 *days* | 9.21 *days* | 12.36 *days* | 18.76 *days* |
| *Distance to Star* | 0.0115 *AU* | 0.0158 *AU* | 0.0223 *AU* | 0.0293 *AU* | 0.0385 *AU* | 0.0469 *AU* | 0.0619 *AU* |
| *Planet Radius* | 1.12 $R_{earth}$ | 1.10 $R_{earth}$ | 0.78 $R_{earth}$ | 0.91 $R_{earth}$ | 1.05 $R_{earth}$ | 1.15 $R_{earth}$ | 0.77 $R_{earth}$ |
| *Planet Mass* | 1.02 $M_{earth}$ | 1.16 $M_{earth}$ | 0.30 $M_{earth}$ | 0.77 $M_{earth}$ | 0.93 $M_{earth}$ | 1.15 $M_{earth}$ | 0.33 $M_{earth}$ |
| *Planet Density* | 0.73 $\rho_{earth}$ | 0.88 $\rho_{earth}$ | 0.62 $\rho_{earth}$ | 1.02 $\rho_{earth}$ | 0.82 $\rho_{earth}$ | 0.76 $\rho_{earth}$ | 0.72 $\rho_{earth}$ |
| *Surface Gravity* | 0.81 *g* | 0.96 *g* | 0.48 *g* | 0.93 *g* | 0.85 *g* | 0.87 *g* | 0.55 *g* |

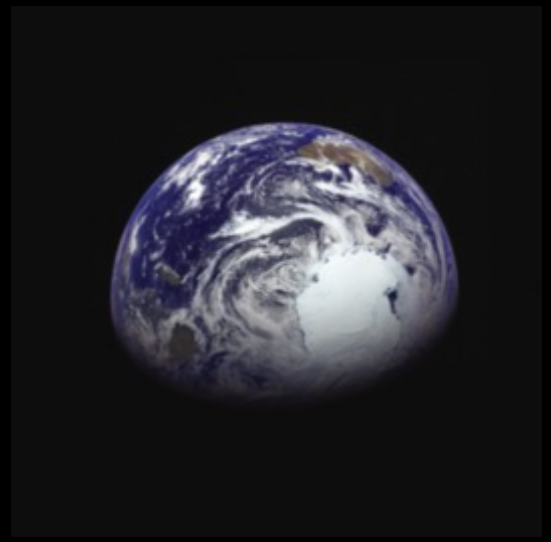


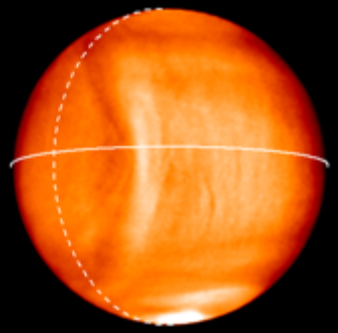
**Solar System**
Rocky Planets

| | Mercury | Venus | Earth | Mars |
|---|---|---|---|---|
| *Orbital Period* | 87.97 *days* | 224.70 *days* | 365.26 *days* | 686.98 *days* |
| *Distance to Star* | 0.387 *AU* | 0.723 *AU* | 1.000 *AU* | 1.524 *AU* |
| *Planet Radius* | 0.38 $R_{earth}$ | 0.95 $R_{earth}$ | 1.00 $R_{earth}$ | 0.53 $R_{earth}$ |
| *Planet Mass* | 0.06 $M_{earth}$ | 0.82 $M_{earth}$ | 1.00 $M_{earth}$ | 0.11 $M_{earth}$ |
| *Planet Density* | 0.98 $\rho_{earth}$ | 0.95 $\rho_{earth}$ | 1.00 $\rho_{earth}$ | 0.71 $\rho_{earth}$ |
| *Surface Gravity* | 0.38 *g* | 0.90 *g* | 1.00 *g* | 0.38 *g* |

Detection
- Transit, RV
↓
Characterization
=>Atmosphere

# Earth and Venus



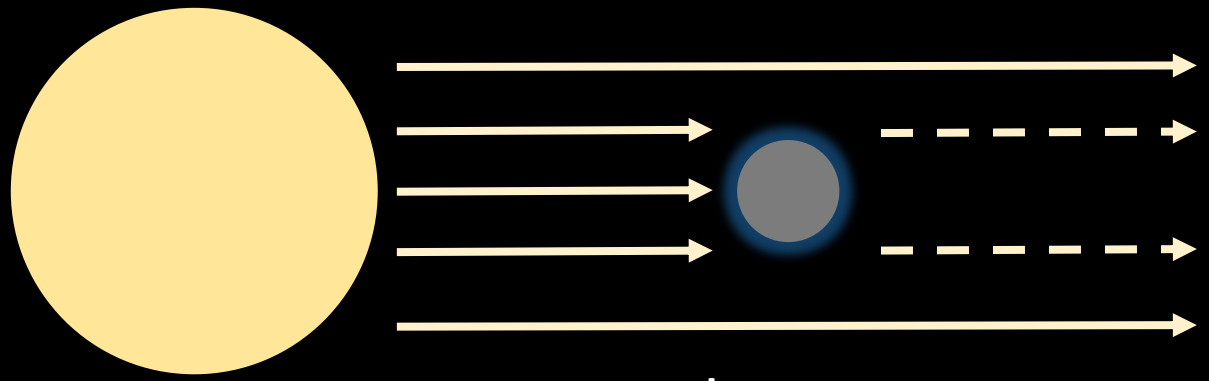


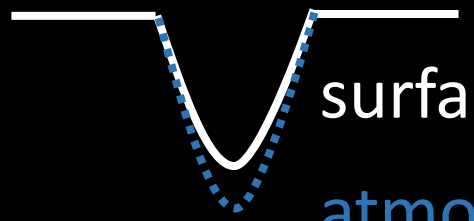
Almost the same in size
Earth R: 6371 km
Venus R: 6052 km

| | |
|---|---|
| Life (Civilization) | No life |
| Ocean | No ocean |
| $N_2$(78%), $O_2$(21%), Low $CO_2$ | $CO_2$ (96%) |
| Magnetic field | No magnetic field |

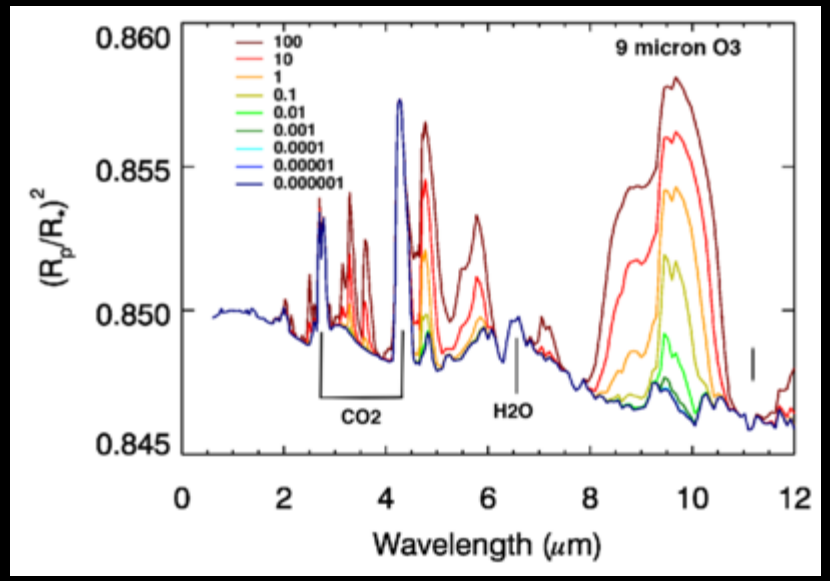
How to distinguish?

