Time Allocation Committee for
MPG time at the ESO 2.2m-telescope
c/o MPI für Astronomie
Königstuhl 17
D-69117 Heidelberg / Germany

Application No.	
Observing period	P106
Received	

APPLICATION FOR OBSERVING TIME

from [X] MPIA [ ] MPG institute [ ] other

1. Telescope: 2.2-m [X] 0104.A-9007(A) **PL**

2.1 Applicant

Paula **Sarkis** — Name
Max-Planck-Institute for Astronomy — Institute
Königstuhl 17 — street
69117 Heidelberg — ZIP code - city
psarkis — ESO User Portal username
sarkis@mpia.de — e-mail

2.2 Collaborators

Kossakowski[1], Henning[1], Trifonov[1] — name(s)
[1]MPIA — institute(s)
Hobson[2], Schlecker[1], Espinoza[3], Brahm[2], Jordán[2] — name(s)
[2]PUC [3]STScI — institute(s)

2.3 Observers

P. Sarkis — name
M. Hobson — name

By specifying the names under item 2.3 it is obligatory to also send out these observers to La Silla, if required. Correspondence on the rating of this application will be sent to the applicant (P.I.) as quoted under 2.1 above.

3. Observing programme: Category: E

Title : **Warm gIaNts with tEss (WINE): RV confirmation**

Abstract : The discovery and characterization of transiting giant planets ($R_P > 4\,R_\oplus$) orbiting bright stars is key for tackling at least two major challenges, namely (i) which properties govern the internal structural composition of planets, and (ii) how giant planets can be found orbiting significantly inside the snowline. It is expected that the *TESS* mission, which is already in operation, will detect > 300 warm giant planets orbiting stars brighter than $V = 13$ mag. Warm giants are ideal for tackling the challenges described. In the context of a collaboration including researchers from Chile we propose to use FEROS, complemented by a suite of other instruments in Chile, to lead the discovery and detailed characterization of warm giant planets and other interesting systems whose transits are uncovered by *TESS*.

4. Instrument: [ ] WFI [X] FEROS [ ] GROND

5. Brightness range of objects to be observed: from 9 to 14 V-mag

6. Number of hours:

applied for			already awarded	still needed
157			466	314
no restriction	grey	dark		

7. Optimum date range for the observations: .... 01.10.2020 – 30.03.2021
Usable range in local sideral time LST: .... 8:00h – 4:00h

Astrophysical context

The number of transiting exoplanets has increased steadily, thanks to dedicated ground and space based (e.g. HATNet [1], *Kepler*) transit surveys. The successfully working TESS mission [2] is expected to find ≈4000 transiting planets around bright stars (V<13 mag) ([3]), thus doubling the number of known systems. Transiting exoplanets provide us with a unique opportunity to improve our knowledge on planetary formation, structure, and evolution. E.g. combining the radius derived from photometry with the mass derived from radial velocity (RV), allows us to constrain the planetary composition by comparing the parameters with those predicted by structure models (e.g. [4]).

Despite the large number of transiting exoplanets discovered so far, only 235 have masses and radii determined at the 20% precision level. Most of them are hot Jupiters (HJs, Figure 1), which have periods < 10 days. Their colder counterparts, warm Jupiters (WJs), defined as giant planets with periods 10 − 300 days, still remain poorly characterised since most of the known WJs orbit faint stars, which are challenging for RV follow-up. The existence of these close-in giant planets pose many challenges for planet formation models. It is believed that these formed beyond the iceline and migrated inwards either through *(i)* disk interactions ([5]), in which planets are kept on circular and aligned orbits or *(ii)* through interactions with a third body, resulting in eccentric and misaligned orbits. While the eccentricities and obliquities of HJs should have been strongly affected by tidal and/or magnetic interactions with the host star, for WJs these parameters contain reliable information about their formation and migration processes. Hence, a systematic detection of transiting WJs, along with a detailed characterization of their orbital parameters, is crucial. Simulations of the expected TESS yield ([3]) predict that TESS will discover more than 300 giant planets ($R_p > 4R_\oplus$) with P>10d orbiting bright stars (V<13) in the Southern hemisphere (see Figure 2). Such a statistically significant sample of warm giant planets will allow for the first time to constrain the long standing challenges about their formation, evolution, and structure.

