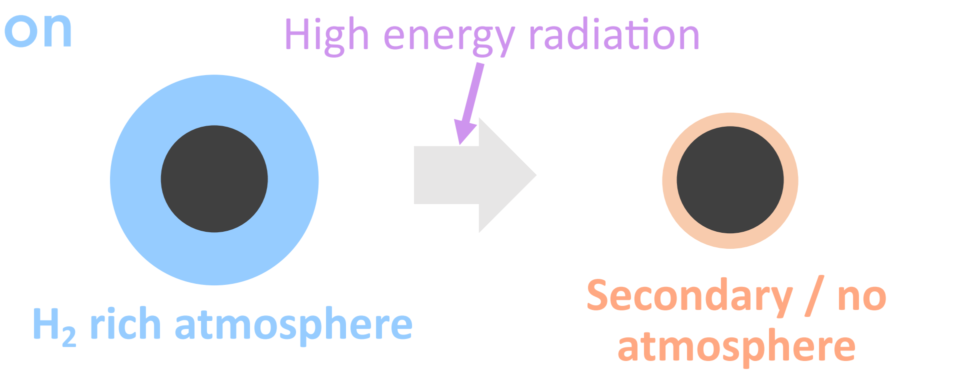
A Warm Sub-Neptune Transiting the M Dwarf TOI-1696

Mayuko Mori (University of Tokyo), John Livingston (University of Tokyo), MuSCAT3 and IRD contributors, TFOP contributors

Motivation

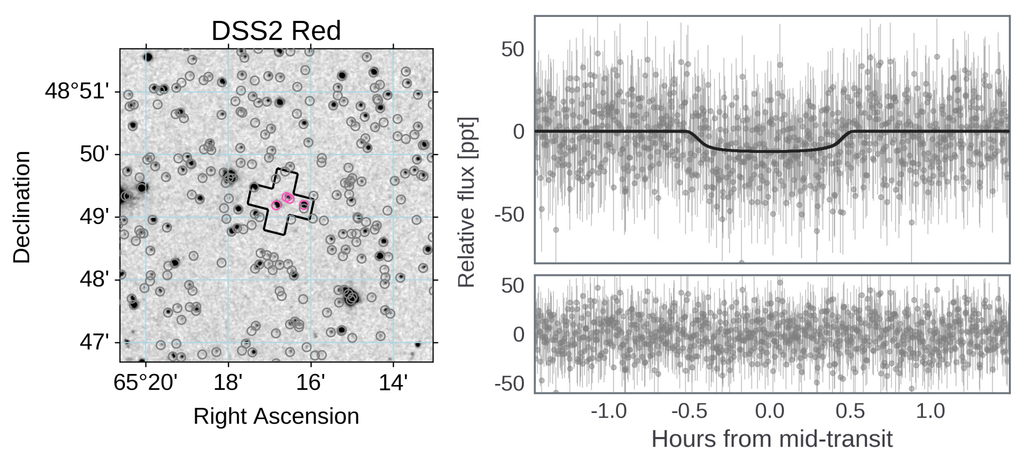
The distribution of known exoplanets shows that planets larger than sub-Neptunes are less common in regions that are close to the central star (“**Neptunian desert”**[1]). It is thought to be due to the process of **photoevaporation**[2], in which planetary atmospheres are lost because of the irradiation from the central star. Therefore, studying the few planets that exist in this region is essential for understanding the formation and evolution of planetary systems and their atmospheres.



We have discovered a sub-Neptune around an M dwarf TOI-1696 through observations with the TESS and ground-based telescopes. The planet is **located near the Neptunian desert** and is expected to be **an important target for atmospheric observations**.

Transit Photometry – TESS & MuSCAT3

TESS observed TOI-1696 in the Sector 19, covering 10 transits. We analyzed the light curve reduced with the SPOC pipeline[3].

