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DRAFT

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APPLICATION FOR OBSERVING TIME

to be assigned

IMPORTANT NOTICE

Probing extended atmospheres of young exoplanets with XSHOOTER

ABSTRACT

The atmospheres of exoplanets transiting in front of their host stars can be investigated using spectroscopy. They can cause excess absorption, i.e. particularly deep transits, in spectral lines that correspond to absorbing compounds in the exoplanet atmospheres. Recently it was shown that the Helium triplet in the near-infrared can be used in ground-based observations to measure the extent of upper exoplanetary atmosphere layers; even ongoing evaporation can be observed through "tails" in the light curves extracted in the Helium lines. We propose to use XSHOOTER to measure this excess absorption for two young exoplanets in short orbits, which should be subject to strong ongoing evaporation, to understand the extent of such atmospheres and test for the presence of evaporation tails. XSHOOTER is the only instrument providing sufficient wavelength coverage and spectral resolution in the southern hemisphere.

SCIENTIFIC CATEGORY

C7 Young binaries, brown dwarfs, exoplanet searches

RUNS

Run	Period	Instrument	Tel. Setup	Constraints	Mode	Type	Propr. Time	Time Constraints	Req. Time
1. Run 1	105	XSHOOTER	UT2	FLI: 1.0 Turbulence: 100% (any Seeing) pwv: 30.0mm Sky: Variable, thin cirrus	SM	Normal	12m	✔	05h56m
2. Run 2	105	XSHOOTER	UT2	FLI: 1.0 Turbulence: 100% (any Seeing) pwv: 30.0mm Sky: Variable, thin cirrus	SM	Normal	12m	✔	05h32m

AWARDED AND FUTURE TIME REQUESTS

Time already awarded to this project

- none -

Future time requests to complete this project

- none -

Special Remarks

We request to collect a continuous time series of XSHOOTER spectra for the two targets. Required calibrations (such as Active Flexure Compensation) can be performed at the typical time intervals between individual exposures of our targets.

To be able to take into account the required overheads for AFC, we have entered approximately 1-hour chunks of observing time into the Observations part of the p1 form. Those represent 1-hour conglomerates of much shorter individual exposures, with the correct individual readout times included as overhead.

DESCRIPTION OF THE PROPOSED PROGRAMME

A- Scientific Rationale

Exoplanets in close orbits around their host stars are expected to undergo atmospheric evaporation. The intense irradiation by the star, especially at short wavelengths, is thought to heat the upper layers of the exoplanetary atmosphere, so that they are lifted out of the gravitational well of the planet and escape. While the evaporation of massive planets makes only a small dent in their mass budget, it is expected that for small exoplanets the evaporation process can strip away the full atmosphere. As such, evaporation is an important ingredient in our understanding of exoplanet habitability. So far, observational evidence for extended upper atmospheres and evaporation is only available for very few targets; we propose to exploit a new observational window, which is only available for the southern sky through XSHOOTER.

For over a decade, the main observational approach to test for ongoing evaporation of exoplanets was through transit observations of the hydrogen Ly-alpha line, which is located in the UV part of the spectrum and only accessible through space-based observations with the Hubble Space Telescope. Such measurements are furthermore complicated by absorption through interstellar hydrogen, as well as the fact that stellar emission in the Ly-alpha line is caused by stellar magnetic activity and is time-variable and not homogeneously distributed over the stellar disk. Only a handful of hot exoplanets were successfully observed in the UV to undergo evaporation, or at least to possess strongly extended upper atmospheres (for example Vidal-Madjar et al. 2003, Lecavelier des Etangs et al. 2010, Bourrier et al. 2013); even fewer have displayed evidence for extended upper atmospheres in X-rays (Poppenhaeger et al. 2013).

Recent theoretical work suggested that the He I lines in the near-infrared (at 10832.1, 10833.2 and 10833.3 Å), which are a triplet of absorption lines of a metastable state of helium, should be a good tracer of extended and evaporating atmospheres of exoplanets, (Oklopcic et al. 2018, see Fig. 1 left); these lines are observable from the ground. They are much less variable through stellar activity, and extinction through interstellar gas is expected to be low.

