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Transits in the Solar System and the Composition of the Exoplanet Atmospheres

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Abstract

Our knowledge about exoplanets depends on very limited measurements and resolution. Atmospheric compositions are limited only to hot Jupiters and Neptunes. Detection of possible biosignatures on Earth-sized planets is not possible today. However, upcoming space missions, e.g. TESS, JWST, CHEOPS, and PLATO will give us unprecedented access to exoplanet light curves and other observations. Before the new results arrive, it could be useful to collect the only known living planet's and other well-known planet's light curves and spectra for the future comparison and habitability modeling. For this, we need to seek possibilities to measure Earth's and other terrestrial planet's transits, occultations, and reflections from different locations in the Solar System. This paper will present some past events and experiments, potential locations and events, probes, and their instruments that could be used, as well some limitations and challenges.

1. Introduction

In a board view, there are three different worlds within the habitable zone of our Solar System: Venus, Earth and Mars. However, only Earth is capable of maintaining life as we know it. Our three terrestrial planets can reveal a lot of what makes planet habitable, and help us to distinguish habitable terrestrial exoplanet apart from e.g. exo-Venus with future observations.

Planetary transits are phenomena where planet appears to move across the disk of system's parent star. Transit method is the most used exoplanet detection method. For example the Kepler space telescope has discovered over 2800 confirmed exoplanets with transit method [1]. The dimming of star's light during the transit is called the light curve. From the photometric light curve, we can measure planet's size. On the other hand, the spectroscopic measurement of light curve can reveal atmospheric composition. However, transmission spectra are extremely weak.

2. Exoplanet Light Curves

Earth-size exoplanet has a very weak transit depth, magnitude in ppm scale (c.f. hot-Jupiters around 1%) and the atmospheric signal of exoplanet is even weaker ($\Delta\delta$ 0.1-1 ppm). Terrestrial planet transits in the Solar System have similar magnitude in atmospheric signal ($\Delta\delta$ 1-10 ppm, slightly bigger due to geometrical effect), which makes them interesting for exoplanet comparison.

With the transits of Venus, Earth and Mars we can mimic Earth-like exoplanet atmosphere detection and help habitability assessment. Moreover, detecting transits of our terrestrial planets serve as technique validation for future exoplanet detection missions.

3. Future Transits

There will be transits of all terrestrial planets in the near future. None of them will be visible from Earth, but could be observed from the outer Solar System, with some ongoing or planned planetary missions. These transits include transit of Earth from Jupiter in 2026, transit of Venus from Jupiter in 2024 and 2030 and from Mars in 2030 and 2032.

4. Spacecrafts

Cassini spacecraft ended its Saturn mission in 2017, and there currently no plans for new one. There will be transit of Venus from Jupiter in 2024, but NASA's Jupiter spacecraft Juno will end its primary mission in 2018. There is a hypothetical possibility of observing the transit of Earth in 2026 and the transit of Venus in 2030 with ESA's JUICE spacecraft (or Joint Europa Mission) on its way to Jupiter. According to ESA, the possibilities of observing these Earth transits in 2026 and the transit of Venus in 2030 from Jupiter will be looked at after the launch, and will be depending on the launch date (currently envisaged in 2022 or 2023), the cruise trajectory (7.6 years interplanetary transfer), and the instrument capabilities. There are several possible interplanetary trajectories for JUICE mission depending the launch date, and it now seems that the transit of Earth in 2026 is not favored in any of the them [2]. On the other hand, the transit of Venus in

November 2030 is favored with the 2022 launch window.

The transits of Venus from Mars in 2030 and 2032 are interesting since there are many current and planned Mars orbiters and rovers. If we put 15 years lifetime limit to orbiter and 10 years to rover, then potential instruments are in ESA's ExoMars Trace Gas Orbiter (TGO) (launched in March 2016) and NASA's Mars 2020 missions. However, at least TGO's camera would be destroyed if we pointed it directly to the Sun, since it has no filters for this.

5. Summary and Conclusions

Transits of the terrestrial planets in the Solar System can help us to identify habitable Earth-like exoplanets in the future. Transit spectrum of Venus has already been obtained. Earthshine and eclipses have been used to get Earth transit spectrum. Next potential transits are: Earth 2026 (Jupiter), Venus 2030 (Jupiter), Venus 2030 and 2032 (Mars).

Among the all currently operational and planned deep space missions, potentially only the transits of Venus in 2030 and 2032 could be observed. By those years, we should have more sensitive exoplanet observing space telescopes in the orbit. So, at least we should have good comparison between Venus and potential exo-Venuses.

Instead of looking for very limited spacecraft opportunities for transit observations, we could observe reflected sun light from planets with space-bound or earth-bound telescopes. This is similar technique as used for earthshine observations, where Sun's light, dimmed by transiting terrestrial planet, is reflected from the current viewpoint planet

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References

[1] https://www.nasa.gov/kepler/discoveries.

[2] ESA: JUICE Red Book. JUpiter ICy moon explorer. Exploring the emergence of habitable worlds around gas giants. European Space Agency, 2014.