Immediate aim

We propose to obtain precise RV measurements with FEROS of TESS candidates to perform for the first time a systematic characterization of the population of transiting WJs. Our plan includes a wide range of facilities but the scientific success of the project heavily relies on the FEROS time.

TESS's large pixel size makes it hard to identify the source producing the transits. Consequently, our team is using CHAT, a 0.7m telescope at LCO, to perform photometric follow-up observations to identify the star responsible for the transit signal. GAIA DR2 is used as well to exclude false-positive scenarios and to improve the stellar parameters of the host. In addition, our team has been granted 13 nights of NTT/Astralux Sur time to identify close companions to TESS targets through lucky imaging. In terms of spectroscopy follow-up, we have ∼ 90 guaranteed nights each year to observe with the FIDEOS spectrograph at the ESO 1.0 m telescope to perform RV monitoring of WJ candidates orbiting the brightest stars (V<10). We also submitted a 9n HARPS proposal to detect ≈ 20 WJs with K<30 m s^{-1}. In this proposal, we aim to use FEROS to detect ≈80 WJs with amplitudes K>30 m s^{-1} orbiting moderately bright stars 11<V<13, and ≈35 WJs with K<30 m s^{-1} orbiting stars with V<11. The full analysis of the systems (transits + RVs) will be MPIA-led using the `juliet` code, which was developed at MPIA ([6]) and focuses on disentangling stellar activity and planetary signals around active stars.

Previous work

Our team already confirmed several TESS gas giant exoplanets ([7], [8]) even pushing the limits of FEROS to detect an ultra-short period planet (HD 213885 b [9], see Figure 3). We also have three additional confirmed warm giant exoplanets in preparation (Rojas et al., in prep.; Espinoza et al., in prep) and several promising candidates that still need RV follow-up observations (Figure 4). Our team is a dedicated partner in the HATS project and has published 1/3 of HATS paper as first author papers ([10],[11], [12],[13], [14],&[15]) and participated in all other papers. We have also characterized several transiting exoplanets from the *K*2 mission ([16, 17, 26, 19]). Our team has the experience and the facilities needed to become a leading group on exoplanetary characterization in the TESS era.

Layout of observations

The spectra will be obtained in the Object-Calibration mode of FEROS, in order to trace the instrumental velocity drift through the night. The exposure times will be chosen taking into account the brightness of the stars to obtain a sufficient signal to noise ratio, necessary to achieve precise RV measurements. Typical exposure times for a $V \sim 12$ mag star is of ∼20 min. The reduction and analysis will be performed with the CERES pipeline ([20]) developed for the echelle spectrographs of La Silla (FEROS, CORALIE, and HARPS), enabling to reach RV precision down to 5 m s^{-1} (see section `8e`).

Strategic importance for MPIA

Building on the success of HATS, we established a new strategic collaboration for TESS follow-up observations, which will combine FEROS with other facilities. The search for WJs is an important goal for the PSF department with strong links to formation models, which will be investigated with our theory group.

8b. Figures and tables

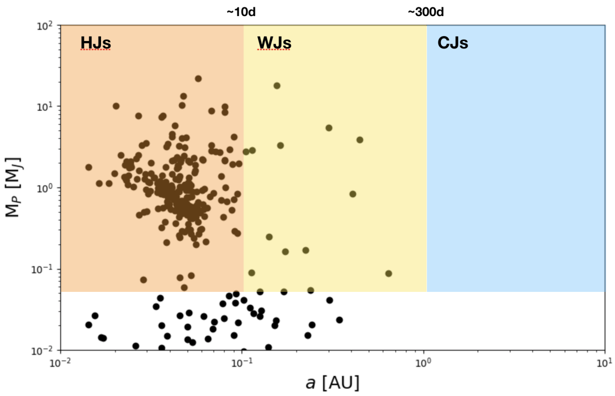

Figure 1: Current sample of transiting planets in the planet mass versus semi-major axis plane having masses and radii determined with a precision of 20% or better. The coloured regions represent the different insolation regimes (orange: hot Jupiters, yellow: warm Jupiters, blue: cold Jupiters). Warm Jupiters, which are key for constraining theories of formation and orbital evolution of giant planets have been sparsely detected.

