Automated code for the selection of targets to be observed with the SAINT-EX telescope

R.P. Petrucci[1,2] & Y. Gómez Maqueo Chew[3]

[1] *Observatorio Astronómico de Córdoba, UNC, Argentina*
[2] *Consejo Nacional de Investigaciones Científicas y Técnicas, Argentina*
[3] *Instituto de Astronomía, Universidad Nacional Autónoma de México, México*

Contact / romina.petrucci@unc.edu.ar

Resumen / En esta contribución, presentamos las características principales y describimos el funcionamiento del código desarrollado en lenguaje *python* para la construcción automática de la cola de observación de los objetos que serán observados durante la noche con el telescopio SAINT-EX de 1-m.

Abstract / In this contribution, we present the main characteristics and describe the functioning of the code developed in *python* language to automatically build the list of objects that are nightly observed in queue mode with the 1-m SAINT-EX telescope.

Keywords / techniques: photometric — planets and satellites: detection — stars: late-type — planets and satellites: terrestrial planets

1. Introduction

SAINT-EX (Search And characterIsatioN of Transiting EXoplanets) is a project that arises as a collaboration between the SAINT-EX Consortium and the Universidad Nacional Autónoma de México (UNAM). This endeavor has two main scientific purposes that involve the use of high precision photometry (Sabin et al., 2018): 1) to detect and characterize terrestrial transiting planets around ultra-cool dwarfs (Sebastian et al., 2021) , and 2) to provide ground-based support for the ESA CHEOPS space mission (Benz et al., 2021). To achieve these goals, between 2017 and 2019 a 1-m telescope equipped with a CCD Andor Ikon camera was installed at the Observatorio Astronómico Nacional de la Sierra de San Pedro Mártir (OAN-SPM, México). In March 2019, the facility became fully operational and, since then, it has been performing nightly observations only interrupted during the first six months of the COVID-19 pandemic. Here, it is important to mention that the scientific objective related to the ultra-cool dwarfs is performed in collaboration with the SPECULOOS team (Delrez et al., 2018).

So far, SAINT-EX has confirmed three planetary systems (Demory et al., 2020; Wells et al., 2021; Schanche et al., 2022), initially identified as candidates by the TESS space mission (Ricker et al., 2015). The success of this project in such a short term can be attributed, in part, to the efficiency in the observing preparation, and the data acquisition and analysis, which are performed in a fully robotic and remote way.

In this context, we present in this contribution the main characteristics and describe the functioning of the code developed in *python* language to build the list of objects that are nightly observed in queue mode with the 1-m SAINT-EX telescope.

2. Code main characteristics and functioning

The purpose of this code, written in *python*, is to automatically generate the list of targets, ordered by priority, that are observed nightly with the 1-m SAINT-EX telescope. It is mainly based on the libraries for observations planning and scheduling provided by the *astropy* (Astropy Collaboration et al., 2013, 2018) and *astroplan* (Morris et al., 2018) software, but also uses different tasks created by the authors to compute the targets' priority. The functioning of the code is shown in Figure 1 and described in the next paragraphs.

It requires as input a file containing the name, equatorial coordinates in epoch J2000, magnitude (J or K), and spectral type of all the stars in the sample. Basically, for each target, the code assesses five different modules and assigns a weight between 0 and 1 each. These modules are:

- Module 1: Number of observed hours. According to Sebastian et al. (2021), the most efficient observing strategy to increase the chances of finding a transiting planet is to observe each target for at least 100 hours on consecutive nights. Therefore, this module assigns more weight to the stars that have been observed for less than 100 hours.
- Module 2: Declination. Given that SAINT-EX is located in the North Hemisphere, if the star has a declination $> +20°$ it receives a greater weight than a star that has a declination $\leq +20°$.
- Module 3: Magnitude. In order to have high signal-to-noise images, this module assigns a greater weight to brighter stars with J ≤ 14.
- Module 4: Spectral type. Stars with spectral types later or equal to M7 receive a larger weight than stars with spectral types earlier than M7.

