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Galactic panel
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Confirming hot and ultra-short period Saturns and Jupiters from the Next Generation Transit Survey

Abstract

The Next Generation Transit Survey (NGTS) is a ground-based wide-field transit survey, monitoring stars with I $<$ 16. It obtains full-frame images from twelve independent telescopes. The NGTS was designed primarily with the aim of discovering Neptunes and Earth-size planets in the southern hemisphere. We request two runs of 4 nights with the FEROS instrument on the 2.2-m ESO/MPG telescope at La Silla Observatory to observe 8 stars from our vetted NGTS candidates that have radii commensurate with Saturn-Jupiter size objects derived from the transit light curve and periods smaller than 10 days. Our radial-velocity follow-up has allowed us to confirm 10 new transiting systems, where FEROS proved to be key in constraining the orbits. In addition to confirming the planetary nature of our candidates, FEROS velocities will also help constrain companion densities, allowing us to study bulk composition and formation mechanisms of the detected planets, and their stellar interactions

Observing Blocks

Instrument/Telescope	Req. time	Min. time	1^{st} Option	2^{nd} Option
FEROS/MPG 2.2-m	4 nights	3 nights	August Any	October Any
FEROS/MPG 2.2-m	4 nights	3 nights	December Any	March Any

CoIs

Name	Institution	e-mail	Observer?
James Jenkins	UCH	jjenkins@das.uchile.cl	False
Didier Queloz	OnCL	dq212@cam.ac.uk	False
Peter Wheatley	OnCL	P.J.Wheatley@warwick.ac.uk	False
Edward Gillen	OnCL	ecg41@cam.ac.uk	False
Maximiliano Moyano	UCN	mmoyano@ucn.cl	False
Alexis Smith	OnCL	Alexis.Smith@dlr.de	False
Daniel Bayliss	OnCL	d.bayliss@warwick.ac.uk	False

Liam Raynard	OnCL	lr182@leicester.ac.uk	False
Christopher Watson	OnCL	c.a.watson@qub.ac.uk	False

Status of the project

- Past nights: 32
- Future nights: 24
- Long term: False
- Large program: False
- Thesis: True

List of Targets

ID	RA	DEC	Mag
NOI-103551	21:20:15.1	-51:18:13.02	V=14.68
NOI-105438	21:03:02.6	-33:33:54.34	V=15.48
NOI-105674	11:49:17.8	-33:23:08.59	V=14.66
NOI-103962	21:39:24.9	-31:23:15.44	
NOI-103958	21:26:46.2	-09:23:43.16	V=14.98
NOI-105758	20:58:18.5	-40:16:07.41	V=13.35
NOI-103547	21:21:03.3	-52:30:19.66	V=14.56
NOI-103954	22:12:26.7	-26:55:35.02	V=12.84

SCIENTIFIC AIM AND RATIONALE

More than 4100 extrasolar planets have been detected to date and ground and space based photometry surveys have allowed us to both further constrain the orbital properties and, most importantly, to characterize the bulk properties for hundreds of these systems over a wide range in the parameter space. However, an important population of hot short-period planets ($P \lesssim 10$ days) have emerged, through which we can test and study current planet formation and evolution theories. Furthermore, an even more extreme population of ultra-short period hot Jupiters ($P \lesssim 1$ day) is emerging, allowing us to also study star-planet tidal interactions and gather candidates for orbital period decay studies, a particularly starved area of study since only one planet, WASP-12, has shown evidence for orbital period variations (Patra et al, 2020).

The Next Generation Transit Survey: The Next Generation Transit Survey (NGTS, Wheatley et al. 2018) was designed and built with the primary aim of discovering Neptunes and Earth-size planets (1.2-6 $R_{\oplus}$) orbiting bright and nearby stars ($V \lesssim 13.5$) in the southern hemisphere (Günther et al. 2017). NGTS consists of an array of twelve 20cm f/2.8 telescopes, robotically operated, at the ESO Paranal Observatory. Each telescope is capable of monitoring 10 deg^2 of the sky at a time, and its one-tenth of a pixel precision guiding over a full night, makes it the most precise ground-based survey currently operating. NGTS is able to detect transits with depths of up to 1-2 mmag on time-scales of 10 minutes. It's also capable of operating at a quick 10s cadence, allowing us to detect transit signatures of ultra-short period transiting planets, including two of the shortest period giant planets discovered (NGTS-6b, Vines J. et al. 2019; NGTS-10b, McCormac et al. 2020)