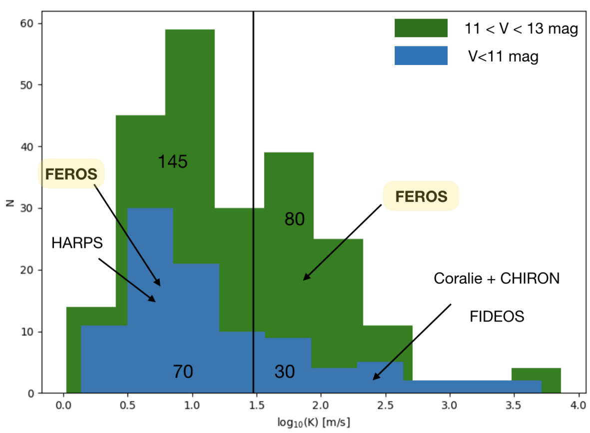

Figure 2: Predicted TESS yield of warm giant planets orbiting bright stars (P>10d, R_P >4 $R_\oplus$, V<13) according to [3]. The FEROS time of this proposal will be primarily used for characterizing the population of giant planets ($K > 30$ m s^{-1}) orbiting moderately bright stars (11<V mag<13), and super Neptune mass planets ($K < 30$ m s^{-1}) orbiting bright stars (V<11 mag).

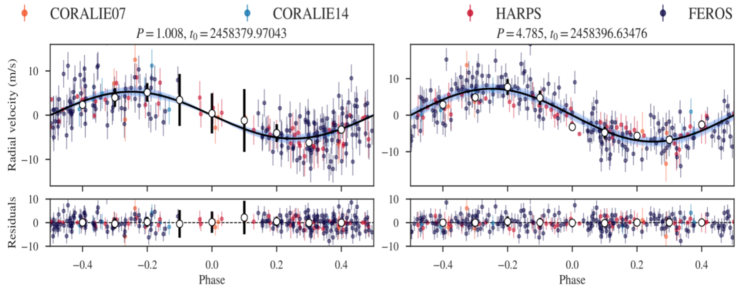

Figure 3: Phase folded radial velocities for the multi-planetary system HD213885 discovered by TESS and analysed using our in-house tool `Juliet`. Note the low-amplitude of the signals detected (5.3 ± 0.39 m s^{-1} and 7.26 ± 0.48 m s^{-1}) and the number of FEROS RV observations that were a key to characterize precisely this system.

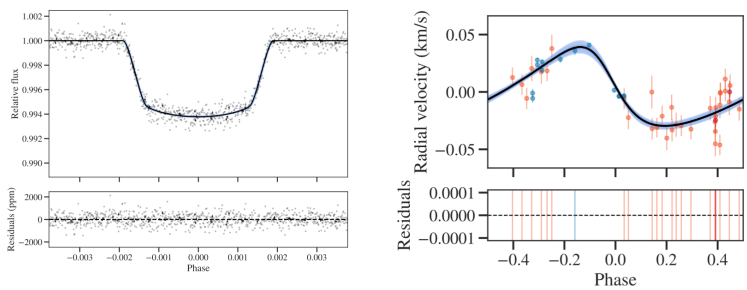

Figure 4: Phase folded TESS light-curve and RVs for TOI-201, a WJ with period = 52 days with a tentative amplitude of 20 m s^{-1} and an eccentricity of $e = 0.3 \pm 0.017$.

