Target proposal for timing validation of TESS

September 18, 2017

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Abstract

Using TESS for asteroseismology introduces strong timing requirements. As described in RS-TASC-04[1], the absolute time for TESS observations must be known to an accuracy better than 0.5 seconds. Although the internal TESS clock is very accurate in its own time, it might have a constant drift and will thus need calibration. The calibration and consequent timing precision can be obtained by means of simultaneous observations of eclipsing binaries and RR Lyrae stars from Earth and TESS. Here we deliver the target list of suitable eclipsing binaries and RR Lyr stars suitable for verification of the time on TESS.

Cadence

This target list is preferentially thought for the 20 second sampling, but we are proposing the targets for both the 20s and 120s cadence. Simulations of the eclipsing binary time calibration procedure show that only few observations of suitable stars and eclipses are needed to achieve the 0.5 sec timing requirement when this cadence is used. Specifically, for a magnitude 9 binary with a flux drop of 50%, three observations are required. On the contrary, when the 120 second cadence is used, the number of eclipse observations required for the same setup can go up to 50. This would be extremely challenging to achieve from the ground, due to the Earth's rotation and the diminishing of observable eclipses due to poor weather conditions. Finally, it is worth to mention that the simulations in this work have been carried out using Gaussian white noise rather than correlated noise, which is more frequent in ground-based observations [Pont et al., 2006].
Therefore, the amount of eclipses to be observed to reach the timing accuracy is, in both cases, only our best-case scenario.

People

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Science Case

In order to compare stellar oscillations measured with TESS with ground based observations, the absolute time of a given photometric data point must be well defined and establish a stable reference.

[1] https://tasoc.dk/docs/SAC_TESS_0002_5.pdf

In order to fulfill these requirements, the absolute time (e.g., BJD) for coherent pulsation modes must be found with an accuracy better than 0.5 s [Kjeldsen et al., 2013].
To do so, the absolute time calibration will be based on simultaneous observations of eclipsing binaries and RR Lyrae stars from both TESS and ground-based telescopes. An initial investigation based on simulating realistic light curves with different stellar parameters for both TESS and a ground based telescope (Stellar Observations Network Group, SONG) demonstrated the proposed method as a both feasible and solid calibration method [Dideriksen, 2016]. The time stamp for each data point from the Earth-bound telescope was shown to have an uncertainty on the scale of milliseconds. The simultaneous observations are cross-correlated, and having a millisecond precision on the ground based-observations, the absolute time for TESS can be found within 0.5 s using a handful observations of complete eclipses, depending on especially the depth and magnitude of the eclipse. As an illustrative example, in Figure 1 we show the uncertainties of the cross-correlation for the simulated light curves as a function of the magnitude of the eclipsing binaries. This is done for several depths for the eclipses. Further tests using light curves of eclipsing binaries from Kepler showed the feasibility and sturdiness of the calibration method.

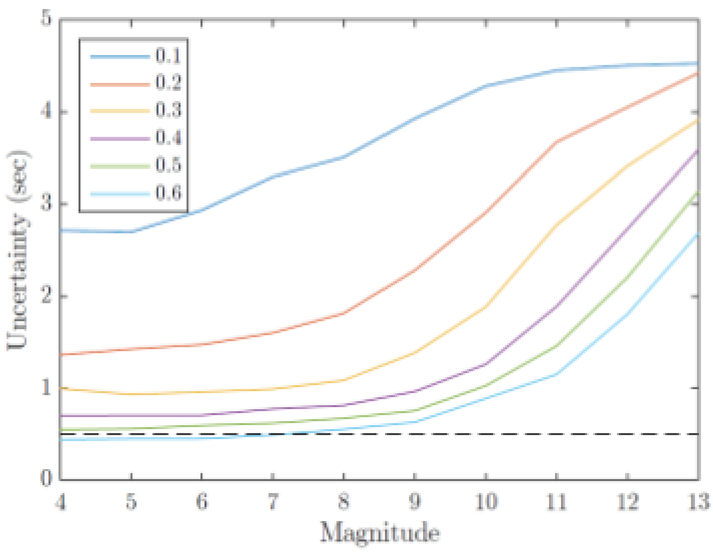

Figure 3: Results from simulations of attainable accuracy in timing versus TESS magnitude for 20 sec cadence. The legend indicates the relative depth of the eclipses used. The dashed horizontal line indicated the target accuracy of 0.5 sec.

This time calibration can be executed continuously during the full extent of the TESS two-year mission, providing a method to minimize future time corrections which proved to be an issue for the Kepler mission. It is worth mentioning that the correlated noise present in all ground-based data, will play a major role in our nal timing accuracy. Therefore, we provide a long list of eclipsing binaries that will be observed as often as possible, until the predicted timing accuracy is reached.