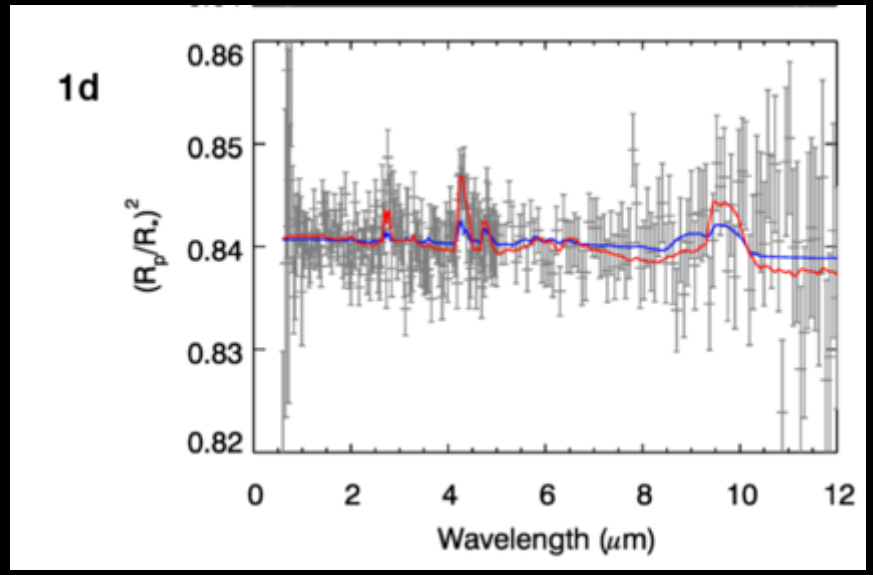
# Transit spectroscopy of exoplanetary atmosphere




(1 – ppm -> 0.99999･･･)



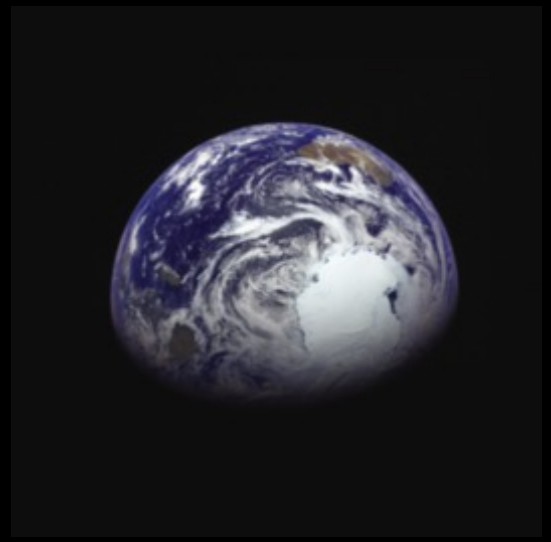

Ozone in Earth-like TRAPPIST-1d

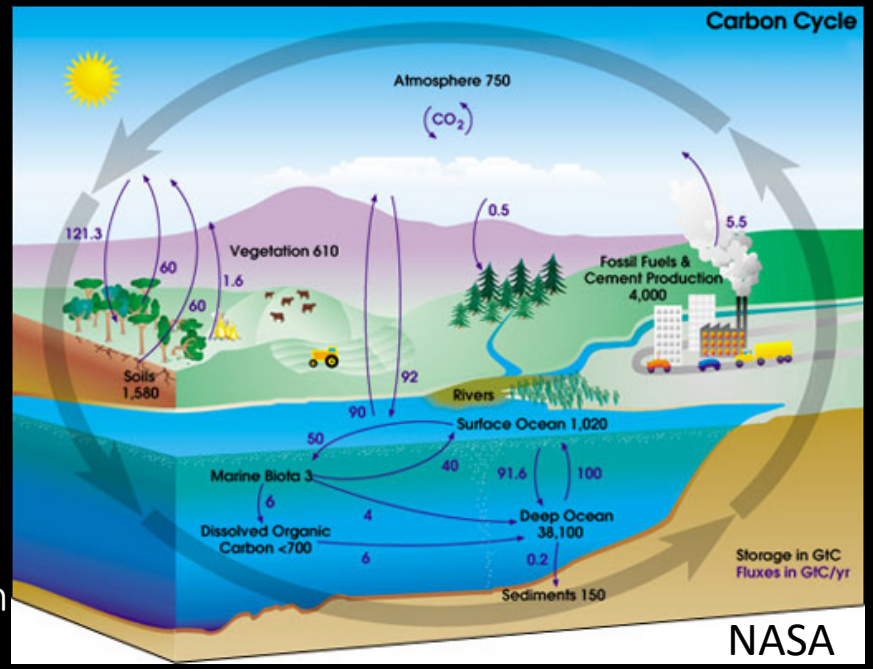
=>

60 transits by JWST (~6 years)

Barstow & Irwin, 2016

# Earth and Venus






Almost the same in
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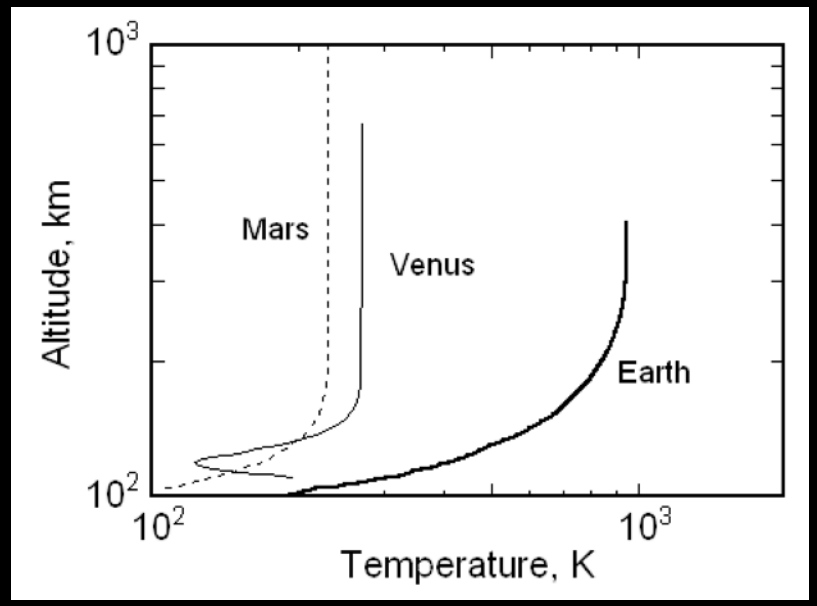
| Magnetic field | No magnetic field |