The NGTS project began its science operations in September 2015. Data from over 100 fields have been reduced, using our automated project pipeline, and a full candidate selection has been performed. Extensive vetting of the candidates has been performed, including ellipsoidal variation, secondary eclipses, and centroid analysis (Günther et al. 2017b), allowing us to detect variable background contaminants, like background eclipsing binaries, vastly reducing the quantity of false-positives in our candidates sample, which can make up to 35% (Cameron 2012). Two of these tests are shown in Figure 1. We have also used the results from the Gaia DR2 in order to obtain parallaxes for our brightest candidates, and to check for nearby blends all the way down to a g magnitude of 20. Final contamination vetting has also been performed using observations with the Coralie spectrograph on the 1.2-m Euler Telescope at La Silla Observatory. This final step allows us to rule out spectroscopic binaries, blended systems with asymmetric line profiles, and eclipsing binaries.

The NGTS also acts as a complement to the space-based mission TESS (Ricker et al. 2015), which has currently observed all 13 southern sectors. Given the significant difference in pixel size ($5{\times}5''$ as opposed to TESS' $21{\times}21''$), NGTS is less affected by blending due to a background stars, allowing us to follow-up candidates in more crowded fields (e.g. NGTS-10b, McCormac et al. 2019), or detect blended eclipsing binary false-positives within the TESS Objects of Interest (e.g. TOI-164 which was shown to be a blended eclipsing binary by NGTS), in addition, the higher cadence of NGTS is an important factor in resolving transits from ultra-short period Hot Jupiters.

Project Aims: We request two runs of 4 nights with the FEROS instrument on the 2.2-m ESO/MPG telescope at la Silla Observatory, to observe 8 stars from our vetted NGTS candidates that have radii commensurate with Saturn-Jupiter size objects, particularly those at very short period, derived from the transit light curve fitting. The spectra will be used to confirm and constrain the planetary nature of these candidates by the radial-velocity (RV) method. The spectra will also provide the activity level of each candidate, and since it has been shown that stellar activity can produce a shift in the spectral lines that can induce RVs in our measurements, similar to the ones used to detect planetary companions (Díaz et al. 2018), we will model the stellar activity to gain a more precise measurement of the planet properties. The data collected here will also be complemented by the spectra already taken by this project using FEROS, which has provided very promising results (see Figures 2 and 3). The need for FEROS data over Coralie data is highlighted in Figure 3, where the RV measurements obtained with FEROS are key to constrain the orbital parameters of the system. **In addition to confirming the absolute mass of the companion, the FEROS velocities will also give us well constrained companion densities, which can then be used to study bulk compositions and hence possible formation channels for detected planets, allowing an insight into the mechanisms behind the formation, migration, and evolution of these systems. Further follow-up with more sensitive instruments in Chile can then allow the chemistries and atmospheric physics of these planets to be probed at very high precision since the primary stars are brighter than the current typical transiting planet host star.**

The FEROS spectra obtained will also be used to compute the stellar properties of the system, by measuring the equivalent widths of specific atomic lines. From these values we will obtain the temperature, surface gravity, metallicity, micro and macroturbulence velocity, rotational velocity, mass, and age of the star, as well as abundances for 11 other chemical elements (see Soto et al. 2018). This method has already been used in other NGTS planetary candidates, like NGTS-2b and NGTS-6b (Raynard et al. 2018; Vines J. et al. 2019)

The follow-up we propose here, along with the observed time already awarded to this project, will help us to focus on the hot and ultra-short period Jupiters and Saturns from the NGTS project. We have also requested observing time with the HARPS at the 3.6m telescope at La Silla Observatory for period P106, in order to follow-up our Neptune to super-Earth size candidates, which are not included in this proposal due to the lower precision of FEROS in comparison with HARPS ($\sigma_{\mathrm{FEROS}} \sim 4$ ms^{-1}). We have already published a new ultra-short period Hot Jupiter using FEROS and CORALIE observations (NGTS-6b, Vines et al. 2019), and we have more discoveries using FEROS data (e.g. NGTS-8b and NGTS-9b, Costes et al. 2019) with others in press.

