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# Observability of oxygen exosphere of an Earth-like exoplanet around a low temperature star

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## Abstract

The Earth's exospheric temperature is higher than those of Venus' and Mars'. The EUV irradiation at habitable zone of a low temperature star is much higher than at Earth, and assuming that an exoplanet there has an Earth-like atmosphere, it would have a far-extended exosphere. On the other hand, assuming that it is a Venus-like or Mars-like planet, its exosphere would not be so much extended. We performed a conceptual design of Ultraviolet Spectrograph for Exoplanet (UVSPEX) for World Space Observatory Ultraviolet (WSO-UV), which enables to distinguish the Earth-like from the Venus-like or Mars-like.

## 1. Introduction

Many Earth-sized planets have been discovered and some appear to lie in the habitable zone. Moreover, several Earth-sized planets were recently detected around low temperature stars near the solar system. However, it is difficult to characterize them as Earth-like or Venus-like because we have no information on their atmospheres. Transit spectroscopy for exoplanetary atmosphere has been performed to characterize larger exoplanets but it requires very high accuracy for Earth-sized planets because of their small size. Hydrogen exosphere has been detected around Neptune-sized exoplanet [1], but an Earth-sized exoplanetary exosphere has not been detected. Recently, Earth's hydrogen exosphere was re-investigated and it was revealed that the Earth's exosphere is extended to ~ 38 Earth radii [2]. On the other hand, Venus' and Mars' hydrogen exosphere is not so much extended because of its low temperature of upper atmosphere. The hydrogen density is estimated about 20 atoms/cm$^3$ at a distance of ~60,000 km in the Earth’s exosphere. The same amount of density is expected to be observed at a distance 10,000-20,000 km in Venus and 30,000-35,000 km in Mars. This is caused by the difference of mixing ratio of $CO_2$ in the upper atmosphere. Venus and Mars have $CO_2$-rich atmospheres with a lower exospheric temperature. On Earth, $CO_2$ was removed from its atmosphere by a carbon cycle with its ocean and tectonics [3]. Translating these arguments to exoplanets in a habitable zone presents a possible marker to distinguish an Earth-like planet from a Mar-like or Venus-like planet. The expanded exospheres can be observed in UV, during the exoplanet transit event in a primary eclipse. It reduces the stellar flux, when an exoplanet orbiting in front of the host star.

## 2. EUV irradiation and exospheric high temperature

Theoretical exospheric models extrapolated these arguments to an oxygen exosphere. Then for oxygen line the predicted transit depths are shown in Fig. 1 assuming that TRAPPIST-1f, at which the EUV irradiation is much higher than at Earth.

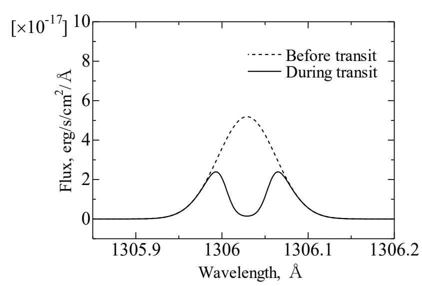


Fig. 1 Predicted theoretical transit photometric curves of TRAPPIST-1f in oxygen OI spectral line at 130.6 nm of Earth-like – dash-marked line in comparison with the non-transit curve black (solid) line.

The temperature of upper atmosphere for the Earth-like is estimated to be ~10,000 K [4]. On the contrary, those for the Mars-like and Venus-like are estimated to be ~300 K and ~600 K, respectively [5]. Then the transit depth at the line center for each case is 76%, 0.7%, or 3.8%, respectively. Due to the large difference in the transit depth, the Earth-like can potentially be distinguished from the Venus-like and the Mars-like. However, high dispersion is required to resolve absorption feature in the O I line shown in Fig. 1. The total transit depth of stellar emission integrated from 130.25 nm to 130.75 nm corresponds to 25%, 0.11%, or 0.20%, respectively, which are also distinguishable with low-dispersion spectrometer. Thus, we selected low-dispersion and high-efficiency design to observe M stars dark in the UV region and to simultaneously detect both hydrogen (~122 nm) and oxygen emission lines (~130 nm).

## 3. UVSPEX for WSO-UV

High sensitivity (photon counting) is required for M-type star faint in UV. Spectral resolution of 0.5 nm is enough for separating major emission lines of exospheric atoms. The spectral resolution will be achievable by spectrometers in the main WUVS block, however, it is difficult to measure the weak flux from M-type stars without a photon-counting detector. To realize exoplanet transit observations in oxygen spectral lines with the desired accuracy, we equip the WSO-UV telescope with the UVSPEX spectrograph. The main engineering requirements for the UVSPEX are following. The spectral resolution is better 0.5 nm to separate O I line from other spectral lines. The spectral range is to exceed the wavelengths from 115 nm to 135 nm to detect at least H Lyman alpha 121.6nm to O I 130 nm. The throughput is better 0.3% accounting more than four terrestrial exoplanets distanced at 5 pc. To achieve these requirements, a simple spectrograph design is proposed, containing the slit, the concave (toroidal) grating as a disperse element and the imaging photo-detector. This optical concept is conventional and used in the other space missions for UV spectroscopy.

Figure 2 shows the UVSPEX principal optical scheme [6]. Spectrometer slit is aligned at primary focus of the telescope from off-axial sub-FoV, at Pos 10 (see Fig. 4). Slit width is 0.2 mm, corresponding to 5 arc-sec. The concave grating is laminar type with groove density of 2400 grooves per mm. It has a toroidal shape with the curvature radii of 266.4 mm in horizontal direction and of 253.0 mm in vertical direction. The effective area has nearly Ø 25 mm and the focal length is ~250 mm. The surface is coated by Al + $MgF_2$ to increase the reflectance, and diffraction efficiency of ~29% can be achieved.

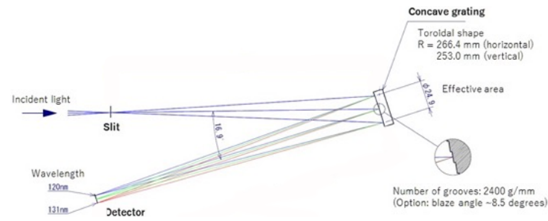


Fig. 2 Optical scheme of the spectrograph UVSPEX

If we assume a star with the same flux as Proxima Centauri at longer distance, the distance of detection limits of Earth-like planet in habitable zone for UVPSEX is 14 pc. Because low temperature stars in a vacuum are dark in the UV range, including the O I emission line, a large space telescope and spectrograph with high efficiency are required to characterize these planetary atmospheres.

## Acknowledgements

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