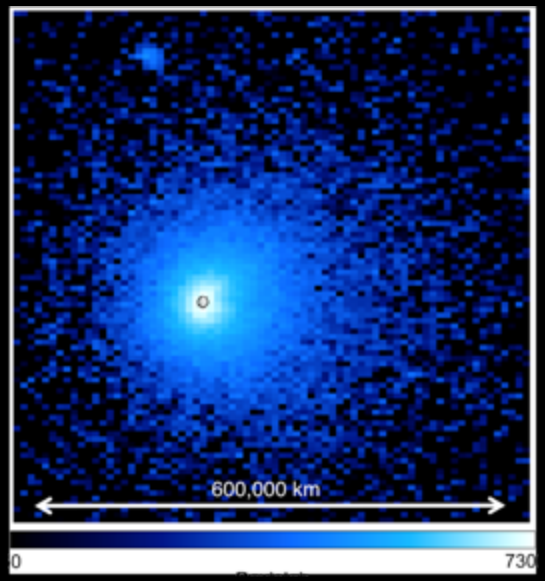
How to distinguish?

# Upper atmosphere (Exosphere)

$CO_2$ is a coolant for upper atmosphere.
Earth (Low $CO_2$) -> 1000 K
Venus, Mars ($CO_2$ dominant) -> 200-300 K

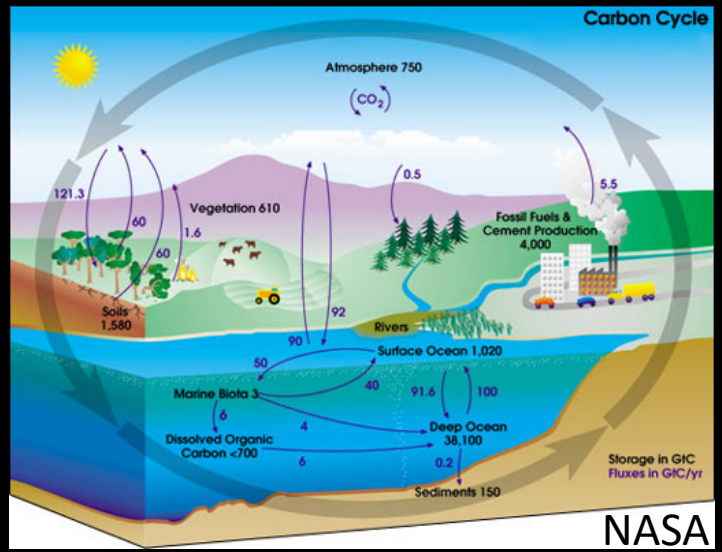
$CO_2$ on exoplanets: detectable
$CO_2$ mixing ratio: difficult (Venus <- In-situ)
(temperature profile, height of cloud, etc.)




Earth's extended exosphere
Kameda+17

Temperature of upper atmosphere
<->? $CO_2$ mixing ratio
<->? Ocean and tectonics



# Stellar Flux at HZ of low-temperature star

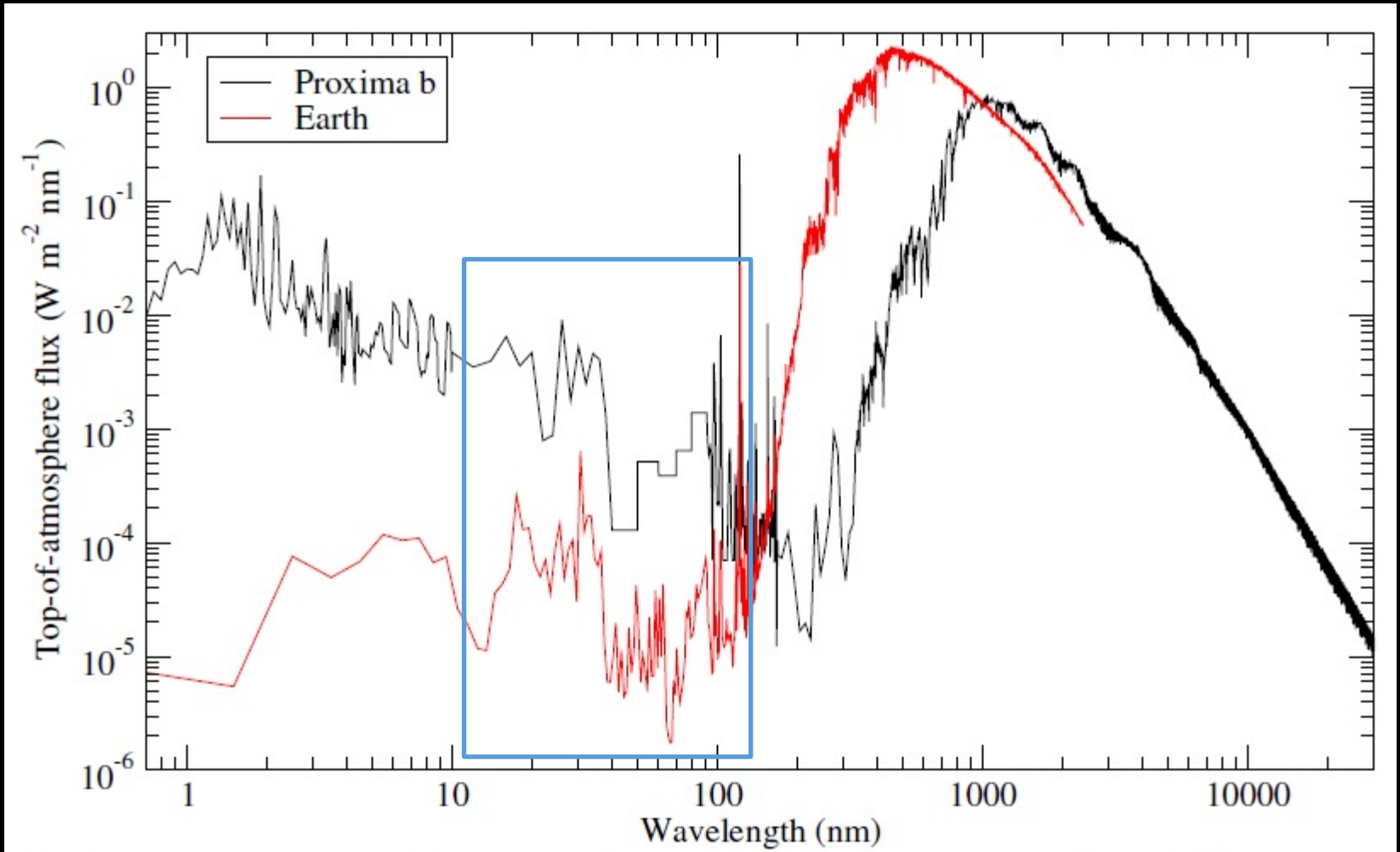



**Fig. 4.** Top-of-atmosphere full spectral irradiance received by Proxima b (black) and the Earth (red). An orbital distance of 0.0485 AU is assumed for Proxima b.