Over the past decade, there has been an explosion of information partially due to the ground-based radial velocity surveys and mainly due to the Kepler mission. The transit method is by far the most successful detection technique contributing to more than 3700 exoplanets. This large sample allows one to do statistical analysis which was not possible few years ago. One major discovery is that even though hot Jupiters are easy to detect, they are very rare ([21]). These close-in giant planets still present a challenge for theorists, as their radii is larger than what is predicted by the standard thermal evolution models ([22]). WJs, on the other hand, in general have equilibrium temperatures of T_{eq} <1000 K, and their structures are not significantly affected by proximity effects. The detection and characterization of transiting WJs is crucial to calibrate theoretical structural models which can then be used on HJs to understand which variables are responsible of inflating their radii.

This proposal is linked to the PhD thesis of Paula Sarkis. The goal of her thesis is to put observational and statistical constraints to explain why hot Jupiters are inflated. In this line, the confirmation and characterization of new warm Jupiters is key for calibrating the structural models in absence of the inflation mechanism. Paula is involved in discovering and characterising transiting exoplanets within the HatSouth survey, $K2$, and *TESS*. While she has directly participated in the discovery of several HJs in the past two years in the context of the HATSouth survey, transiting warm Jupiters are significantly harder to detect from the ground. Space-based telescopes on the other hand allow the continuous monitoring of thousands of stars significantly increasing the ability of discovering transiting signals with periods longer than 10d. For this reason the candidates that the TESS mission will provide will be fundamental for strengthening the scientific value of Paula's PhD thesis.

Data reduction and analysis

The spectra obtained with FEROS are extracted using the CERES pipeline expressly written for this instrument and optimised for the subsequent radial velocity measurements. A complete description of the pipeline can be found in ([20]). In brief, each spectrum is extracted and subsequently calibrated in wavelength using the ThAr spectra. The RV is then measured cross-correlating the observed spectrum with a binary mask chosen according to the spectral class of the target.

Additionally, the bisector of the CCF (i.e. the deformation of the line shape) can be determined as a supplemental parameter. This parameter is very important for identifying subtle blended eclipsing binary systems where dilution from a bright star results in light curves and RV curves that resemble those due to a transiting planet system. We also estimate the atmospheric stellar parameters including effective temperature $T_{\rm eff}$, surface gravity $\log g$, and metallicity [Fe/H].

The precision in RV obtainable with CERES is of the order of 5-10 m/s. FEROS is therefore a very competitive instrument for the measurements of the RVs of stars in the southern hemisphere.

Results highlight

Our team contributed with major exoplanet discoveries using both ground-based surveys (HATSouth) and space-based surveys ($K2$) and already characterized several TESS candidates. The characterized planets span a large region in parameter space, ranging from small planets down to $\sim 9\,\mathrm{M}_{\oplus}$ around an active M dwarf ([19]) to massive ones three times Jupiter's mass ([13]). HATS-59 [14] is the first multi-planetary system discovered by HATSouth, composed of a hot Jupiter and an outer massive companion, and only the 8$^{\rm th}$ system with a resolved orbit of the outer companion with a period of 1422 days. Worth mentioning is also HATS-17 b: the longest period transiting exoplanet discovered by a ground-based transit survey ([23]). We contributed with many well characterized hot Jupiters ([10, 11, 17, 15]). Our team also characterized 3 warm Saturn-like planets both on eccentric orbits and discovered part of the $K2$ mission ([26, 16]). Finally, HATS-6b and HATS-71b are two out of only four confirmed transiting hot Jupiters around M dwarfs ([24, 25]).

Future Plans

TESS is the most important mission for exoplanet search presently in orbit. The mission observed the Southern hemisphere for one year and is expected to discover more than 300 giant planets around bright stars ($V < 13$ mag) and hence suitable for RV follow-up observations with FEROS. We plan to systematically characterize the full population of transiting WJs that will be unveiled by TESS. **To accomplish this goal, our program requires a total of 780 hours of telescope time distributed into 5 semesters of which we were already awarded 309 hours for P103 and P104. We were awarded 157 hours for P105 but no observations have been carried out due to the current situation. For P106, we are applying for 157 hours.** For the next semesters, we still need 314 hours if no observations were carried out this semester to complete the RV monitoring of the remaining systems predicted from the TESS simulations (Fig 2, see also Section 10). A lot of these discoveries will be also suitable for atmospheric characterization with JWST and hence they will have a large impact.