Length of the time series

In order to perform periodic time calibrations for TESS, the targets should be distributed evenly over the entire sky. This will increase the possibilities for observable eclipses from the

Earth. Since the calibration method is using cross-correlation of simultaneously observed eclipses, the usable time series from TESS are limited by the duration of the night on Earth. A further limitation is the length of the eclipse, which should be shorter than the duration of the night, in order to observe a full eclipse. To maximize the occurrence of simultaneous observations from the ground-based telescopes and TESS, we will require continuous observations of TESS over the targets proposed here, at least around the predicted eclipses plus two hours of off-eclipse data, to ensure a proper removal of extrinsic and intrinsic variability. The normalization of eclipse data is fundamental to properly determine the mid-eclipse time. Therefore, eclipses will be observed fully. Eclipsing binaries in the CVZ will be of the highest priority. Considering the Earth's diurnal rotation, the Earth's atmosphere, the weather conditions and the impact of correlated noise in photometric data, targets that can be constantly monitored from both space and ground will help us reach the timing requirements.

Quality of TESS data

The most limiting factor for this proposal is the signal-to-noise ratio for the ground based telescopes, which can be seen in Figure 2. In order to get a proper time series from ground-based observations, the eclipsing binaries observed must be fully resolved and have usable comparison stars nearby to perform differential photometry. All the targets proposed here have been checked for suitable reference stars, proper eclipse duration and eclipse depth.

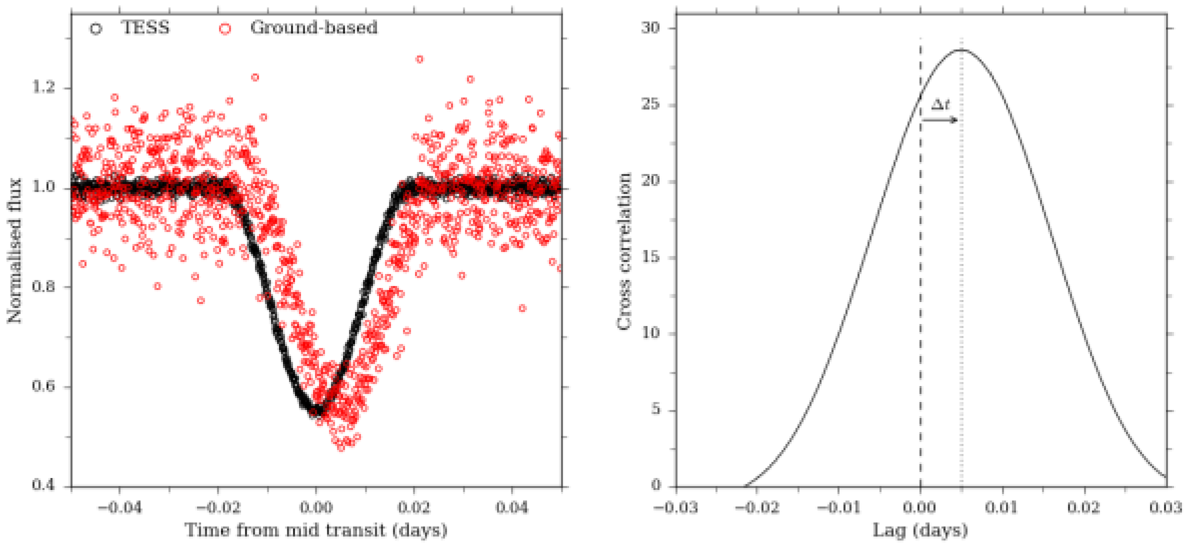

Figure 2: Simple illustration of the concept behind a potential time offset between TESS and a ground-based (GB) station. Left: simulated eclipse light curves with added noise (shot noise for TESS; shot noise + correlated noise for GB). Right: Cross-correlation between the light curves, peaking at a lag of ~0.005 days, corresponding to the input offset between the eclipse times of the light curves.

Priorities of the targets

The current target list of EB and RR Lyr stars proposed for the timing validation can be found in Table 1. All of them were selected with respect to the eclipse duration, the eclipse depth, the visual apparent magnitude and the position in the sky.

We have given targets *not* in the CVZs highest priority to make sure they will be observed whenever it is possible. The northern and southern hemisphere has simply been put after one another as targets on one hemisphere would never interfere with targets on the other hemisphere.

Ground-based observations in relation to this proposal

Simultaneous ground-based observations is a fundamental part of this project, and we have therefore set up a network of currently six telescopes in Argentina, Lithuania, Tenerife and China. These will be used to regularly perform simultaneous photometric observations of the same targets.