Red: Solar flux (1AU)

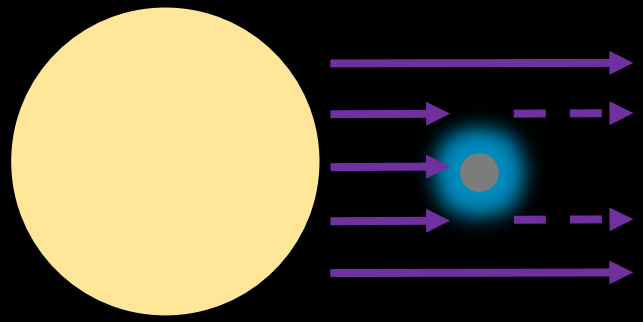
Black : Proxima Centauri' s flux at Proxima b (0.0485AU)

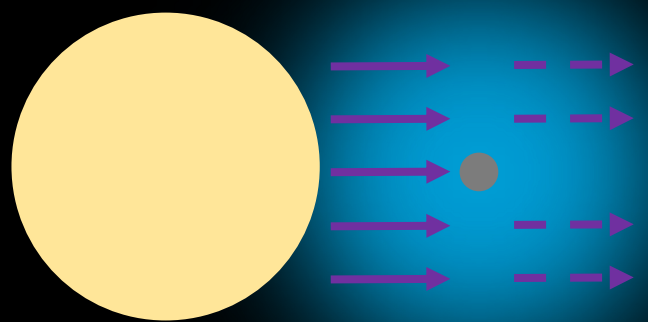
Heat source of Upper atmosphere

EUV:10-105nm

- Difference between Solar and M-type stellar fluxes.（Ribas et al., 2017）

# Extended oxygen exosphere at high EUV





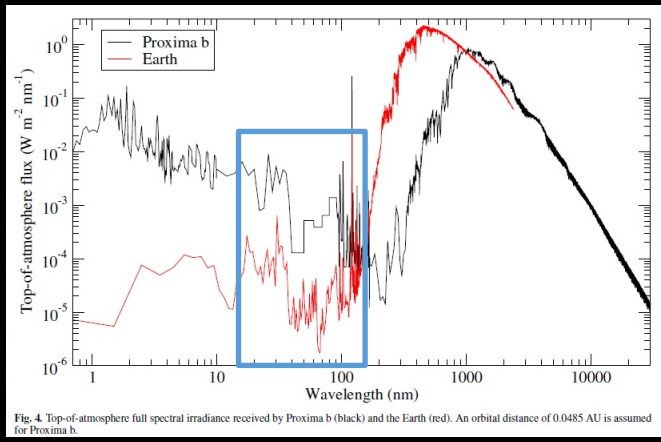
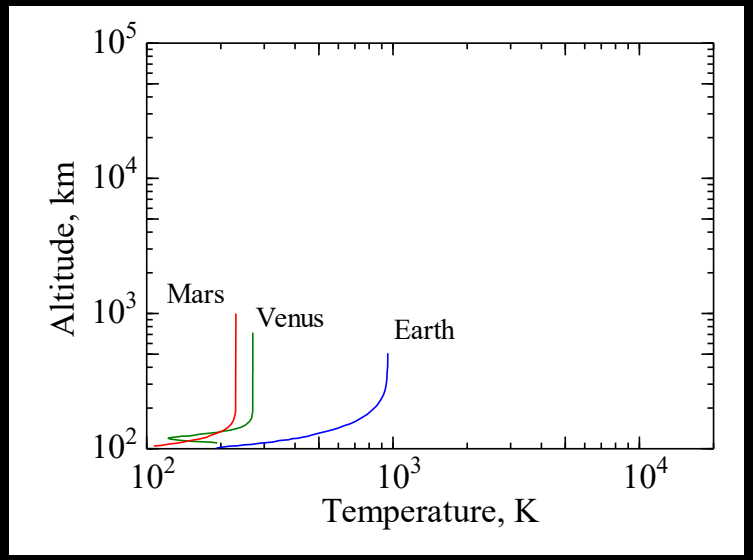
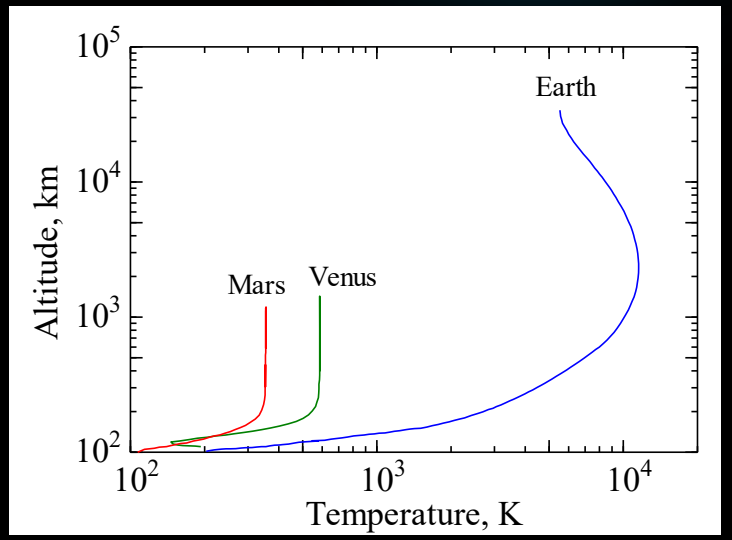


Fig. 4. Top-of-atmosphere full spectral irradiance received by Proxima b (black) and the Earth (red). An orbital distance of 0.0485 AU is assumed for Proxima b.