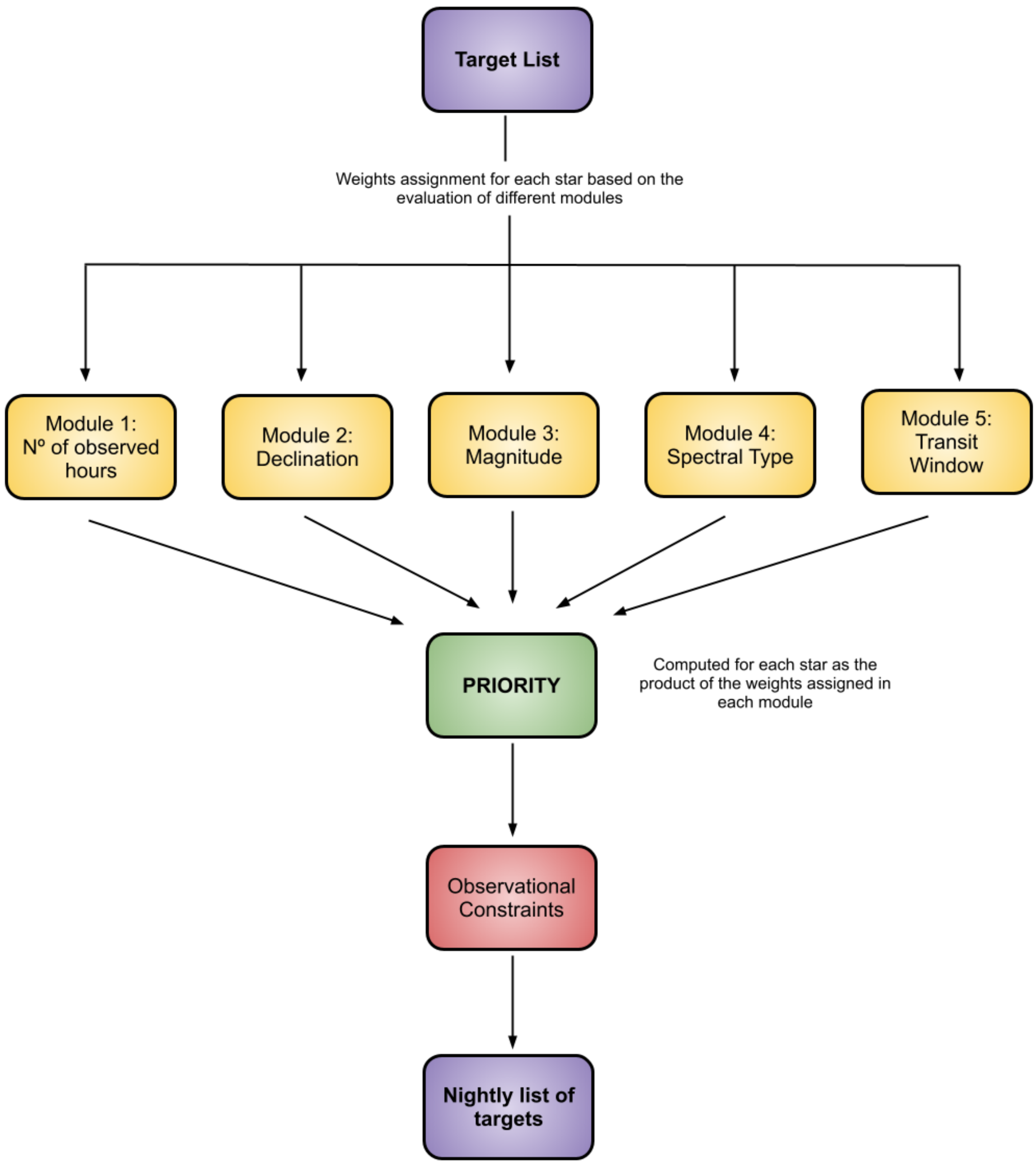

Figure 1: Flow Chart describing the functioning of the code to select the optimum targets to be observed by the SAINT-EX telescope in regular operations using queue robotic mode. See the text for details.

