The RV stability and precision budget for NIGHT*

*a compact, near-infrared, hi-res spectrograph to survey helium in exoplanet upper atmospheres (Farret Jentink et al., in prep)

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INTRODUCTION

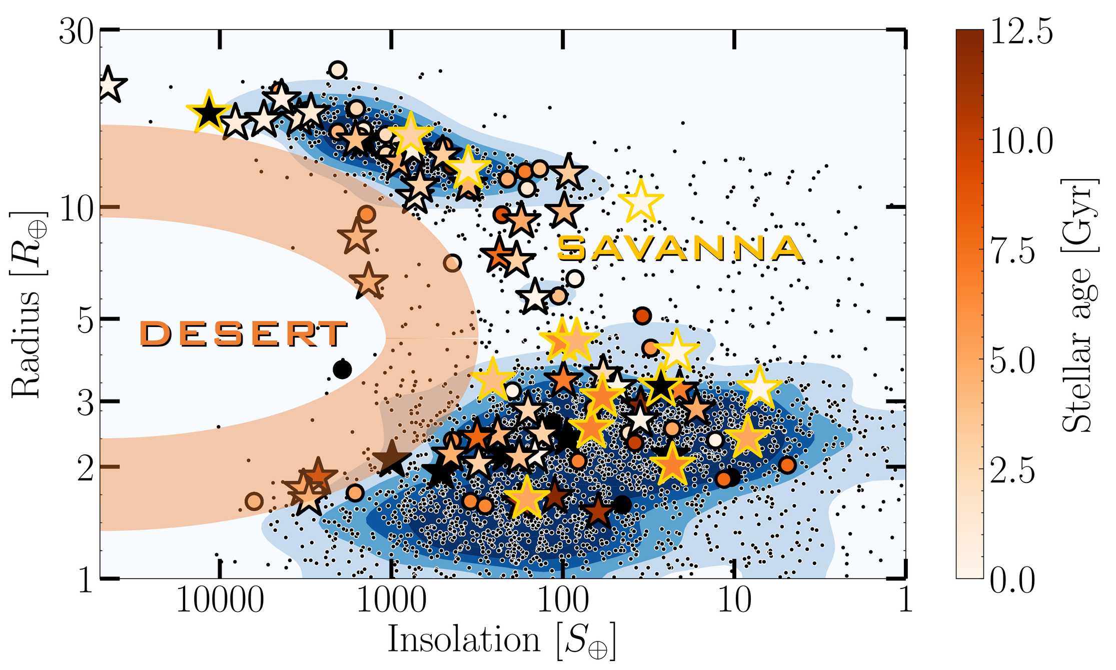
Among the broad ensemble of exoplanets discovered close to their star, there is only a handful in the Neptune-size range. To probe atmospheric escape as one of the possible mechanisms for the creation of this hot Neptune desert, we propose NIGHT (the Near-Infrared Gatherer of Helium Transits) - a high-resolution spectrograph dedicated to surveying extended atmospheres via their absorption in the Helium I triplet at 1083nm. Besides, NIGHT will temporally monitor the atmospheres of >100 exoplanets. Over a few years of surveying, it could provide us with detailed insights into the potential mechanisms that shape the hot Neptune desert. First light of NIGHT is aimed for 2024.

SCIENCE CASES

The science cases of NIGHT have been established as follows:

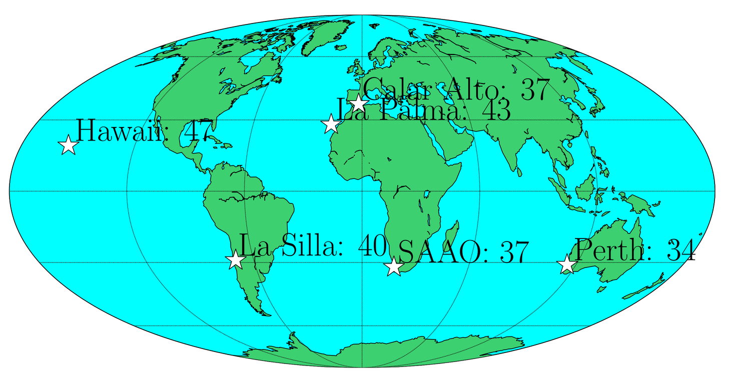
- Observe helium transits of exoplanets with sufficient sensitivity, temporal, and spectral sampling to probe the dynamics of the extended atmosphere and its variability;
- Spectrally resolve the He-I triplet at its typical broadening;
- Detect 0.4% temporal variability in peak absorption depth between two transits at 3 sigma for at least 50 planets on a 2-meter class telescope;
- To fulfil the science case, the instrument should be cost-efficient and compact.