FEROS is a strategically well placed instrument and is one of the few suitable instruments in the Southern hemisphere for follow-up observations. MPIA along with our colleagues at PUC in Chile have the experience and the facilities needed to excel in the exoplanetary field and to be a leading group in the TESS era.

9. Objects to be observed

(Objects to be observed with high priority should be marked in last column)

Designation	α (2000)	δ (2000)	magnitude in spectral range to be observed	priority
TIC52059926	$1^h\ 7^m\ 5.44^s$	$-68°\ 22'\ 05.17''$	13.72	1
TIC206541859	$1^h\ 12^m\ 11.64^s$	$-56°\ 55'\ 31.40''$	10.94	1
TIC237913194	$1^h\ 29^m\ 46.99^s$	$-60°\ 44'\ 23.68''$	12.14	1
TIC54002556	$1^h\ 34^m\ 05.15^s$	$-14°\ 25'\ 08.94''$	12.46	1
TIC394287035	$2^h\ 6^m\ 45.77^s$	$-81°\ 14'\ 50.55''$	12.33	1
TIC4672985	$2^h\ 33^m\ 52.96^s$	$-10°\ 39'\ 26.58''$	11.50	1
TIC257527578	$3^h\ 5^m\ 10.23^s$	$-21°\ 56'\ 01.13''$	11.23	1
TIC279070369	$3^h\ 19^m\ 32.78^s$	$-1°\ 14'\ 16.56''$	13.11	1
TIC358107516	$3^h\ 24^m\ 54.82^s$	$-73°\ 57'\ 27.17''$	13.00	1
TIC262843259	$3^h\ 30^m\ 07.49^s$	$-60°\ 52'\ 32.24''$	13.16	1
TIC399967279	$3^h\ 37^m\ 33.18^s$	$10°\ 3'\ 27.89''$	13.24	1
TIC237922465	$3^h\ 49^m\ 21.35^s$	$-60°\ 47'\ 13.87''$	13.02	1
TIC238197638	$3^h\ 49^m\ 57.37^s$	$-72°\ 47'\ 37.44''$	12.02	1
TIC332558858	$4^h\ 6^m\ 44.69^s$	$-16°\ 45'\ 20.72''$	13.25	1
TIC38760164	$4^h\ 28^m\ 33.66^s$	$-63°\ 40'\ 09.34''$	13.39	1
TIC450075744	$4^h\ 46^m\ 01.22^s$	$6°\ 13'\ 34.04''$	11.96	1
TIC55525572	$4^h\ 50^m\ 46.56^s$	$-60°\ 54'\ 19.66''$	10.36	1
TIC259592689	$4^h\ 51^m\ 54.46^s$	$-53°\ 49'\ 50.10''$	10.84	1
TIC77437543	$4^h\ 52^m\ 29.88^s$	$-36°\ 15'\ 25.55''$	12.18	1
TIC55652896	$4^h\ 55^m\ 55.26^s$	$-63°\ 15'\ 36.23''$	12.32	1
TIC399868187	$4^h\ 57^m\ 29.99^s$	$10°\ 25'\ 00.25''$	11.08	1
TIC13072758	$5^h\ 4^m\ 21.22^s$	$-29°\ 2'\ 03.05''$	12.70	1
TIC13093071	$5^h\ 4^m\ 46.19^s$	$-26°\ 51'\ 32.96''$	12.32	1
TIC13344668	$5^h\ 14^m\ 52.75^s$	$-29°\ 43'\ 46.78''$	13.70	1
TIC309792357	$5^h\ 20^m\ 25.31^s$	$-59°\ 53'\ 44.38''$	10.70	1
TIC179582003	$5^h\ 21^m\ 48.33^s$	$-69°\ 59'\ 17.58''$	10.81	1
TIC24358417	$5^h\ 25^m\ 22.70^s$	$-34°\ 40'\ 05.70''$	12.48	1
TIC382200986	$5^h\ 27^m\ 16.48^s$	$-54°\ 56'\ 45.96''$	12.69	1
TIC66561343	$5^h\ 46^m\ 57.17^s$	$-11°\ 14'\ 07.23''$	11.43	1
TIC149601126	$5^h\ 47^m\ 24.23^s$	$-60°\ 31'\ 16.71''$	14.22	1
TIC149601557	$5^h\ 49^m\ 07.82^s$	$-60°\ 29'\ 54.41''$	10.51	1
TIC350618622	$5^h\ 49^m\ 36.41^s$	$-54°\ 54'\ 38.64''$	9.07	1
TIC363914762	$5^h\ 56^m\ 56.56^s$	$-49°\ 0'\ 25.02''$	11.19	1
TIC318013179	$5^h\ 59^m\ 41.14^s$	$-16°\ 43'\ 29.96''$	13.00	1
TIC37117064	$6^h\ 1^m\ 57.19^s$	$-29°\ 8'\ 11.12''$	11.95	1
TIC20299658	$6^h\ 3^m\ 51.34^s$	$-39°\ 32'\ 47.21''$	13.18	1
TIC71794859	$6^h\ 5^m\ 00.93^s$	$-6°\ 47'\ 31.96''$	12.49	1
TIC219181903	$6^h\ 7^m\ 25.64^s$	$-51°\ 53'\ 48.67''$	12.92	1
TIC260640693	$6^h\ 31^m\ 16.92^s$	$-58°\ 19'\ 13.58''$	13.33	1
TIC176956893	$6^h\ 43^m\ 19.95^s$	$-66°\ 56'\ 51.56''$	12.25	1
TIC123846039	$6^h\ 53^m\ 28.58^s$	$-6°\ 30'\ 28.17''$	9.96	1
TIC177162886	$6^h\ 57^m\ 58.19^s$	$-71°\ 31'\ 23.19''$	12.25	1
TIC157698565	$7^h\ 9^m\ 57.16^s$	$-37°\ 13'\ 51.42''$	11.41	1
TIC278138619	$7^h\ 11^m\ 16.70^s$	$-78°\ 14'\ 18.47''$	13.78	1
TIC349972412	$7^h\ 37^m\ 52.15^s$	$-62°\ 4'\ 41.80''$	13.36	1
TIC364395234	$7^h\ 46^m\ 00.34^s$	$-61°\ 52'\ 47.27''$	12.68	1
[a]				