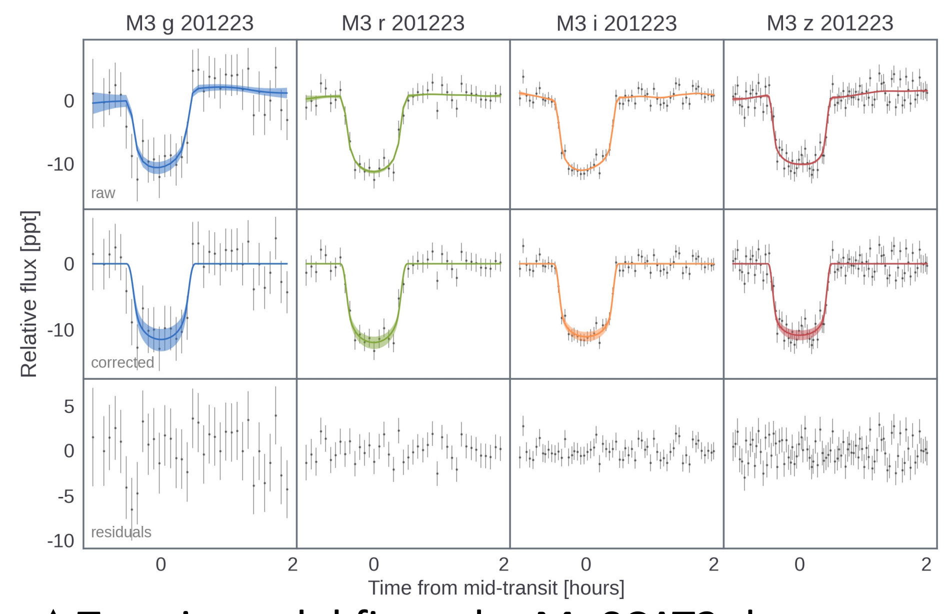


▲ TESS photometric aperture and Gaia sources (left), phase-folded TESS light curve (right).

TOI-1696	
T_{eff} (K)	3116 ± 114
M_* (M_{Sun})	0.26 ± 0.01
R_* (R_{Sun})	0.27 ± 0.02
distance (pc)	3350 ± 120

TOI-1696.01	
R_p ($R_\oplus$)	3.08 ± 0.29
a (au)	0.0230 ± 0.0004
P (days)	2.50078 ± 0.00044
T_{eq} (K)	505 ± 24

The follow-up photometry was done with **MuSCAT3**[4], a four optical-band simultaneous imager on LCO's 2-meter telescope at Haleakala Observatory. We obtained a full-transit of TOI-1696.01 on 2020-12-23. MuSCAT3 light curves confirm that **the signal is achromatic and on-target**. Information on the shape and depth of the light curves confirm that the signal could not be reproduced by a typical hierarchical eclipsing binaries.



▲Transit model fit to the MuSCAT3 data.

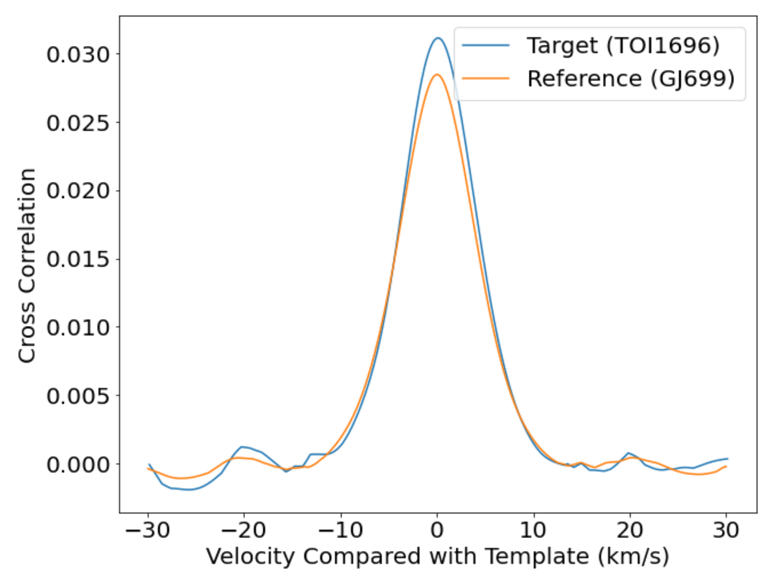
Spectroscopy – The Subaru Telescope/ IRD

We obtained high resolution spectra of TOI1696.01 with the Subaru telescope / Infrared Doppler instrument (**IRD**)[5][6]. The observations were conducted on 2021-01-30 at 22:53 in UTC, which is corresponding to the orbital phase at ~ 0.25.