THE NIGHT SURVEY



NIGHT will survey and monitor 100+ planets in and around the hot Neptune desert. Targets for which we could detect 0.4% absorption depth variability inbetween 2 transits are highlighted as star-shaped markers. Targets with known evaporating atmospheres are gold-colored.

NIGHT will temporally monitor a large group of exoplanet atmospheres of various masses, radii, insolations, periods and ages. In this survey it will search for new extended atmospheres and study their stability. From this data we can accurately determine mass-loss rates and probe the dynamics. This will help us shed a light on the role of atmospheric escape in planetary evolution.

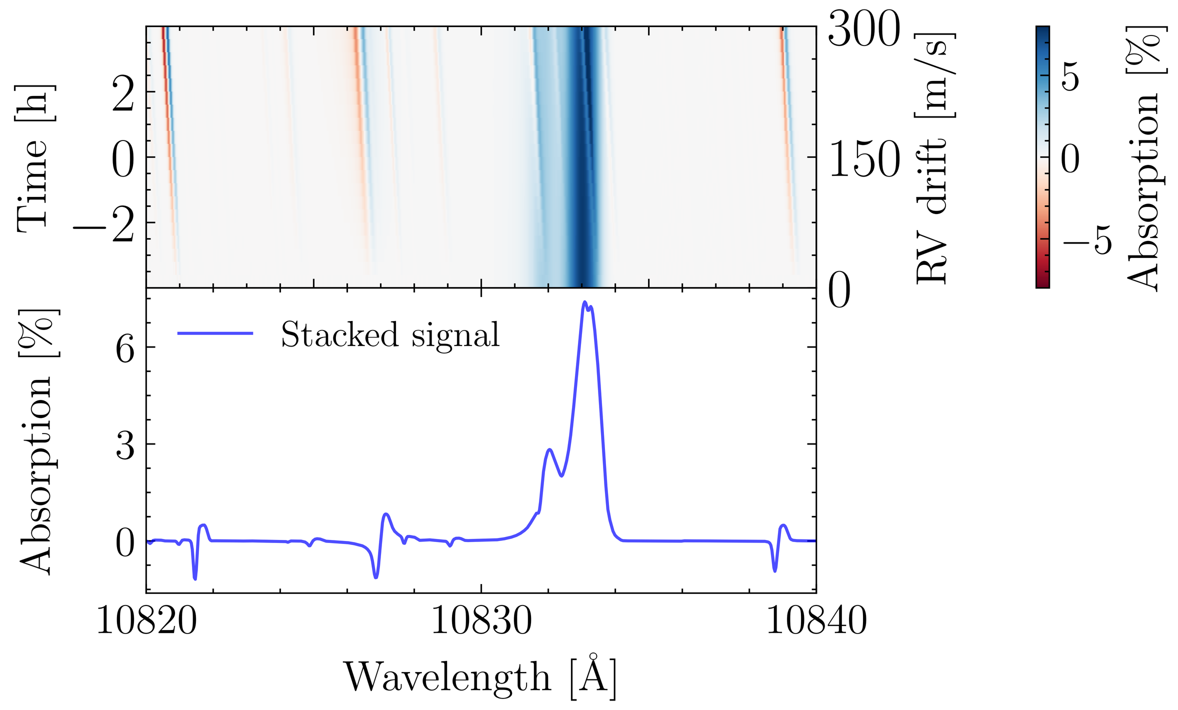


The number of exoplanets for which we could observe temporal variability in one year.

Mont Mégantic: a 1.6-meter telescope in Quebec as possible location for NIGHT.