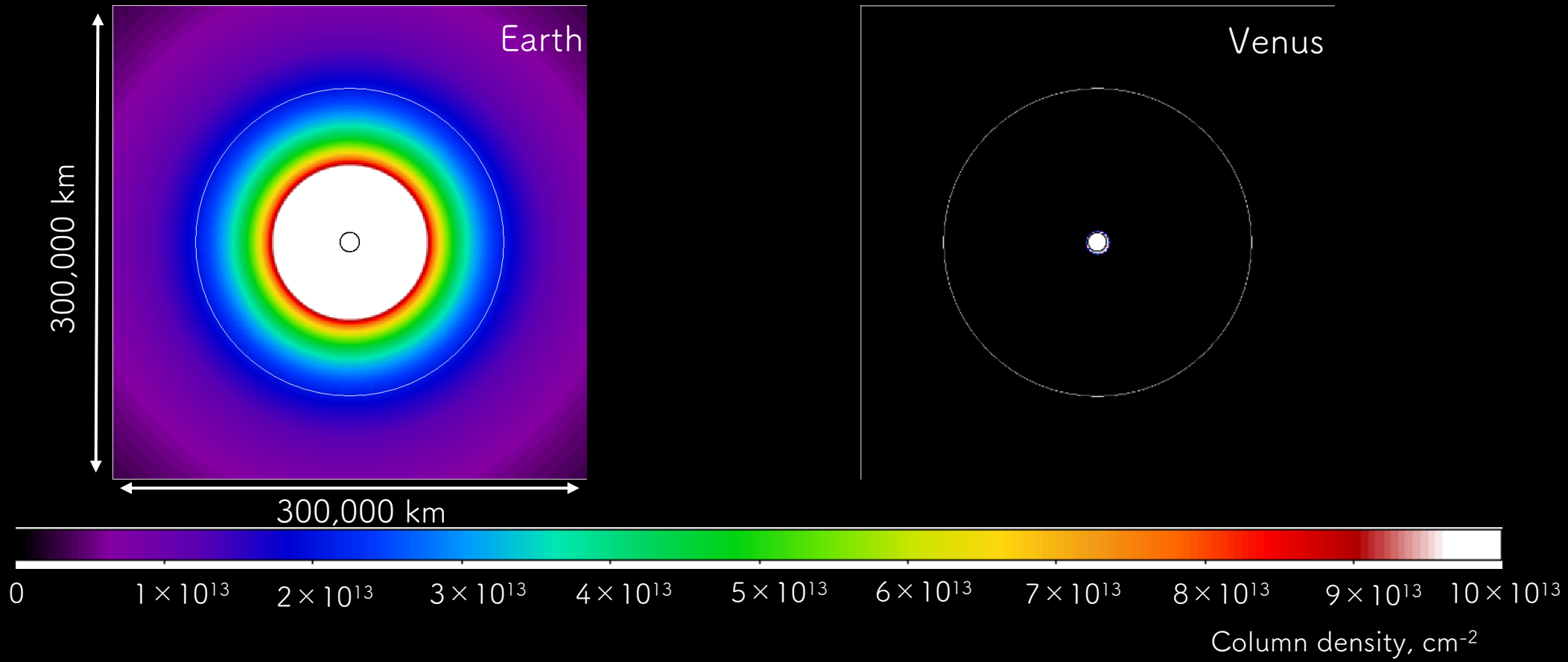



Kulikov+07
Tian+08

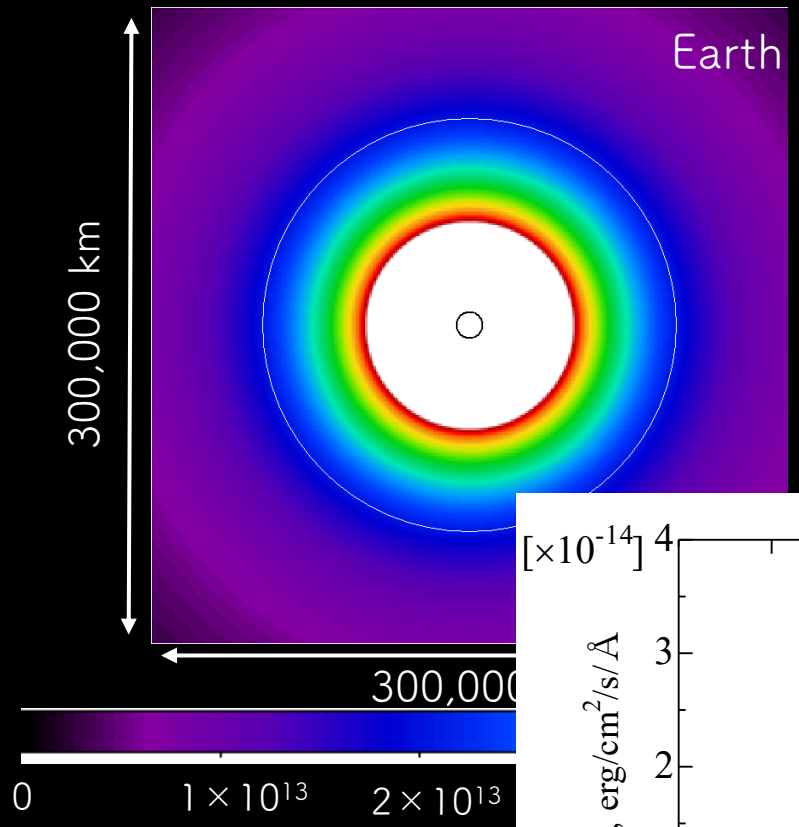
High EUV -> expanded upper atmosphere

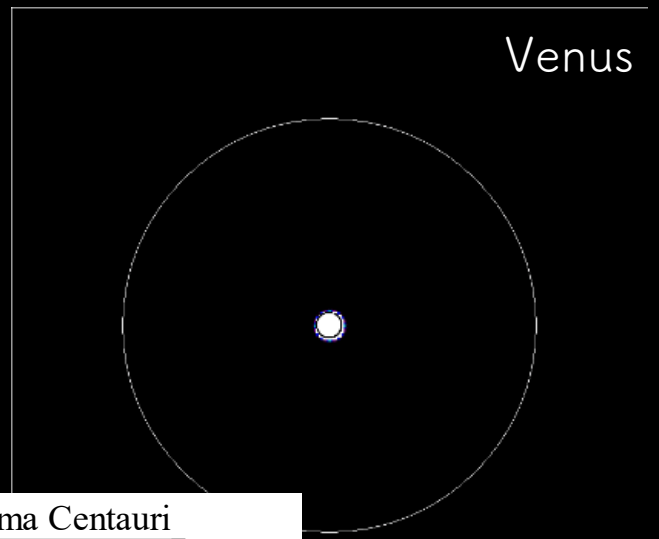
# Oxygen Exosphere(10EUV)