[a] TESS alerts of each Sector are out as soon as the observations of each Sector is over. Hence the list of candidates could evolve when future data from upcoming sectors are released.

10. `Justification of the amount of observing time requested:`

Using the predicted yield of TESS ([3]), we estimate that TESS will detect ~ 300 WJs ($R_p > 4R_\oplus$ and $P > 10$ days) around bright and moderately bright stars ($V < 13$ mag). FEROS will be systematically used to characterize all (≈80) moderately bright systems (11<V<13) presenting RV semi-amplitudes of K>30 m s^{-1} (type I candidates), and also a fraction (≈50%) of the lower mass systems (K<30 m s^{-1}) orbiting bright (V<11) stars (type II candidates). In order to constrain the orbital parameters and measure the planetary mass with a precision around 20%, we anticipate we need around 20 spectra at different orbital phases. We assume that there will be also an equal number of false positives among our candidates that can be discarded after 4 RV observations.
For type I candidates, with a mean exposure time of 1200s, we require 640 hours to fully characterize these systems. **As for type II candidates**, with an execution time of 600s, we need 140 hours.
Thus, to succeed in systematically characterizing warm giant planets detected with TESS, we need around **780 hours** of telescope time, distributed into 4 semesters.
For this semester, we are applying for 157 hours.
We reduce and analyse the data immediately every night. This allows us to quickly discard false-positives and hence focus on promising targets and use the allocated time more efficiently.