The data we extract from these observations will form the basis of our studies of the population of nearby planets from Jupiter to super-Earth bodies, in a uniform and homogeneous way, allowing us to explore the transition stage from gaseous-like planets, to smaller ones with or without a thick gaseous envelope, and finally to terrestrial planets with compositions similar to the Earth. We will also provide a number of planetary candidates that will be used to perform detailed atmospheric studies by instruments on some of the largest ground-based telescopes, such as the VLT and the upcoming GMT and ELT. The NGTS data and the quantity of follow-up studies provides a great opportunity to detect exciting planetary candidates, allowing us to better constrain theories of formation and migration from giant to rocky planets. **In particular, thus far only one planet, WASP-12b, shows strong evidence for tidally driven orbital decay (see Yee et al, 2020; Bouma et al, 2020), therefore we aim to increase the yield of USP planets, building up the sample of worlds with decaying orbits, whilst also allowing further insights into star-planet magnetic interactions and photoevaporation processes.**

References:

Batalha, N. M. et al. 2010, ApJ, 713, L103; Cameron, A. C. 2012, Nature, 492, 48; Díaz, M. R. et al 2018, AJ, 155, 126; Günther, M. et al. 2017a, MNRAS, 465, 3379; Günther, M. et al. 2017b, MNRAS, 472, 295; Raynard, L. et al. 2018, MNRAS, 481, 4960; Soto, M. G. & Jenkins, J. S. 2018, A&A, 615, 76; Wheatley, P. et al. 2018, MNRAS, 475, 4476; Vines, J. I. et al. 2019, MNRAS, 489, 4125; Ricker et al. 2015, JATIS; McCormac et al. 2020, 493, 126; Costes et al. 2019, 491, 2834; Patra et al. 2020, 159, 150; Yee et al. 2020, 888, 5Y; Bouma et al. 2020 893L, 29B

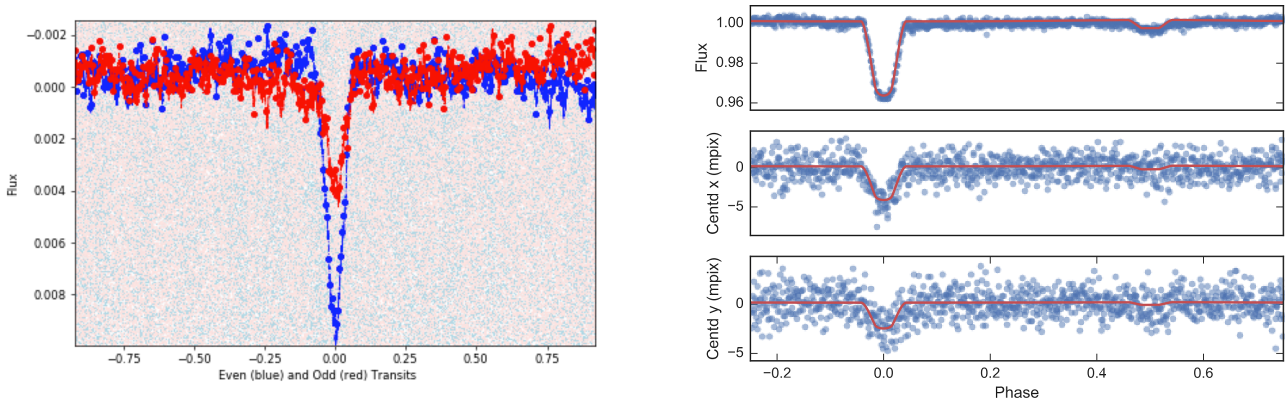

Figure 1: Example of two vetting diagnostics used in all possible candidates, before obtaining follow-up data. Left: Difference between odd and even numbered transits (Batalha et al. 2010). Right: Centroid shifting diagnostic. Figure from Günther et al. 2017b.