Even though this new observational window was only presented in theoretical work in 2018, already several exoplanets have been shown to display excess He I absorption during transits, indicating extended atmospheres and in some cases with detected wavelength shifts also evaporation, see Fig.$\tilde{1}$ right (Spake et al. 2018, Nortmann et al. 2018). Within a year, about the same number of atmospheric detections has been made using the infrared Helium triplet as in a decade of ultraviolet hydrogen Ly-alpha observations, demonstrating the richness of this new observational window.

We have chosen two young, relatively small, Neptune-sized exoplanets in short orbits as our targets. These planets are AU Mic b and DS Tuc A b, which have been discovered recently by Co-Is Plavchan and Newton (see Fig. 1, left). We expect to see a strong evaporation signature in the helium lines because of two aspects:

1) Recent works have shown that the radius distribution of small (Earth-like and Neptune-like) exoplanets shows a gap which is likely related to the evaporation of the primordial hydrogen-helium envelope of those exoplanets (Fulton et al. 2017, van Eylen et al. 2018). Young exoplanets should therefore be the prime targets for which evaporation is currently observable.

2) Small exoplanets can exhibit huge evaporation plumes, as seen in the Neptune-like exoplanets GJ 436 b when observed in the hydrogen Ly-alpha line, where its transit depth is about 40 (!) times as deep as in the broadband optical (Kulow et al. 2014, Ehrenreich et al. 2015). To see a strong signature in the helium lines, previous photo-excitation of the helium in the exoplanetary atmosphere is required by high-energy stellar photons; as our host stars are young and therefore X-ray bright, the helium absorption signature of our targets should be easily observable, if extended atmospheres and/or evaporation plumes are indeed present.

We propose to use XSHOOTER – the only instrument in the southern hemisphere currently capable of suitable He I transit observations – to

– test for excess absorption in the target exoplanets;

– measure the amount of excess absorption, in order to infer the spatial extent of the upper atmospheres of the target exoplanets (or derive a quantitative upper limit);

– and test for the presence of tails (late egress times) in the Helium transit light curves, which would indicate ongoing evaporation.

B- Immediate Objective

We propose to observe one transit each for two exoplanets in short orbits, using XSHOOTER in its highest spectral resolution mode (0.5″ for UVB, 0.4″ for VIS and NIR, i.e. reaching a resolution of ca. 1 Å around the Helium triplet) to collect a time series of spectra. We want to extract narrow-band light curves in a 2 Å bandpass around the Helium I triplet, located at 10830 Å, to compare the Helium transit profile to the well-studied white light optical transit profiles of these planets and reach the science goals listed above. XSHOOTER's spectral resolution will be sufficient to fit a nearby telluric line (at 10835.1 Å, which is 1.8 Å from the nearest He I line) in the in- and out-of-transit spectra to ensure it does not influence the He I triplet measurements. The NIR arm contains the spectral region which is of prime interest to us; we plan to use XSHOOTER's wavelength coverage in the UVB and VIS arms to monitor the stellar activity of the host stars through chromospherically active lines, and test for further potential atmospheric excess absorption of the planetary atmospheres in other relevant lines (Na, Mg); however, the Helium absorption is our main science driver.

The two exoplanets are AU Mic b, a Neptune-sized planet in an 8.5-day orbit around a ≈20 Myr old star of spectral type M1V (Plavchan et al. submitted), and DS Tuc A b, another Neptune-sized planet in an 8-day orbit around a ≈50 Myr star of spectral type G6V (Newton et al. 2019). The mass of AU Mic b has been determined as well and is indeed close to one Neptune mass; DS Tuc A b's mass has not been measured yet. The host stars are bright with $J = 5.4$ mag (AU Mic) and $J = 7.1$ mag (DS Tuc A).

Observationally, we aim to cover a time stretch starting ca. 1 hour before transit onset for each planet and stopping ca. one after the end of the transit, to also collect a high-quality spectral template of the unocculted star. The transit duration (first to fourth contact) of the exoplanets is ca. 3.6 (3.2) hours for AU Mic b (DS Tuc A b).