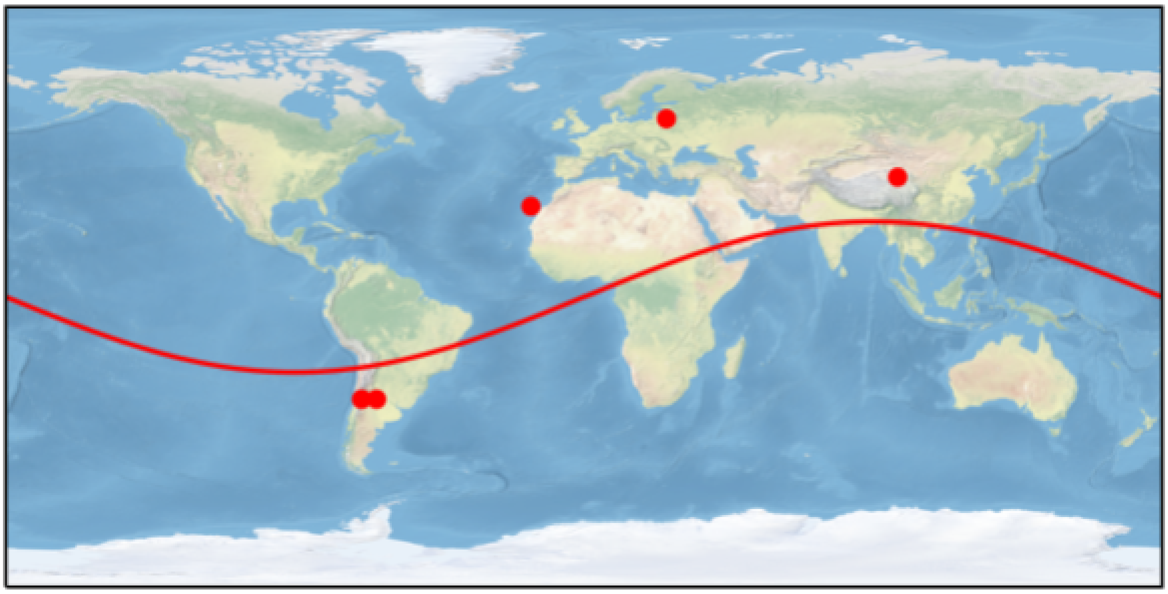

Figure 3: World map showing the locations of ground-based observatories participating in the time verification of TESS. The full red line indicates the trace of the ecliptic equator - observatories on the southern part will be the most useful for TESS time verification during the first year of operation, where the southern ecliptic hemisphere is being observed.

References

[Dideriksen, 2016] Dideriksen, A. K. (2016). A Time Calibration Method for TESS using Eclipsing Binaries. Bachelor thesis.

[Kjeldsen et al., 2013] Kjeldsen, H., Christensen-Dalsgaard, J., and Chaplin, W. J. (2013). Requirement Specifications for TESS: Timing requirements for Asteroseismology. SAC/TESS/0002(5).

[Pont et al., 2006] Pont, F., Zucker, S., and Queloz, D. (2006). The effect of red noise on planetary transit detection. MNRAS, 373:231-242.

Target Lists

Southern Ecliptic Hemisphere

Name	TIC	RA (J2000.0)	DEC (J2000.0)	Tmag	Type	Period (d)
Not in CVZ						
GH Eri	129888462	03 44 13.0345	-41 16 46.855	8.496	EB	0.7223894
KELT S37l016726	64437380	235.69754	-57.50992	9.855	EB	
KELT S34l003519	356520906	134.37860	-62.89841	8.414	EB	
KELT S37lc011371	41561453	228.13962	-55.31390	9.642	EB	
KELT S37lc008662	209113931	209.78667	-57.65257	9.604	EB	
KELT S37lc010251	314406170	202.68196	-63.80058	9.543	EB	
KELT S36lc01679	291329564	260.94639	-55.06226	10.031	EB	
KELT S36lc004189	73945470	263.70478	-57.14803	8.616	EB	
KELT S20lc002055	220420532	71.98984	-56.00782	9.585	EB	
KELT S29lc001123	237332597	346.82919	-60.87695	8.181	EB	
KELT S27lc010353	387107961	283.90880	-62.48110	9.879	EB	
KELT S29lc002627	220388567	337.30155	-56.87014	9.183	EB	
In CVZ						
AV Dor	149473467	05 41 04.92	-61 51 28.2	9.317	EB	1.09487
WZ Pic	350443417	05 41 13.11	-57 26 28.2	9.015	EB	1.21672
VW Ret	38699825	04 25 35.41	-60 45 24.9	8.616	EB	2.08470
AO Pic	260161144	06 11 08.50	-58 17 15.7	8.953	EB	2.23415
AT Men	30034081	04 52 06.94	-70 43 52.5	10.54	EB	2.3446345