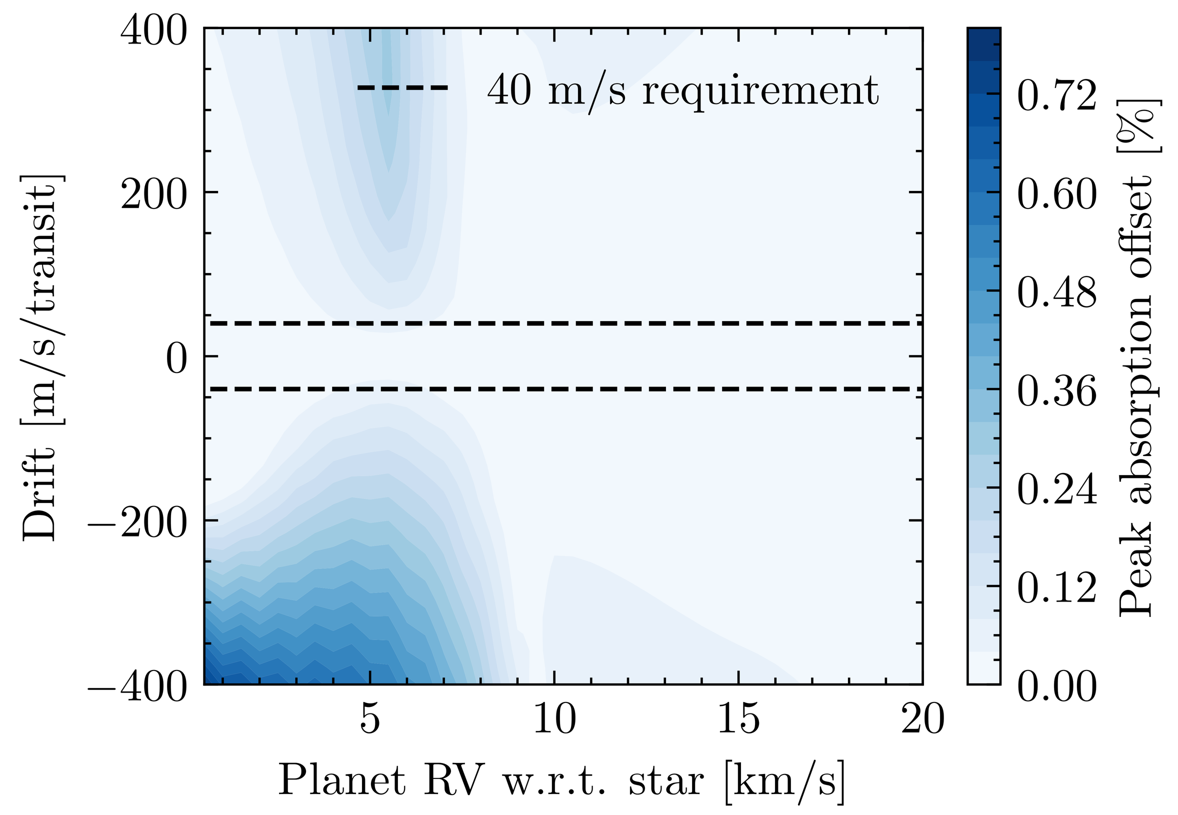
TRANSIT SIMULATIONS

NIGHT will be the first ground-based instrument solely dedicated to the study of exoplanet atmospheres. Because of this dedicated science case, instrument requirements are less stringent than for previously realized high-resolution spectrographs for exoplanetary science, where the recovery of RV signatures was the leading science requirement. To set a requirement on RV stability and precision we simulated transits based on a previously detected signal from Allart et al. (2019) in WASP-107 b. We applied a linear uncalibrated instrumental RV drift on this dataset and studied the offset generated in the final retrieved signature. An example of such a simulation can be found below:



A river diagram (absorption spectra over time) in the planetary restframe is shown. The strong absorption signature around 10833 Å is the He-I triplet absorption from the atmosphere. The inclined lines are stellar absorption lines that are not fully divided out as a result of unknown instrumental drift increasing from 0 to 300m/s over the full transit (8 hours). The lower panel shows the stacked signal, where the He-I triplet is recovered, but p-cygni profiles are introduced as a result of the drift.