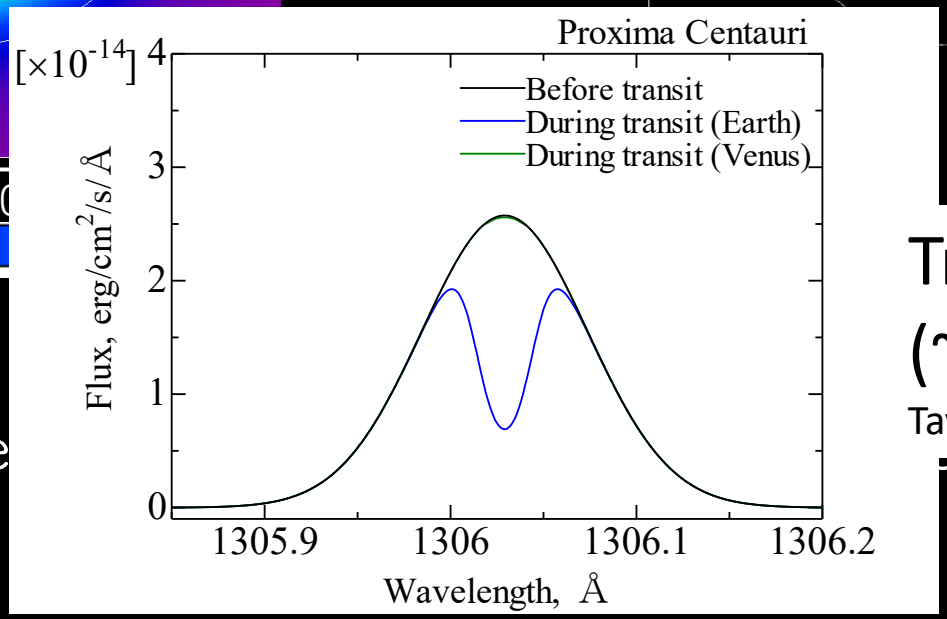



- Black circle: planet　White circle: star(Proxima Centauri)
- Earth-like case: Optically thick oxygen to ~8$R_e$ （$1 \times 10^{14}$ $cm^{-2}$ ~ $\tau$ =1）

# Oxygen Exosphere(10EUV)




Transit depth: ~24%
(~70% at line center)
Tavrov, Kameda+2018

- Black circle: plane
- Earth-like case: O

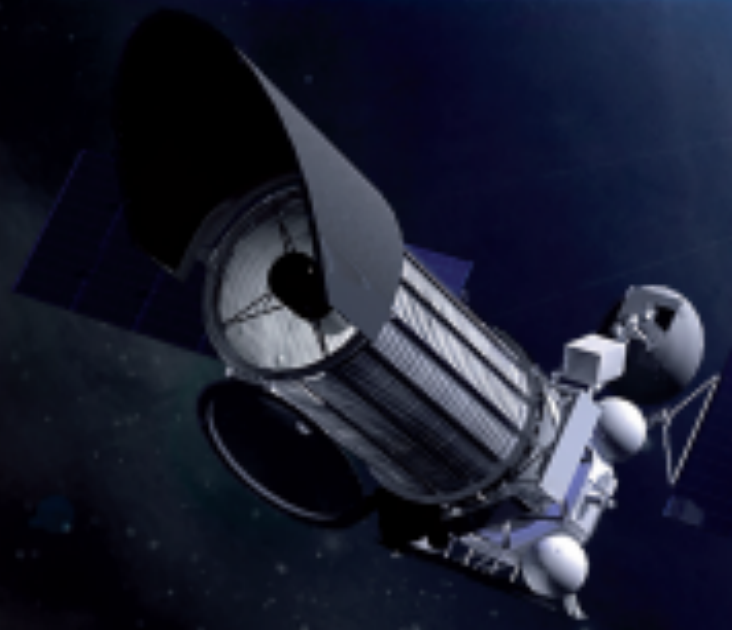
$\times 10^{14}$ cm$^{-2}$ ~ $\tau$ =1)

Large UV space telescope!

(HST is inside Earth’s oxygen corona)

[NASA]

# World Space Observatory UV (WSO-UV)



**Russia, Spain (UV imager)**
**+Japan (UV spectrometer)**

- Target launch: 2025 Oct
- Diameter：1.7 m
- Spectral range： ~110-320 nm
- Orbit: GSO (6.6 Re) -> ***outside of Oxygen geocorona*** (HST ~400km)