We aim for a S/N per pixel and exposure of ca. 250 around the helium triplet, which will avoid overexposing the NIR spectra, and will also avoid entering the extrapolated regime for pixels in the NIR. We require exposure times of 3 seconds in the NIR for AU Mic, and 15 seconds in the NIR for DS Tuc A. The readout time of the IR arm is ca. 1 s. The data from the VIS and UBV arms is only of ancillary importance to our science goal, and we have chosen the fastest readout mode (2x2 fast) for those arms.

The broadband optical transit depths of the two young exoplanets are ca. 0.3%. For larger exoplanets like Hot Jupiters, helium triplet observations found excess helium depths between 50% and 200% of the optical broadband depth. But even if the evaporation tails and extended atmospheres of our two targets are unexpectedly smaller, the data quality will allow us to detect excess transit depths in the helium triplet down to fractions of the broadband transit depth. If we co-add the proposed observations to one hour bins, we could detect excess helium transit depth down to 0.05% for AU Mic b and 0.1% for DS Tuc A b at 3σ level per bin, i.e. 16% and 33% of the planetary broadband transit depths.

Given the short required exposure times of the proposed observations, we will be able to study evaporation tails, manifesting themselves as delayed egresses, with high time resolution.

There is one full transit of DS Tuc A b and two full transits of AU Mic b observable with sufficient moon distance during the current proposal call period.

Figures

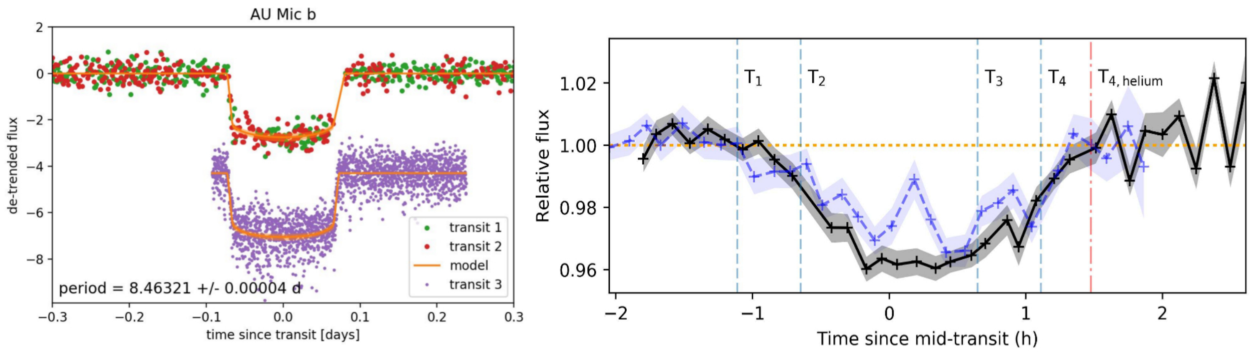

Fig. 1: *Left:* Broadband optical (top) and infrared (bottom) transit of the Neptune-sized planet AU Mic b, the transit depth is ca. 0.26% (Plavchan et al. submitted).
Right: Two transit light curves (black and blue) of the exoplanet WASP-69 in a 1 Å bandpass around the He I triplet. The continuum transit profile has already been subtracted, so that the plot shows the excess absorption in the He I triplet, which is twice as deep as the broadband transit. There is also evidence of an evaporation tail (late egress); data from the northern hemisphere CARMENES spectrograph (Nortmann et al. 2018).

References

Vidal-Madjar+ Nature 422 6928 143 (2003) • Lecavelier des Etangs+ A&A 514 A72 (2010) • Bourrier+ A&A 551 A63 (2013) • Poppenhaeger+ ApJ 773 1 62 (2013) • Oklopcic+ ApJL 855 1 L11 (2018) • Spake+ Nature 557 7703 68 (2018) • Nortmann+ Science 362 6421 1388 (2018) • Kulow+ ApJ 786 2 132 (2014) • Ehrenreich+ Nature 522 7557 459-461 (2015) • Plavchan et al. submitted to Nature • Newton+ ApJL 880 1 L17 (2019)