RX Pic	150443185	06 31 28.29	-63 32 07.4	10.046	EB	2.593666
UNSW-V 738	306773020	08 04 04.20	-67 38 40.0	11.287		2.75424
AR Dor	55404385	05 12 03.06	-65 10 32.6	6.661	EB	2.952057
AH Vol	349059354	07 10 01.10	-64 37 07.6	10.928	EB	3.32932
HD 54011	279569707	07 03 52.33	-57 37 44.9	8.967	EB	3.97948
ASAS J071006-6932.3	300034498	07 10 06.16	-69 32 16.3	11.159	EB	1.7829
ST Pic	150166721	06 14 01.1688	-61 28 23.527	9.001	RR Lyr	0.486
RX Eri	114923989	04 49 44.2915	-15 44 28.243	9.365	RR Lyr	0.5872453
UV Oct	291451813	16 32 25.5326	-83 54 10.500	9.136	RR Lyr	0.54258

Northern Ecliptic Hemisphere

Name	TIC	RA (J2000.0)	DEC (J2000.0)	Tmag	Type	Period (d)
			Not in CVZ			
KELT N24lc003424	422106434	335.71883	55.61341	9.314	EB	
KELT N16lc002022	452997239	9.07974	56.56633	8.831	EB	
KELT N23lc003833	233291862	300.42185	58.09557	8.854	EB	
KELT N24lc026075	233793497	303.05561	59.12413	9.203	EB	
KELT N23lc019127	233576880	282.50116	64.50920	9.668	EB	
KELT N24lc018647	337105054	335.50370	60.33599	9.190	EB	
KELT N24lc031289	337094559	335.63678	63.58701	9.292	EB	
KELT N21lc002677	316450573	221.75949	63.72769	9.237	EB	

KELT N20lc017223	302668828	163.25624	57.70361	8.648	EB	
KELT N23lc009822	267751030	293.14413	54.55095	8.889	EB	
KELT N23lc002569	259126645	291.47877	68.93857	9.091	EB	
KELT N23lc022777	377192658	285.91573	57.45726	9.080	EB	
KELT N21lc002780	157332634	182.02824	63.76927	9.272	EB	
KELT N24lc008331	277423903	310.77762	55.74019	9.479	EB	
KELT N23lc040230	230376136	285.00936	62.74786	8.575	EB	
KELT N24lc092699	322262620	325.34213	69.69541	7.785	EB	
In CVZ						
HZ Dra	258351350	19 46 02.54	+69 55 09.0	7.906	EB	0.772943
GSC 03885-00583	199688409	16 52 12.36	+57 43 31.7	11.994	EB	0.86829
GSC 03898-00272	199716496	16 57 33.88	+59 31 51.9	10.531	EB	1.04577
NSVS 1197350	229742425	18 38 52.91	+70 13 53.7	10.347	EB	1.265344
NSVS 1102319	229585356	18 05 31.16	+72 04 27.4	8.983	EB	1.419580
NSVS 2855392	462616850	16 44 09.47	+65 20 50.2	11.469	EB	1.63928628
NSVS 1252240	237199163	19 30 05.23	+76 19 43.6	10.777	EB	1.64483822
NSVS 3045474	232646886	18 46 35.41	+59 41 08.1	11.937	EB	1.85843000
GZ Dra	356896561	18 12 40.95	+54 46 06.8	9.151	EB	2.253355
NSVS 1091964	441793160	17 31 56.58	+73 34 09.7	10.922	EB	2.56292000
NSVS 1224090	280071515	19 52 04.89	+71 22 54.4	11.21	EB	2.90299954

NP Dra	329248002	17 35 16.29	+55 00 12.2	8.733	EB	3.10886
NSVS 2934997	353894978	18 06 44.66	+56 24 24.7	10.301	EB	3.34181534
NSVS 3021899	229910234	19 09 36.99	+61 03 52.0	9.889	EB	3.78370568
NSVS 2844818	230068527	16 11 10.99	+68 01 39.1	10.336	EB	3.93208514
XZ Dra	229913521	19 09 42.6073	+64 51 32.138	9.856	RR Lyr	0.476497
XZ Cyg	267808239	19 32 29.306	+56 23 17.50	9.623	RR Lyr	0.4666
RS Boo	409373422	14 33 33.2133	+31 45 16.614	10.299	RR Lyr	0.37733896