After SDSS-IV Letter of intent

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Science: In this letter we follow up on our previous White Paper, where we proposed to use Apogee at APO to study the atmospheres of currently-known giant exoplanets and future TESS planets orbiting bright stars. We chose to perform high-resolution transmission spectroscopy in the near infrared (NIR) due to the reliability of the method to detect molecular species and measure their relative abundances (Brogi et al. 2012,2013,2014,2016; Birkby et al. 2013; de Kok et al. 2013,2014). Despite the use of the largest ground-based facilities (VLT and Keck), past studies have been limited to the brightest exoplanet systems (NIR magnitudes < 7). In our white paper we showed that this limitation mostly depends on the low throughput and small spectral range of past spectrographs. We demonstrated on SDSS data that Apogee is 7× more efficient than CRIRES at VLT. Together with the 4× larger spectral range, this makes the Sloan telescope (2.5m) only 30% slower than a VLT (8.2m) to reach the same S/N. By using the former in a semi-dedicated fashion rather than for a few hours per object, we can target significantly fainter planets. Figure 1 (left) shows the sample of known transiting exoplanets for which water vapor can be confidently detected (S/N > 5) after 1 observing season with Apogee/APO in the *current* observing mode. The simulations are based on injection and retrieval of *H*-band model spectra on real data, and were updated from our White Paper by explicitly accounting for RA and DEC of the targets, computing their total visibility from APO, and scaling the signals accordingly. Since the current sample of known planets is biased towards the northern hemisphere, 100 of the 123 known systems are visible from APO, 60 of which can be detected at S/N > 5 after 1 year of survey. Given that current comparative studies (Sing et al. 2016; Kataria et al. 2016) rely on a sample of about 10 hot giants, the size and diversity (masses, temperatures, radii) of the APO sample is unprecedented.

In the early 2020s, Apogee will be also able to characterize planets found by the Transiting Exoplanet Survey Satellite (TESS). These will be smaller (mostly 2-4 R_{Earth}) but will orbit bright stars (K_S < 13 mag). Their characterization will be the first step towards future studies of terrestrial habitable planets. JWST will follow-up the most promising targets, but the sample size will be small due to the limited telescope time. Moreover, it will observe at relatively low spectral resolution. Traditional ground-based follow-ups with differential spectro-photometry will be challenged by the lack of suitable reference stars, saturation, and possible sources of systematic noise. On the other hand, high-dispersion spectroscopy (HDS) does not need reference stars and is nearly unaffected by systematic noise, even at the 10^{-5} level, which is routinely achieved (Brogi et al. 2012,2014). HDS with Apogee will allow us to detect H_2O (and potentially additional species such as CH_4) on a large sample of TESS planets (Figure 1, right panel) and measure line/continuum contrasts. These will complement broadband measurements by JWST, helping us to constrain the atmospheric properties. Furthermore, clouds are thought to be ubiquitous in exoplanet atmospheres. They can potentially shield most of the spectroscopic features at low spectral resolution (Kreidberg et al. 2014). Since the narrow core of molecular lines generally forms above the cloud deck, HDS enables detections of molecular species even in cloudy atmospheres.

TESS will preferentially observe the galactic poles, meaning that at least half of the stars will be visible from APO. We performed S/N calculations on the simulated yield of Sullivan et al. 2015 (~1700 planets), resulting in ~300 atmospheric detections if all the small planets can retain hydrogen-rich atmospheres, and 127 atmospheric detections (25 giant planets and 102 super-Earths) if smaller planets are progressively depleted in hydrogen. The latter scenario is more realistic and it is shown in Figure 1 (right panel). Given the big size of the accessible sample of exoplanets (current + TESS) we will need to identify a sub-sample to target, at least for the first 1-2 years of operations. The top-50 planets with the best S/N have radii between 1.7 and 20 R_{Earth} and temperatures between 500 and 2500 K. Their characterization will require 390 hours/year on sky, observing every time a transit is completely or partially visible. For 50% of clear nights, the allocated time would be 780 hours/year. Despite being a considerable time investment, the science revenue is unprecedented. In the early 2020s APO will deliver the first homogenous characterization of small exoplanets, and will determine the most promising candidates to follow-up in the late 2020s with Extremely Large Telescopes (once equipped with HDS) and deep-field JWST campaigns. These are crucial steps towards the characterization of terrestrial planets.

