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# 3 Proposal information

- Title: Transit Monitoring from the South (TraMoS) project
- abstract: We propose to extend our Transit Monitoring from the South campaign in the post-TESS context to both mon itor variability in the transit lightcurve of exoplanets as well as to obtain refined planetary system parameters. The large amount of observable systems will guarantee that any observing block scheduled will provide a large number of observable systems with meter-class telescopes. ?e candidates to observe will be ranked to maximize the scientific return.
- telescope: Speculoos
- time requested: 50 nights (minimum 19)
- requirements: None

# 4 The Project

Photometric monitoring of transiting events yield copious amounts of information about the planet and planetary system: planetary radius, orbit's inclination, precise planetary mass, among others. Even more, analysis of the transit events at several epochs will permit detection of variability in the transit's parameters (TPV). Variation that will imply time-dependent changes in the orbital parameters of the transiting planet caused by a non-keplerian motion. Measuring deviations in the timing of the central transit (TTV) is currently the most sought- after TPV, they can either be small but continuously changing variations, or have large amplitude variations in short period of time. TTVs can be attributed to, among others, the presence of otherwise undetectable Earth-like planets in the system, exomoons, non-spherical stars, secular orbital changes, relativistic effects, or tidal orbital decay (e.g. Jontof-Hutter et al. 2016, Hoyer et al. 2016a,b, Agol et al. 2005, Kipping 2009a, 2009b, Heyl & Gladman 2007, Adams & Laughlin 2006, Sasselov, 2003). Some of the effects will be detectable in timescales of 10-20 years; while in some other systems with orbital resonance TTV can be detected after a few transits. Through the monitoring of a transiting planet, we are thus studying the planetary system, its multiplicity, its formation history, and more.

The Kepler mission with its high duty-cycle monitoring produced the first two observational breakthroughs with the announcement of Kepler-9 and Kepler-11 systems (Holman et al 2010, Lissauer et al 2011). For the latter, they even heavily constrained the mass of the six planets in the system solely by measurements of their TTV: no longer were radial velocity measurements a must for the procuration of dynamical mass. In fact, the TTV technique was the most used approach to confirm exoplanets among the Kepler's candidates in multiple systems. Examples of "TTVs" exoplanetary systems are: Kepler-19 (Ballard et al. 2011), Kepler-23,-24 (Ford et al. 2012), Kepler-25,-26,-27,-28 (Steffen et al. 2012), Kepler-29,-30,-31,-32 (Fabrycky et al. 2012), Kepler-48, -60 (Steffen et al. 2013), Kepler-47 (Hinse et al 2015), Kepler-11 (Weiss et al. 2015), Kepler-539 (Mancini et al. 2016), the discovery of a non-transiting planet Kepler-82f based on TTVs (Freudenthal et al. 2019), and the still record-holder Kepler-90 (Cabrera et. 2014) with a planet with a TTV of 25hrs. Beyond the large amount of TTV planets in the Kepler mission yield exciting TTV results have been reported: for example, the discovery of two planet companions to the Hot Jupiter WASP-57b via TTVs (Becker et al. 2015), the interacting giants around WASP-148, where only one of them transits while exhibiting TTVs (Hébrard et al. 2020), and the confirmation of the TTV technique as a great tool for measuring eccentricities (Hadden et al. 2017).

The recent TESS mission has also lived up to expectations providing several interesting new transiting systems among stars much brighter than Kepler's. Most notably so far published are perhaps the 2:1 resonant duo around TOI-216 (Kipping et al. 2019, Dawson et al. 2021) and the multi-transiting system TOI-178 (Leleu et al. 2021). The latter is a 6-planet system of which 5 are locked in a chain of Laplace resonances requiring nonetheless a puzzling formation process to account for their non-monotonous density variation across orbital distances. Despite the interesting results so far, and the fact that their southern-hemisphere observations are soon to finish, the true cornucopia of scientific discoveries empowered by this mission might be on the follow-up observations as most of the expected TTV planets (Warm or Cold Earth-to-Jupiters) are expected to be observed only once (Hadden et al. 2019). Also, our long-running campaign is perfectly suited to complement TESS with several systems observed before its launch that are currently being analyzed together with the new data releases of the satellite (Ortiz et al. 2021, in prep)