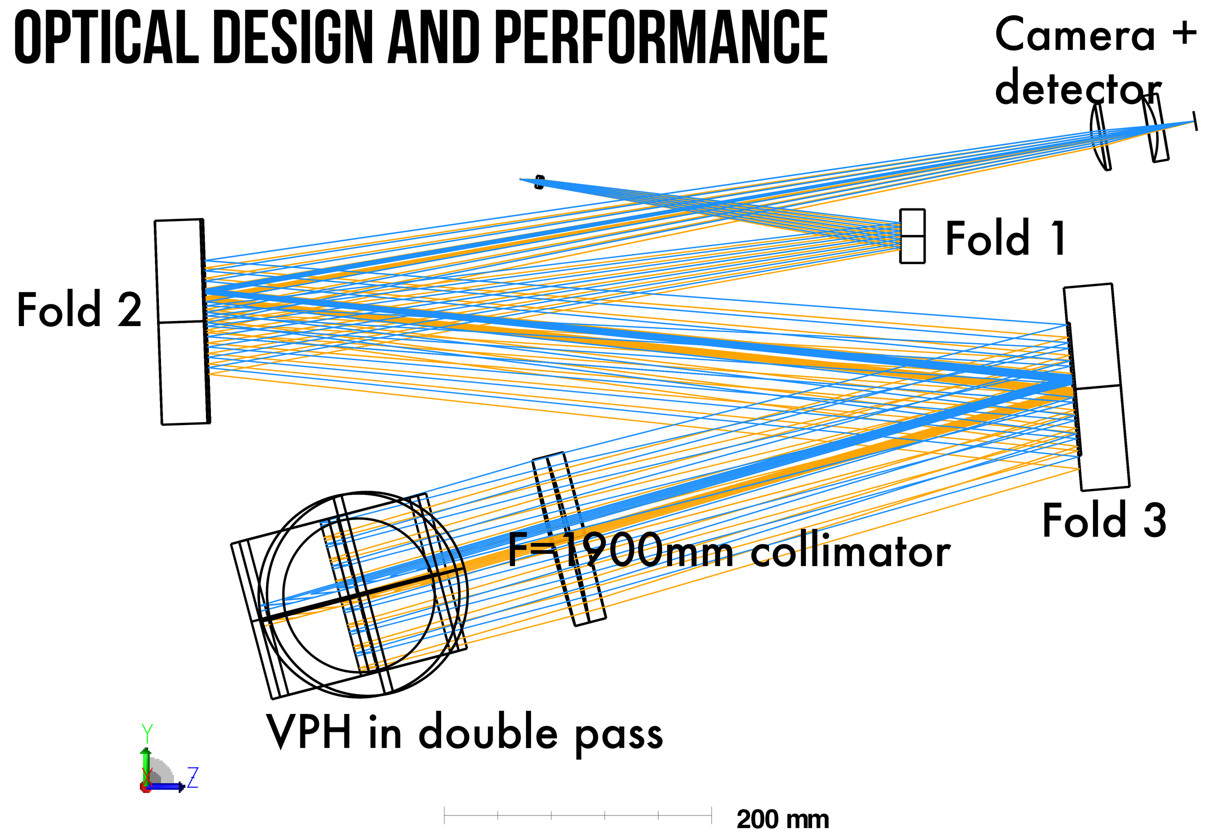
To quantify the effect of unknown drift on the retrieved signature, we studied the offset introduced at the peak absorption of the triplet with respect to the original model. We did this analysis for a range of linear drifts and planet ingress velocities:



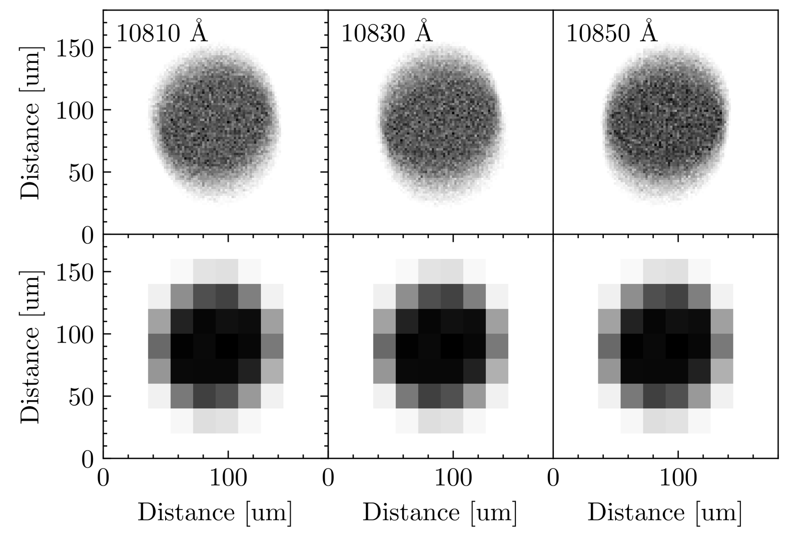
The contour shows the peak absorption offset for a range of linear drifts (vertical axis) and planet ingress velocities (horizontal axis). We find that for a high ingress velocity, p-cygni profiles moslty cancel out when frames are stacked. The most stringent case is found around 5km/s ingress velocity, where we find that 40m/s uncalibrated drift assures a maximum offset of .04%, 1/10th of the temporal variations we would like to study.