Team: The project requires a relatively small team, due to the availability of a tested pipeline for processing time series of high-resolution spectra: 1 coordinator (senior post-doc level or above), 1 post-doc for the spectral modeling, and 1 for the improvement of the pipeline and the analysis. Due to the high scientific impact of the data, involvement of graduate students is also possible. The same team would also work on the target selection.

Instrumentation: Apogee in its current configuration is already suitable for this survey. In some case the total exposure time per frame (or the number of co-added integrations) will be reduced to prevent saturation, which for t_{exp} = 470 s happens around H = 7 mag. We would need one fiber on target, a few on the sky, a few on telluric standards. Most of the 300 fibers would be still available for simultaneous galactic/extragalactic surveys, if suitable targets are present in the field of view. Moreover, the characterization of TESS host stars, which is promoted in the final report of the time domain committee, could be done on the same spectra of our project. An alternative implementation would require feeding Apogee with a fiber bundle (7-9 fibers arranged in a circular pattern) from the 3.5-m telescope. This would further increase S/N due to the larger mirror and the bigger fraction of the stellar PSF encompassed.

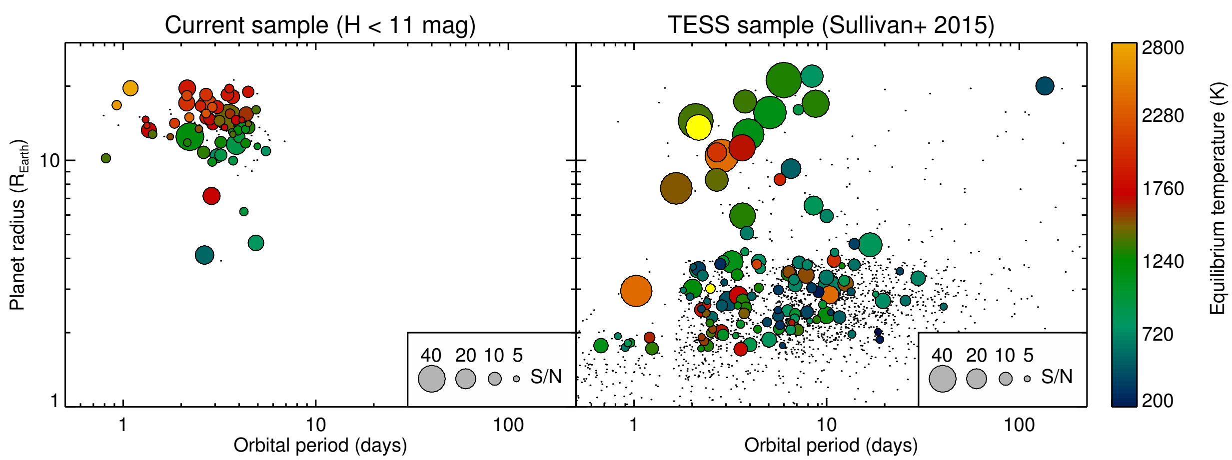

Figure 1: Current sample of transiting exoplanets (left), and future sample of planets detected by TESS (right) for which atmospheric characterization is within the reach of Apogee. The size of the circles is proportional to the S/N (see legend) while their color indicates the planet equilibrium temperature. Planets for which we will not be able to detect an atmosphere are plotted with a black dot. In the right panel we assume that TESS planets smaller than 4 R_{Earth} have atmospheres progressively depleted in hydrogen.