Transits of Hot Jupiters (large planets orbiting its host star with periods of a few days) are easier to monitor from ground based telescopes due to its relative large transit depths. However they mostly do not show clear evidences of TTVs (e.g. Cortes-Zulueta et al. 2020, Hoyer et al. 2016a,b, 2013, 2012, 2011, Adams et al. 2010a, Nascimbeni et al. 2013). These non-detections can be attributed to an observing bias (García-Melendo & López-Morales 2011) or also due to formation process of Hot Jupiters (Rasio & Ford 1996). Kepler mission's results have shown that the exoplanets in multiple systems have smaller radii and Steffen et al. (2016) showed that TTV technique is most sensitive to detect planets with smaller masses when compared with the Radial Velocity technique. Nevertheless, hints of TTVs detections on Hot Jupiters have been reported: the case of WASP-3b, which has been subject of intense monitoring after a detection of TTVs with ampli- tudes of up 3 min (Maciejewski et al. 2010), with no clear resolution so far (Montalto et al. 2012, Nascimbeni et al. 2013); hints of TTV in the systems TrES-3b, and Qatar-1b (Jiang et al. 2013, von Essen et al. 2013).

Orbital decay of close-in exoplanets can also probe the structure of their host stars (e.g. Penev et al. 2012, Birkby et al. 2014). By measuring the orbital decay it is possible to determine the tidal effciency factor, $Q_*$. Two preliminary detections of orbital period decays of $-60 \pm 15$ ms/yr of OGLE-TR-113b (Adams et al. 2010b) and $(-1.7 \pm 0.3) \times 10^{-8}$ days of WASP-43b (Blecic et al. 2014). Via transit monitoring, we have discarded the orbital decay of these two objects and constrained $Q_*$ to values larger than $10^5$ (Hoyer et al. 2016a,b).

## 4.1 Scientific Aim

We aim to continue and expand the sample monitored since 2008 building on the large expertise gained by the group, and increase the number of publications now that a human-resource hiatus for the project has been solved. We will continue the monitoring to search for TPV among all known and newly discovered transiting planets south of $\delta < +10^{\circ}$ and magnitudes $V < 13$. Note that TESS will stop its Southern Hemisphere campaign in July 2021, so this proposal perfectly fits the post-TESS era. This semester, we propose to make use of meter-class telescopes to observe more transits of the exoplanets that will be studied and analyzed for our group in the next publications. Our transit follow-up will allow us to perform, in addition of the timing analysis, a reffinement of the transit and physical parameters of the systems using BATSignal, our new computational tool for constrain those parameters [1]. This new computational tool is based on Monte Carlo Markov Chain and Gaussian Processes regression in order to get constrained parameters from a bayesian point of view.

## 4.2 The sample and strategy

All transit events are time critical, exactly which object will be observed will depend on which night it is assigned. However, the large availability of transiting systems ($> 500$) makes the precise choice of nights less of a concern as it is guaranteed that there will be targets observable any single night.

We are currently incorporating TESS predictions into our tools to apply different ranking criteria for the best candidates to observe on a given night (baseline, airmass, TTV probability, publications, etc.) and we expect to have it fully functional and updated with the latest discoveries by the time the currently requested observing blocks start. For instance, two transits of the exciting TOI-178 system will be ideally observed just during the first half of the October chilean observing block for the Danish telescope (times of central transit: 2021-10-18T06:03:36, 2021-10-21T01:39:00), or in several of the Chilean nights with Speculoos (20210-10-08T06:49:32, 2021-09-04T02:49:38, 2021-11-04T01:05:28, 2021-09-11T05:18:34, 2021-09-21T04:23:40, 2021-10-01T03:28:47, 2021-11-22T03:04:13, 2021-10-18T06:03:36, 2021-11-13T03:50:32, 2021-09-21T05:47:30, 2021-11-06T04:34:38, 2021-12-01T01:55:09)