- Module 5: Transit window. This module was designed for those targets that have to be observed on a specific time interval, for example, to confirm a known transit event. In these cases, the star receives the highest weight to be observed in the transit window.

After the evaluation of each module, the priority of each star is computed as the product of the weights assigned per module. Then, a preliminary list of selected targets is set, where the target with the highest priority is ranked in the first place. The final list is generated in the next step, after the code checks different observational constraints, including among others:

- The separation between Moon and target. This needs to be larger or equal to 30° to avoid excessive scattered moonlight, which is difficult to correct.
- The amount of night time that the target is visible above 28° over the horizon*. This point is very important because, in the preliminary list, several targets will have the same highest priority, but the code will only select the ones visible for the longest

*This limit of 28° is set by the minimum altitude the telescope can reach safely.

periods as "optimal".
- If the target has a specified transit window.
- The times at which different twilights occur to properly set the start and end times of each target's observations.

If any of the top priority stars in the preliminary list has a conflict with any observational constraint, it is removed and the next target in the list is considered. As result, the code builds up the final list of targets to be observed nightly.

As output, the code provides: i) a visibility plot of the selected optimum targets as shown in Figure 2. Colored solid lines indicate the airmass of the star as a function of time and the shaded areas point out the time interval at which each target will be observed by SAINT-EX. The gray shaded areas mark the civil, nautical, and astronomical twilight at dawn and dusk, ii) a series of scripts with information about the exposure time, filter, start and end of the observations of each target, also instructions to open and close the dome, to turn on and off the telescope and CCD, and to take the number of the required calibration images (bias, dark, and dusk and dawn flat-fields) with their corresponding integration times. These scripts are uploaded to the telescope control computer with the appropriate format to be read by the program that carries out the automated observations.

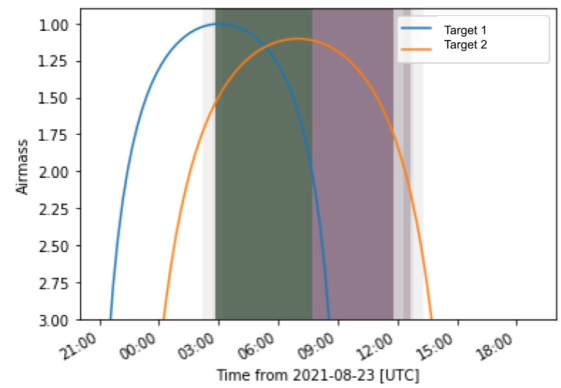

Figure 2: Visibility plot of the optimum targets selected by the code. Blue and orange solid lines indicate the airmass as a function of time of targets 1 and 2, respectively. Dark green and violet shaded areas point out the time interval at which each of these targets will be observed by SAINT-EX. Different gray shaded areas mark the civil, nautical, and astronomical twilight at dawn and dusk.

3. Conclusions

This code has been successfully used to select the optimal targets to be observed nightly, since the commissioning of the SAINT-EX telescope. However, there are some aspects that still need to be improved. As an example, so far, the code computes the integration time ($t_{\rm exp}$) of each star only through its magnitude. In some cases, this leads to an overestimation of $t_{\rm exp}$ producing saturated or near-saturated images. In the future, it would be desirable that the code calls to a more sophisticated tool, such as the Exposure Time Calculator (ETC) used by the SPECULOOS team (Delrez et al., 2018) that includes information about the CCD, atmospheric conditions, etc to calculate realistic $t_{\rm exp}$. Another point of improvement would be to include the number of hours that each ultra-cool dwarf is observed with the SPECULOOS telescopes. At the moment, module 1 only considers the hours monitored by SAINT-EX. Additionally, so far, this code is optimized for the SAINT-EX observation queue, only. In the near future, we expect to implement an option that will allow the user to enter the coordinates (latitude, longitude, and height above sea level) of any observatory to generate its own observation queue. This new version of the code will be available for the community through GitHub.

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