Our analysis shows that NIGHT can be build with much less stringent requirements on instrumental stability – allowing for a cost-efficient design of mostly off-the-shelf components. The narrow wavelength range allows for low-cost optics and high overal throughput of the instrument.

OPTICAL DESIGN AND PERFORMANCE



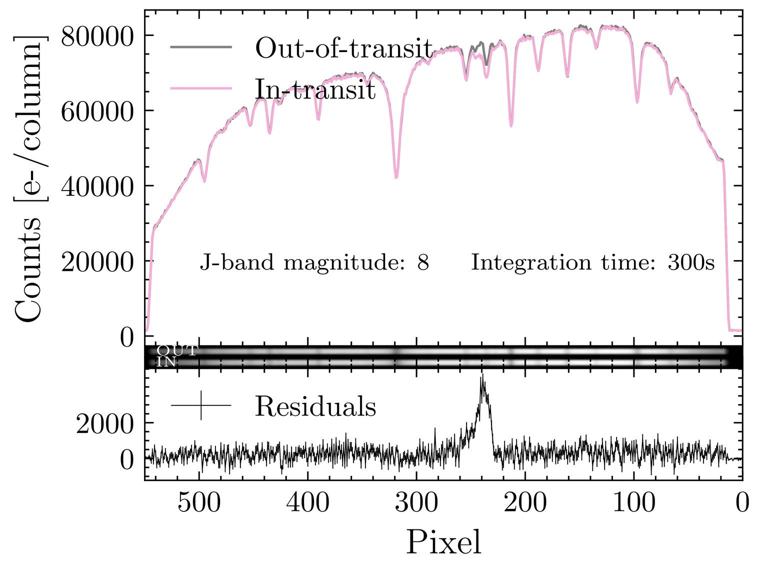
The optical design of the NIGHT backend. Night will be fibre-fed with a 60um 0.125NA fiber. After 3 fold mirrors the light will be collimated by an OTS achromatic doublet. Two singlet lenses form the rest of the camera.



The optical performance of NIGHT. Our PSFs show that NIGHT will reach a R~70k resolution at 2.9 pixel sampling, independent of grating type.

Currently, two grating solutions are proposed: a VPH in double-pass or an R2 echelle grating in 51st order with custom order sorting filters in the frontend of NIGHT. Further testing in our optical lab will tell if a VPH in double-pass will perform up to requirements. The VPH in double-pass will increase throughput with ~30% w.r.t. an echelle grating. Given NIGHT will observe in the NIR, we require a HgCdTe detector to achieve high enough Q.E. and low enough dark noise. Currently, engineering grade HAWAII-2RG detectors are being tested at the University of Montreal for requirements verification. Engineering grade detectors can work for NIGHT given the limited need of detector footprint (600x30 pixels), and dark noise requirement of <1 pix/e/s.

Below, we show a figure displaying a simulated in-, and out-of-transit spectrum. In the top frame we show the retrieved spectra in counts/detector column. Underneath we show the ray-trace of both spectra. The residuals (subtraction of both spectra) can be found in the lower frame. We can see that for a J-band magnitude of 8 and an integration time of 5 minutes, the He-I signature can already easily be retrieved.



The PSF generated by the ray-trace of our optical model, together with the efficiencies of the optics (echelle grating in this figure) and detector properties, were used to make an instrument simulator of NIGHT.

Instrument integration will happen over the upcoming year, and first light is planned for 2024.

Farret Jentink, C., et al. (in prep.) "NIGHT: a compact, near-infrared, high-resolution spectrograph to survey helium in exoplanet upper atmospheres."

Allart, R., et al. (2019) "High-resolution confirmation of an extended helium atmosphere around WASP-107b."