11. `Constraints for scheduling observations for this application:`

Since our candidates have a wide spread in RA and DEC, the schedule can be very flexible, and as we have many candidates to observe at any time, we can avoid to collect redundant data. **We however prefer if our observations can be scheduled evenly throughout the semester as much as possible.** In the previous semester, we successfully managed to share time with Olga Zakhozhay. This allowed us to have approximately 2 months of continuous observations. This is especially important for the planets where only one transit was observed. However, we understand that this might not be feasible and we plan to continue sharing time with Olga Zakhozhay.

12. `Observational experience of observer(s) named under 2.3:`
`(at least one observer must have sufficient experience)`

Paula Sarkis has good observing experience with the 2.2m MPG telescope in la Silla. Diana Kossakowski has also good experience observing with FEROS and HARPS.

13. `Observing runs at the ESO 2.2m-telscope (preferably during the last 3 years)`
`and publications resulting from these`

Telescope	instrument	date	hours	success rate	publications
2.2m	FEROS	Oct 15 - Mar 16	143 hrs	83%	[12] [13],[14]
2.2m	FEROS	Apr 16 - Sep 16	163 hrs	85%	[10], [15], [11]
2.2m	FEROS	Oct 16 - Mar 17	162 hrs	85%	[10], [15], [11]
2.2m	FEROS	Apr 17 - Sep 17	181 hrs	100%	[10], [15]
2.2m	FEROS	Oct 17 - Mar 18	124 hrs	100%	[10], [15]
2.2m	FEROS	Apr 18 - Sep 18	165 hrs	100%	[8], [9]
2.2m	FEROS	Oct 18 - Mar 19	160 hrs	100%	[7], [9]
2.2m	FEROS	Apr 19 - Sep 19	149 hrs	100%	[26], [27] and many in prep.

14. References for items 8 and 13:

[1] Bakos *et al.* (2004), PASP, 116, 266

[2] Ricker *et al.* (2014), SPIE, 9143, 914320

[3] Barclay *et al.* (2018), arXiv:1804.05050

[4] Thorngren *et al.* (2016), ApJ, 831, 64

[5] Lin *et al.*(1996), Nat, 380, 606

[6] Espinoza *et al.* (2018b), arXiv:1812.08549

[7] Kossakowski *et al.* (2019), submitted

[8] Brahm *et al.* (2018c), arXiv:1811.02156

[9] Espinoza *et al.* (2019), arXiv:1903.07694

[10] Henning *et al.* (2018), AJ, 155, 79

[11] Espinoza *et al.* (2016), AJ, 152, 108

[12] Mancini *et al.* (2015), A&A, 580, 63

[13] Ciceri *et al.* (2016), PASP, 128, 074401

[14] Sarkis *et al.* (2018b), AJ, 156, 216

[15] Espinoza *et al.* (2018a), arXiv:1812.07668

[16] Brahm *et al.* (2018b), MNRAS, 477, 2572

[17] Espinoza *et al.* (2017), MNRAS, 471, 4374

[18] Jordan *et al.* (2019), AJ, 157, 100

[19] Sarkis *et al.* (2018a), AJ, 155, 257

[20] Brahm *et al.* (2017), PASP, 129, 034002

[21] Howard *et al.* (2012), ApJS, 201, 15

[22] Guillot & Showman (2002), A&A, 385, 156

[23] Brahm *et al.* (2016), AJ, 151, 89

[24] Hartman *et al.* (2015), AJ, 149, 166

[25] Bakos *et al.* (2018), submitted

[26] Jordan *et al.* (2019), submitted

[27] Schlecker *et al.* (2020), in prep

Tolerance limits for planned observations:

maximum seeing:	2.5″	**minimum transparency:**	60%	**maximum airmass:**	1.9
photometric conditions:	no	**moon: max. phase / ∠ :**	1/30°	**min. / max. lag:**	0/0 nights