[1] https://github.com/gmansir/BatSIGNAL

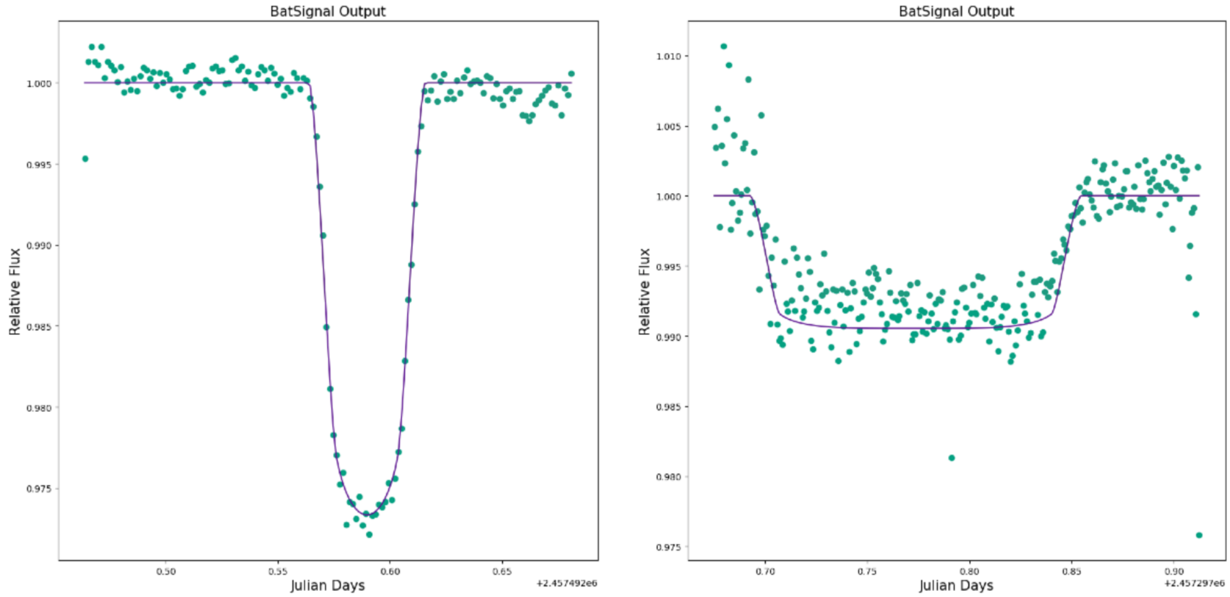


Figure 1: Sample light curves obtained during in the last semesters, for two targets under different weather conditions with the Danish telescope. The solid lines show our best model fitted using BATSignal.