The derived spectra were compared with the IRD spectra of an M4 dwarf GJ699, by calculating the cross-correlation function. We confirmed that the absorption lines are single-peaked, which shows that **no suspicious companions are detected** to mimic the transit signal.

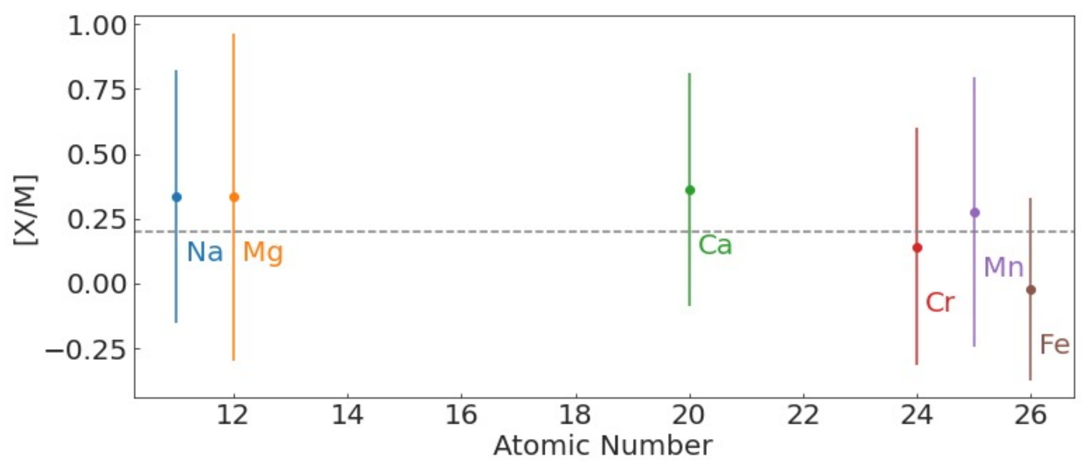
The derived FWHM of the cross correlation function in TOI1696 is ~ 9.2 km/s, which is small enough considering the radial velocity resolution of IRD at ~ 4.5 km/s. This means that the stellar rotation speed of TOI1696 is slow, suggesting that **the star is relatively old**.

The spectra were also used to calculate the **stellar metallicity**. The averaged metallicity is 0.20 ± 0.20 dex, which is consistent with the metallicity derived from isochrone method.



▲Cross-correlation function of the TOI 1696 spectra with GJ699, along with the self-correlation function of the GJ699 spectra.

▼TOI1696 metallicity from the IRD spectrum. The dashed line corresponds to the weighted averaged value.