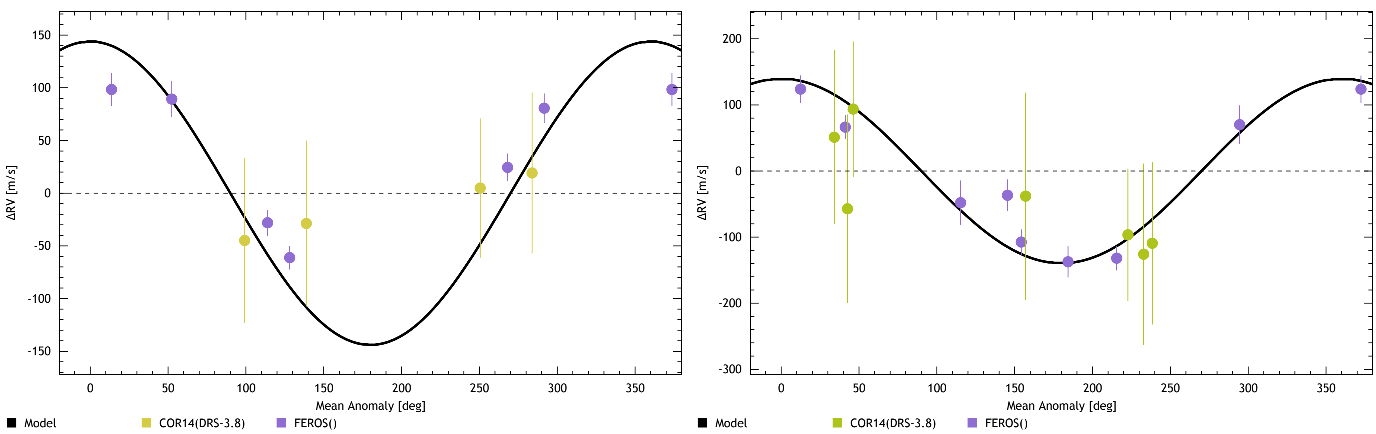

Figure 2: FEROS observations for (left) NOI-101195 and (right) NOI-103524 from our 2019A run. In both cases yellow points are Coralie observations and purple are FEROS. It is clear how FEROS is needed to recover the planets orbits. More observations are needed to fully constrain the orbits of these and many other NGTS targets which are not included in this plot to conserve space.