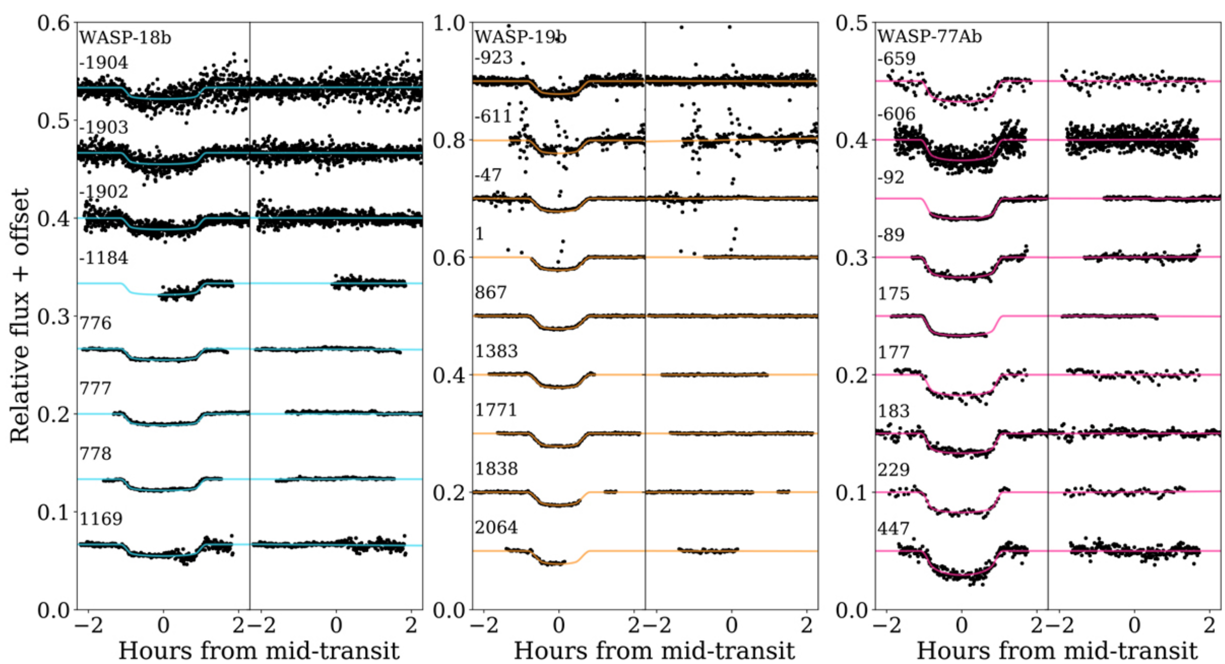


Figure 2: Fig. 1 from Cortés-Zulueta et al. 2020. Light curves of WASP-18A, WASP19 and, WASP77A during eight, nine, and nine different transits, respectively with best-fit models from EXOFASTv2

## CURRENT STATUS OF THE PROJECT

Thanks to the successful previous awarded time for observations with meter-class telescopes, five papers have been published for the TraMoS project (Cortés-Zulueta et al 2020, A&A 636, 17; Hoyer et al 2011, ApJ. 733, 53; Hoyer et al 2012, ApJ, 748, 22; Hoyer et al. 2013, MNRAS. 434, 46; Hoyer et al. 2016. MNRAS. 455, 1334).

Two new students (Yu-kary Ortiz, undergrad, and Alejandra Meza, MSC) have joined the project and will help with the observations. Furthermore, we are finishing the analysis of TraMoS planets observed with TESS and we are preparing a publication to extend the satellite observing baseline by several years (Ortiz et al 2021, in prep).

As part of the thesis of MSc student, Pía Cortes-Zulueta (currently following her PhD in Marseille) a fully automatized pipeline was developed to analyze each transit from the raw data of multiple telescopes, going though the differential photometric analysis, to the constrained parameters of the system using BATSignal.

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# 5 Requested telescopes

From the beginning of this project in 2008 to today, the group has developed a remarkable experience using one-meter class telescopes. This experience had been passing trough the generations of the undergraduate and graduate astronomers involved. For years we have been using a wide range of telescopes and instruments such as: Danish, Warsaw, SARA and SMARTS 0.9m and 1.3m, among others. A python automated pipeline is fully functional to reduce the data (Cortes-Zulueta et al. 2020). This pipeline is currently working for data from Danish, SMARTS 0.9m, 1m, and 1.3m, SOAR, REM, and Warsaw. However, it is easily extensible in order to work with data from other sources.

For the current Fast-Track call, we ask for time in the following telescopes: Speculoos. Based on previous observations, we will be able to perform relative photometry down to $\sim$ 1 (e.g. Fig. 1). Together with careful selection of reference stars, we will be able to obtain $\sim$ 2 minute precision per epoch in the timing of the transit's center. To avoid being dominated by reading overheads, we will defocus to secure spending at least more time on targets than on overheads.

# 6 Requested time

Depending on the target, the total time needed for one transit observation varies from 4 to 7 hours, which includes the necessary data before and after transit. However, we can guarantee that we are able to use all the observing hours of each night, inasmuch as we have a large list of candidates that we have been observing through the years. Also, due to the large number of transiting exoplanets, the scheduling of transit observations for any given night are assured.