**Exoplanet**

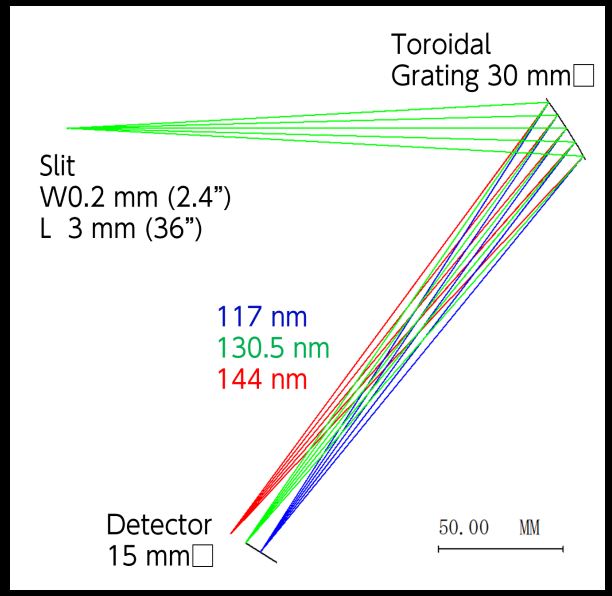
**UV irradiation**

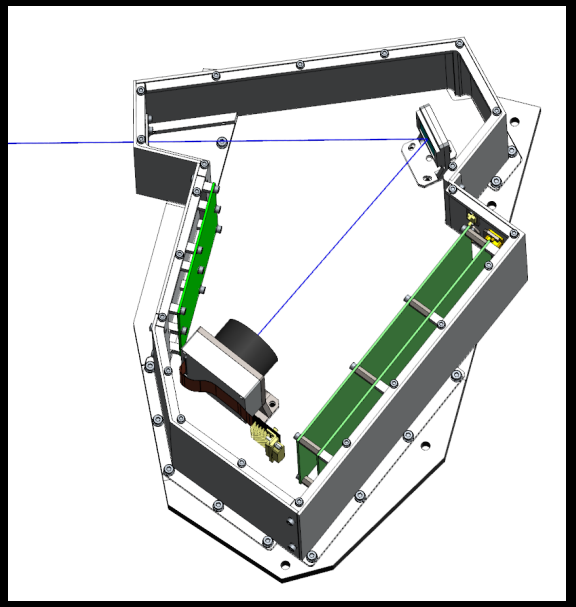
**Upper atmosphere**

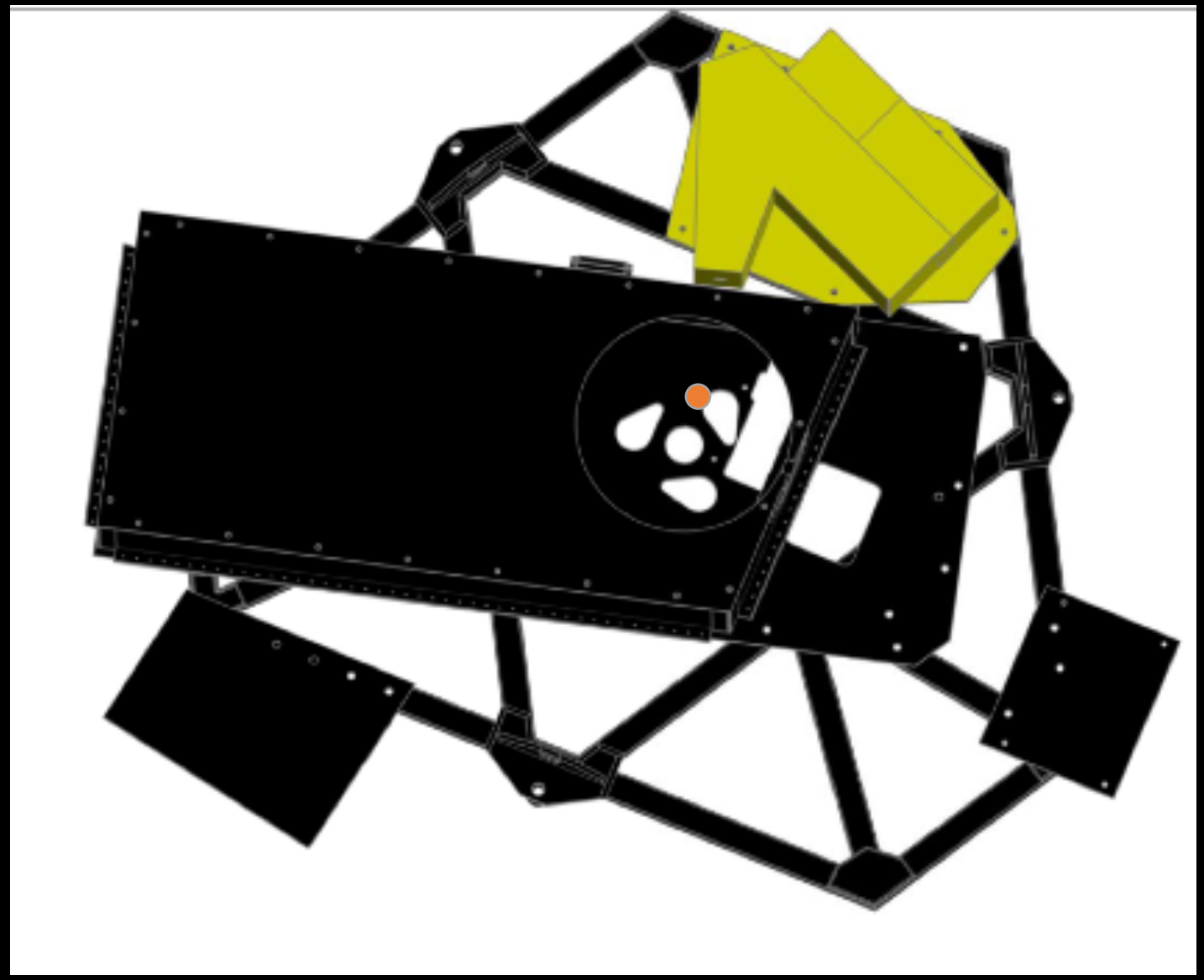
# UV spectrograph for Exoplanets (UVSPEX)

- Slit＋Concave (Toroidal) grating＋Detector (MCP)
- Spectral range：117-144 nm
- Spectral resolution：~0.3 nm @130 nm
- Slit：2.5″ (= 200 um)
- Grating：Toroidal blazed grating, Al+MgF2 coating, $\phi$ 30 mm, 2400 gr/mm, f = 250 mm
- Detector：Image Intensifier (CsI photocathode＋Funnel-type Microchannel Plate（MCP）
- Mass：< 7 kg
- Power: < 7 W

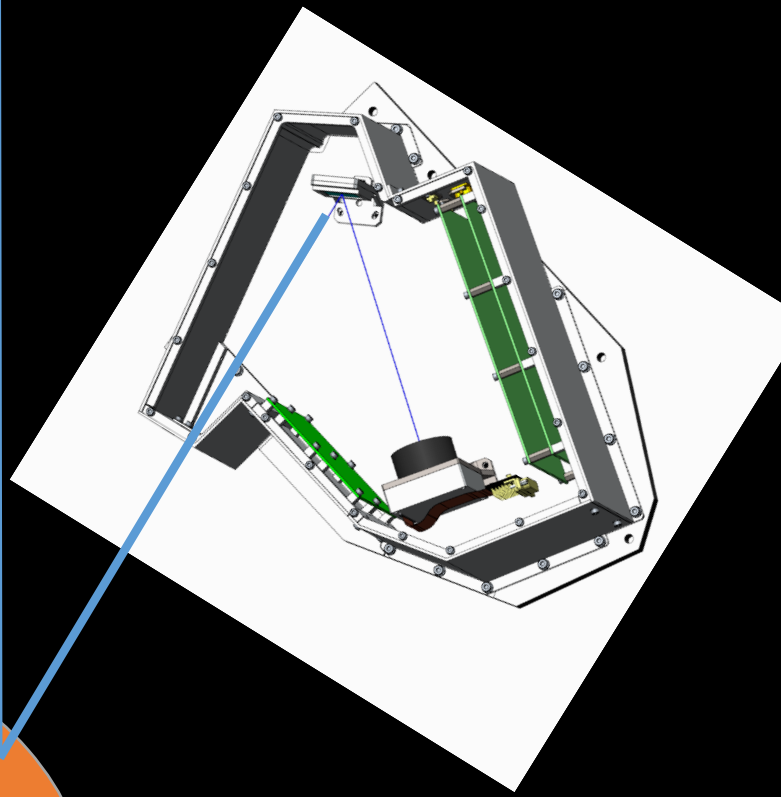
- 10-20 Earth-size exoplanets
  Oxygen <-> Ocean
- Earth-like TRAPPIST-1e can be detected in ~13 transits
- Model for upper atmosphere