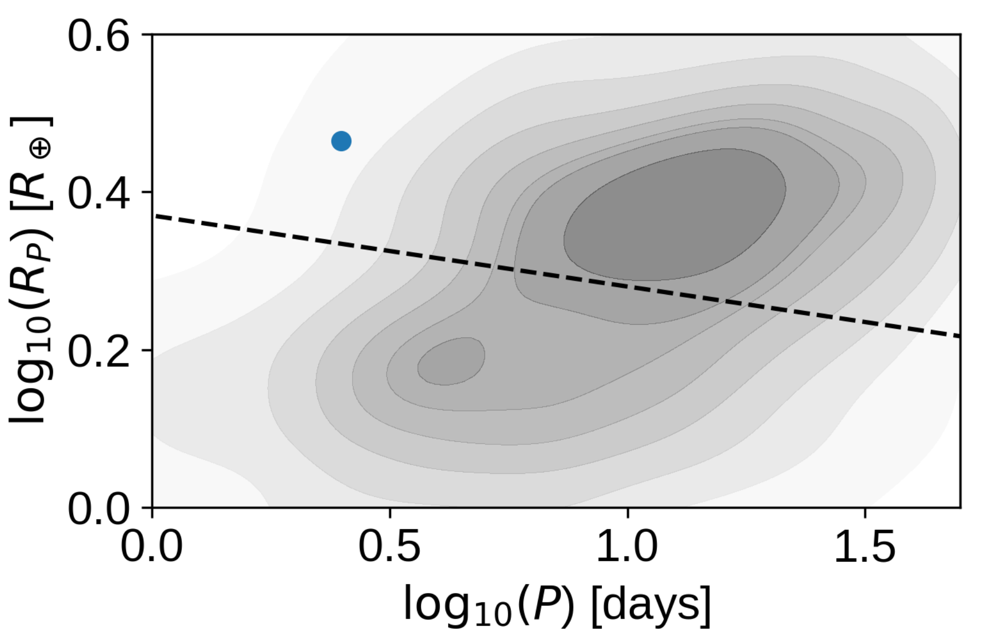


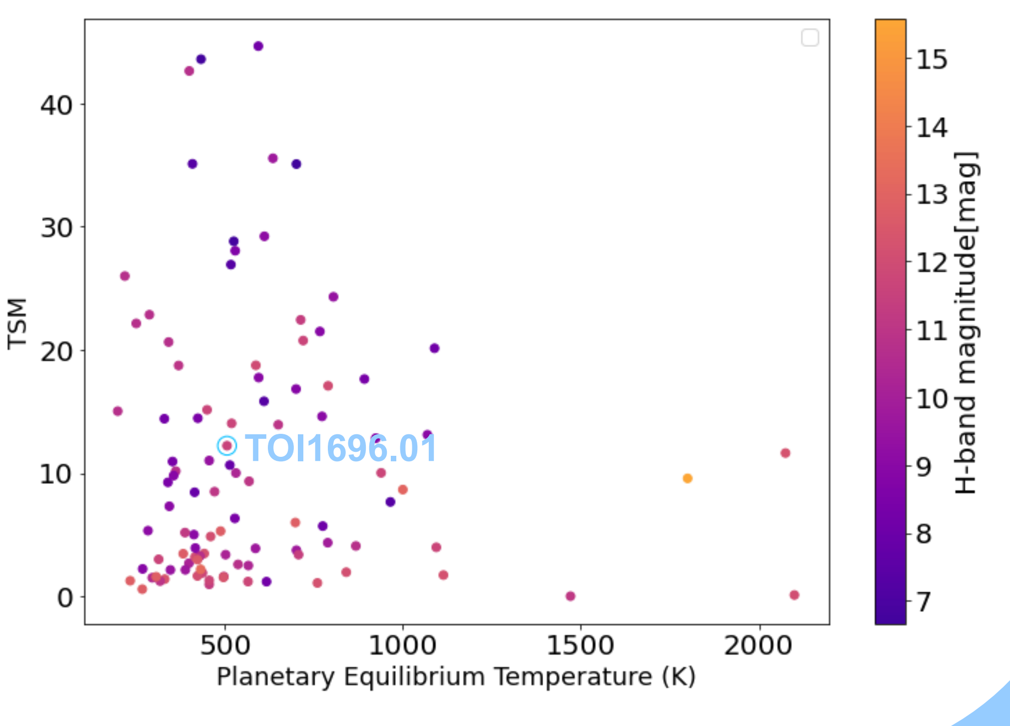
Discussion

The expected planetary mass is 8-14 $M_\oplus$, corresponding to a radial velocity semi-amplitude 9-16 m/s. At J=12.2 mag, it is potentially a good target for mass measurements with NIR spectrographs.

More interestingly, this object is located near the Neptunian desert. The brightness of the target makes it all the more valuable. The **high Transmission Spectroscopy Metric** (TSM [7]) confirms that the planet is one of the most the important targets for planetary atmosphere studies with next-generation instruments.

▶ TOI 1696.01 radius vs period, with kernel density estimate of known planets with P < 50 days and $R_P < 5R_\oplus$ for comparison. The dashed line is the location of the radius valley from Van Eylen 2018 (Top).
T_{eq} vs TSM of known planets with the stellar effective temperature < 4000K, and for which planetary parameters are available (Bottom).





References

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[2] Owen, J. E., Wu, W., 2017 ApJ 847 29
[3] Jenkins, J.M. et al. 2016, Proc. SPIE 9913, 99133E
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