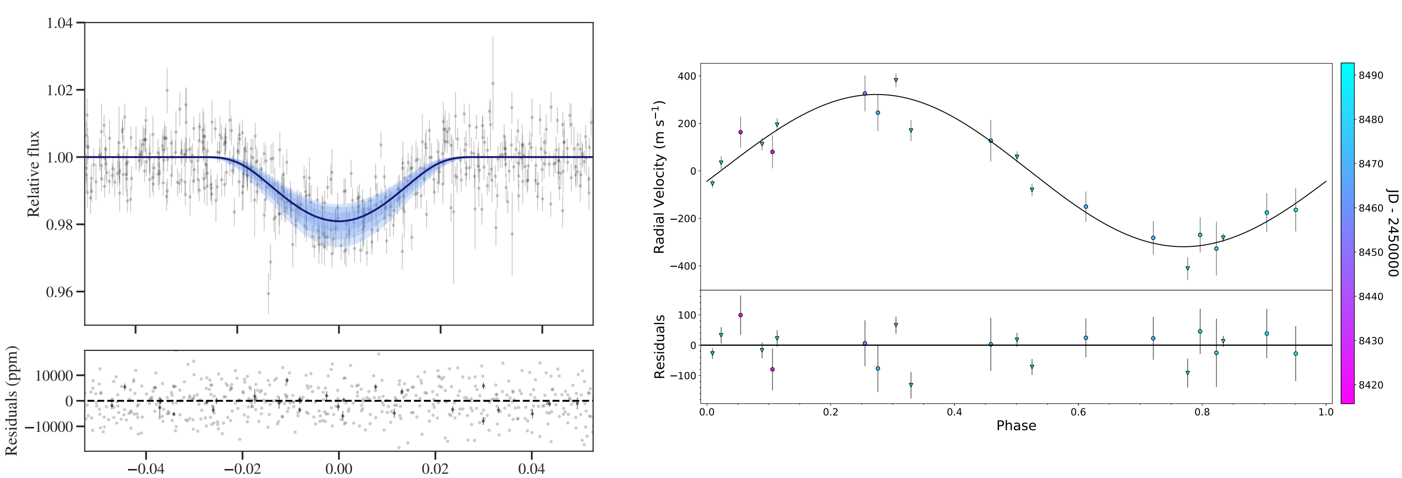

Figure 3: NGTS-6b transit light curve (left) from Vines et al. (2019), along with the simultaneously fit RV data (right). The blue and black solid curves and the blue shaded regions mark the best fit model and associated uncertainties, respectively. Upside down triangles are FEROS observations and circles are Coralie observations.

CURRENT STATUS OF THE PROJECT

The Next Generation Transit Survey (NGTS, Wheatley et al. 2018) is an array of 12 independently mounted 20-cm telescopes located at Cerro Paranal, capable of monitoring 96 $\deg^2$ of the sky. The telescope array observes a number of fields every night for up to 5 months each. It was designed to look for transit signals from the brightest stars of the southern hemisphere (V $\lesssim$ 13.5), to detect planets as small as Neptune-size orbiting solar-type stars, and super Earth-size candidates around K-dwarfs and M-dwarfs. This is possible thanks to the high quality imaging cameras, and the tracking capability, allowing NGTS to achieve sub-millimag photometry on 10 minutes time-scales, and therefore allowing the detection of transits up to 1-2 mmag depth.

The NGTS consortium is formed by astronomers from different European and Chilean institutions: Universidad de Chile, Universidad Católica del Norte, University of Warwick, Observatoire Astronomique de l'Universite de Geneva, University of Leicester, University of Cambridge, Queen's University Belfast and Deutsches Zentrum fuer Luft- und Raumfahrt e. V. It also builds on over a decade of experience from the WASP project (Pollacco et al. 2006) - the most successful ground based survey for transiting planets.

Science Operations began in September 2015, and the full survey with all 12 telescopes observing began in April 2016. The data collected for each field is processed by our automated project pipeline, which includes the computation of the BLS periodogram (Kovács et al 2002) for each light curve, in order to detect potential planetary candidates. These candidates are then screened in order to eliminate eclipsing binaries or blended eclipsing binaries, thanks to different vetting techniques developed by our team, which include the detection of ellipsoidal variation and secondary eclipses in our light curves, as well as centroiding analysis to detect photometric centroid offsets during transit, produced by variable background sources (Günther et al. 2017). The remaining candidates have also been observed with the Coralie spectrograph, on the 1.2-m Euler Telescope at La Silla Observatory, in order to eliminate too hot or too rapidly rotating host stars.

We request 8 observing nights with FEROS, located at the 2.2-m MPG telescope and the La Silla Observatory, to follow-up our Jupiter to Saturn-size planets, with orbital periods $P < 10$ days, in order to obtain precise values for their masses. This project has already been awarded 32 nights from 2016B to 2019B, and we have lost a total of 8 full nights due to weather problems. The previous data obtained with FEROS has been analysed by our team, showing promising results (Figures 2 and 3 in Scientific Rationale). We have also thus far been awarded time with the HARPS instrument in 7 periods. This time will be used to observe the Neptune and super-Earth size planetary candidates. Our radial-velocity follow-up data has allowed us to confirm 10 new transiting systems, including two ultra-short period Hot Jupiter discoveries, including the one with the shortest period to date (NGTS-6b, Vines J. et al. 2019; NGTS-10b, McCormac et al. 2019), and two new Hot Jupiters (Costes et al. 2019). **We also have 14 more confirmed planets, 8 of which where FEROS observations were integral for constraining the planetary parameters, and we will publish them in the next couple of months.**

The student Vines is playing a major role in these discoveries, performing joint modeling of the transits and RVs using a Bayesian formulism, whilst also calculating the stellar parameters using a new code he developed for his work called ARIADNE[1] (Vines & Jenkins 2020 MNRAS, submitted)

References:

Bayliss, D. et al. 2018, MNRAS, 475, 4467; Günther, M. et al. 2017, MNRAS, 472, 295; Kovács, G.; Zucker, S. and Mazeh, T. 2002, A&A, 391, 369 ; Pollacco, D. et al. 2006, Ap&SS, 304, 253; West et al. 2018, MNRAS; Wheatley, P. et al. 2018, MNRAS, 475, 4476; Vines, J. I. et al. 2019, MNRAS, 489, 4125; McCormac et al. 2019, 493, 126; Costes et al. 2019, 491, 2834

[1]https://github.com/jvines/astroARIADNE

TECHNICAL DESCRIPTION

We request 8 observing nights with the FEROS instrument during period 2020A to follow-up 8 stars with Jupiter and Saturn-size planetary candidates from the NGTS project. We request two runs of 4 nights each, bracketed at the beginning and end of the semester so that we can access our full RA range from the NGTS fields we are following up. We note that we request a minimum of 6 nights that would be best scheduled as a single run in early-August 2020 or early-December 2020. Our targets have visual magnitudes $I \leq 12.5$, and the inferred planetary radii ranges from 0.5-2 R_J (assuming that $R_\star = R_\odot$). Planets with these sizes, orbiting stars with $M \sim M_\odot$ at periods $P \sim 4$ days (average period for the NGTS candidates), induce radial velocity amplitudes from 50 to 120 m s^{-1} (assuming the evolutionary models from Fortney et al. 2007, and that planets with these orbital periods have been found to be inflated). Our previous experience using FEROS (Soto et al. 2015, and our 2016-2019 runs) shows us that we can obtain a RV precision of $\sim$ 10 ms^{-1}, when the signal-to-noise (S/N) of the spectra is of the order of $\sim$ 45. This S/N is then enough for us to reach the desired precision that will allow us to detect the planetary candidates mentioned previously.

Our previous experience observing NGTS candidates with FEROS showed us that the most efficient way to reach a S/N$\sim$ 45 for targets with $I \sim 11.5$ is to have 30-minutes long exposures. Including overheads and any other delays, we should spend an average of 40 minutes per target. Assuming an 8h night, that would translate into 12 stars being observed per night. First off, for our new targets, our observing strategy consists of obtaining one spectra per star, to check for eclipsing binaries by looking for features in their CCFs, and active stars by measuring the $\log R_{HK}$ index (Noyes et al. 1984), allowing us to select quiet stars for radial-velocity studies. The majority of our sample are already known to be inactive and non-eclipsing binary systems through reconnaissance Coralie observations, and these will be monitored to confirm their planetary status and constrain their masses.

As part of our previous campaigns on FEROS, we have lost at least 1/3 of the nights due to a GRB alert, 5 full nights due to weather conditions and issues with the CCD affected the data of three nights. We also need to observe a radial-velocity standard star each night, in order to correct for effects in the resulting RVs which could not be corrected by our pipeline. Taking all of these disruptions into account, we estimate that we will observe from 9 to 10 targets per night. In order to reach full-phase coverage for our confirmed candidates (after checking new targets for eclipsing binaries or active stars), we would expect to observe each vetted candidate at least 4 times during the run, once per night (assuming an average orbital period of 4 days). All of these factors lead us to request a total of 6 nights to obtain full phase coverage for at least 10 of the well vetted targets that are included in the target list for this program.

The data will be processed using the FEROS pipeline developed by Brahm et al. (2017), which performs the spectrum extraction, correction for the barycentric and nightly drift velocities (when using the simultaneous calibration lamp mode), computation of radial-velocities by performing the cross-correlation function using a binary mask (available for G2, K5 and M2 spectral types), and measurement of activity indicators (bisector), allowing us to extract as much information as possible from each observation. We will also process the data independently using codes developed by our team for the computation of activity indices and stellar parameters, such that we can confirm all measured RVs. The pipeline also considers Moon contamination in the measurements of the radial-velocities, allowing us to observe our candidates even in bright nights. Our targets won't be in close proximity to the Moon, reducing even more any chances of Moon contamination affecting our results.

References:

Brahm, R. et al. 2017, PASP, 129, 973; Fortney, J. J. et al. 2007, ApJ, 659, 1661; Noyes, R. W. et al. 1984, ApJ, 279, 763; Soto, M. G. et al. 2015, MNRAS, 451, 3131