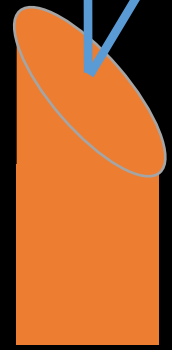




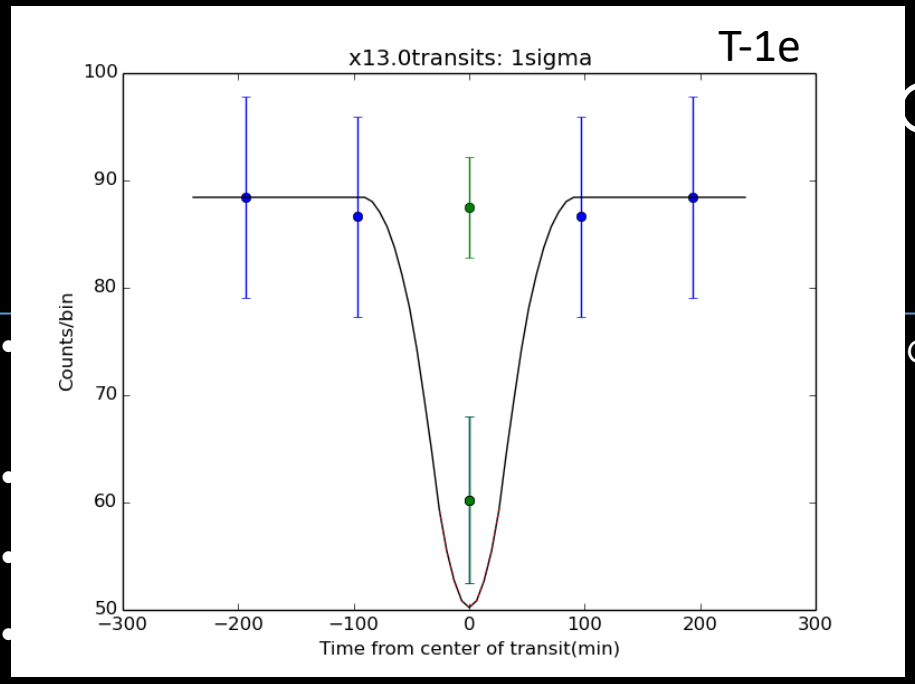
UVSPEX-S



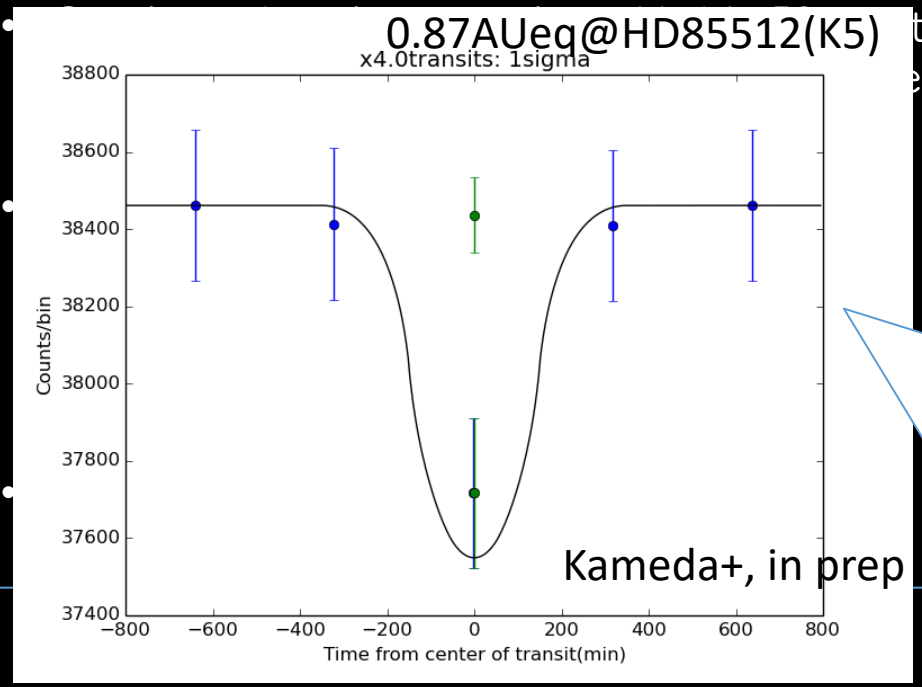


UVSPEX-M

# oh for Exoplanets

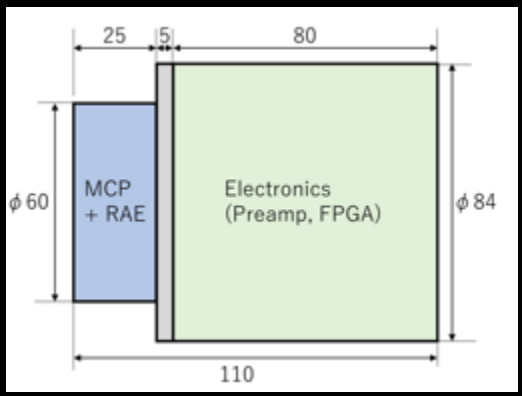


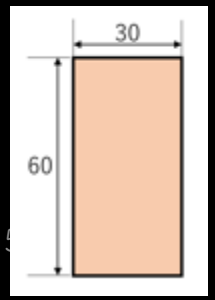

- 10-20 Earth-size exoplanets
  Oxygen <-> Ocean
- Earth-like TRAPPIST-1e can be detected in ~13 transits (3σ)
- Model for upper atmosphere




150 mm

Earth-like planet
~4 transits (3σ)
Transit depth ~3%
Much higher flux



# Telescopes for exoplanets in 2020-2030

## UV

Mid 2020 CUTE
(cubesat, >200nm)

-20?? HST

ESCAPE

2025 WSO-UV

UV irradiation, [Hydrogen, Oxygen] of terrestrial - Jupiter

## VIS/IR SPACE

2018 TESS

2019 CHEOPS

2021 JWST

Mid 2020s WFIRST

2023 Twinkle

2024 Small Jasmine

2026 PLATO

2028 ARIEL

## VIS/IR Ground

Subaru/IRD, MuSCAT

VLT/Espresso,,,

GMT, TMT, E-ELT,・・・・

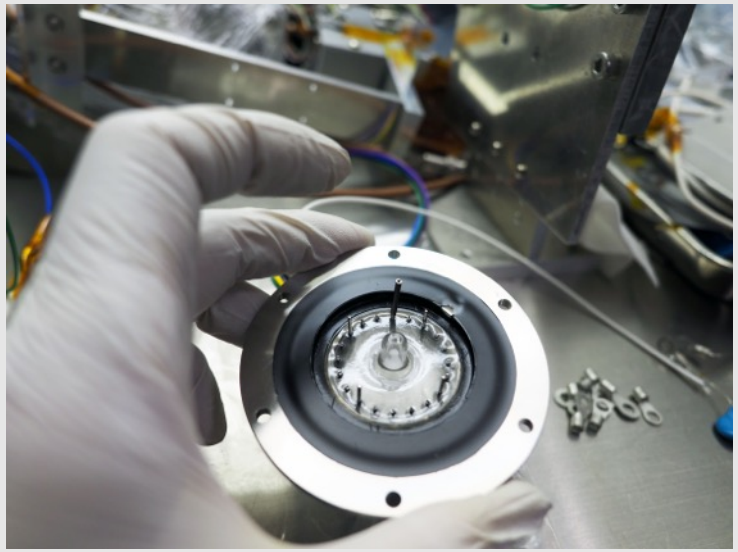

- Oxygen （＋Hydrogen) Exosphere observation by VUV spectroscopy
- EUV-VUV flux is important as heat source for atmosphere
- WSO-UV is outside of oxygen geocorona
  ->Earth-like oxygen exosphere
- 2020-2030 Combination (mass, size, age, lower-upper atmosphere)

# New type MCP : Specification

**R10110M07505FR**

- MgF2 window : t3.0mm
- Photocathode : CsI
- MCP : 5-stage (1st :Funnel)
- Anode : RAE
- Effective Area : 16x16mm

  (smaller than previous version)



→Phosphor
And CMOS
readout
For WSO-UV