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SAINT-EX: SCIENTIFIC RESULTS AND OBSERVATIONS FROM SAN PEDRO MÁRTIR

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RESUMEN

Presentamos SAINT-EX, sus primeros resultados científicos y un resumen de las observaciones desde su instalación a la fecha. SAINT-EX consiste en la instalación y operación científica un telescopio de un metro de diámetro, y cuenta con un CCD Andor Ikon y filtros optimizados para obtener curvas de luz de alta precisión, localizado en el Observatorio Astronómico Nacional de San Pedro Mártir en Baja California. Su operación es remota y robótica y desde el marzo de 2019 y hasta el cierre por la pandemia, SAINT-EX operó de manera rutinaria y regular. SAINT-EX, como todo el mundo, se vió obligado a cerrar por la pandemia, pero afortunadamente en enero y febrero de 2020, llevamos a cabo las observaciones de las cuales obtuvimos las curvas de luz de TOI-1266 que nos permitieron validar la naturaleza planetaria de los dos tránsitos detectados en la curvas de luz del satélite TESS (Demory et al. 2020). Después de un cierre completo, en noviembre y diciembre de 2020, obtuvimos las curvas de luz con SAINT-EX que validaron la naturaleza de otro sistema planetario, éste con un solo planeta alrededor de una estrella tipo M (Wells et al. 2021). Así, SAINT-EX y el equipo continuamos conforme la crisis mundial lo permite.

ABSTRACT

We present SAINT-EX, its first scientific results and summarize the observations acquired since its installation to date. SAINT-EX consists on the installation and operation of a one-meter telescope with an Andor Ikon CCD and filters optimized to obtain high precision light curves. It is located at the Observatorio Astronómico Nacional de San Pedro Mártir, Baja California. SAINT-EX's operation is remote and robotic, and since march 2019 until the beginning of the pandemic, our operations were regular and routine. SAINT-EX, like the World, had to close for the pandemic, but fortunately in January and February 2020, we obtained the observations from which we derived light curves of TOI-1266 that allowed us to validate the planetary signature of the two transits identified by the TESS satellite (Demory et al. 2020). After a full closure, in November and December 2020, we obtained with SAINT-EX the light curves that allowed us to validate another planetary system, this one composed of a single planet orbiting a low-mass, thick-disk M star (Wells et al. 2021). Thus, SAINT-EX and its team continue observing as the world crisis permits.

Key Words: exoplanets — planetary systems — telescopes

1. INTRODUCTION

Dedicated astronomical observations have driven the field of exoplanets, since its beginning with the identification of the exoplanetary system around a pulsar (Wolszczan & Frail 1992) and the first exoplanet detected around a main sequence star 51 Peg (Mayor & Queloz 1995). As observing capabilities, instrumentation, and analysis techniques are developed and honed, the observed parameter space that define a planetary system is extended. Thus, the theory of planet formation and evolution is tested and has to account and allow for the observed characteristics of the known exoplanet populations.

Currently the only exoplanetary systems that allow for the detailed characterization of Earth-sized planets are those found around the coolest, least massive stars in the solar neighborhood. And it is transiting planets that allow for the measurement of the size of the exoplanets (Seager & Mallén-Ornelas 2003). For example, the detection of the 7-planet system around the ultracool dwarf TRAPPIST-1 (Gillon et al. 2016) has become a test case for the formation of small planets in temperate environ-

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ments. The identification of exoplanets around these cool stars will provide with upcoming facilities (like JWST and the ELT) the only probe of Earth-sized planet atmospheres in the near future. With this in mind, several projects have targeted ultracool dwarfs (with SpT M7 and cooler) to identify signatures of exoplanetary systems orbiting them. In particular, the transiting planet project SPECULOOS (Sebastian et al. 2020).

Here, we present the SAINT-EX project that consists in the installation and scientific operation of a telescope that is dedicated to the detection and characterization of exoplanets. In Section 2, we describe the facility and a summary of the observations that we have made, their scheduling and their processing to derive light curves. And in §3, we present two exoplanet systems that have been confirmed to be real, based on SAINT-EX data.

2. THE SAINT-EX PROJECT

SAINT-EX is a 1-m F/8 Ritchey-Chrétien telescope by ASTELCO, on an equatorial mount, and equipped with a deep-depleted and back-illuminated Andor Ikon CCD (2k×2k pixels), an FLI filterwheel, and SDSS $u'g'r'i'z'$ broadband filters. SAINT-EX is the result of the collaboration between the University of Bern, the Universidad Nacional Autónoma de México (UNAM), the NCCR PlanetS working group, the University of Geneva, the University of Cambridge and the University of Liège.

SAINT-EX was installed in late 2018 at the Observatorio Astronómico Nacional de la Sierra de San Pedro Mártir (OAN-SPM) in Baja California, México that is managed by UNAM. Given the favorable astroclimactic conditions of the site and its location (115° 27' 17.15" W, +31°02'36.30" N, 2778 m), SAINT-EX complements facilities with similar capabilities in the North. The OAN-SPM has been shown both historically (Tapia et al. 2007) and more recently (Schöck et al. 2009) to have excellent astroclimatic conditions.

SAINT-EX is dedicated to the discovery and characterization of transiting exoplanets through the acquisition of precise time-series photometry. In collaboration with the SPECULOOS project (Sebastian et al. 2020), we have observed about 50 ultracool dwarf stars (SpT M7 or later) between 50 and 80h each since beginning regular operations in March 2019. We are also collaborating with the ESA satellite CHEOPS, and have contributed to TESS planet candidate follow-up (see §3).

SAINT-EX operations are remote and robotic. The observations are scheduled from a list of known list of ultracool dwarfs, giving a priority for each target based on observability, number of observed hours and spectral type. Each night the queue is scheduled and if weather conditions allow it, we observe typically two objects per night. The facility does not require an observer on site. If conditions worsen, the facility will close and observations are stopped. At the end of each night, the SAINT-EX automatic reduction and photometry pipeline (PRINCE; Demory et al. 2020) is launched. PRINCE first corrects each frame, finds each star in the field, does the photometry and corrects the light curves for systematics using several detrending algorithms (e.g., Bailey 2012). A report with that night's light curves is created, and includes information on all targets and their comparison stars.

Because of the COVID pandemic, operations were completely halted between March and November 2020 at OAN-SPM. Working closely with the OAN-SPM technical staff and on-site personnel, the SAINT-EX team was able to develop a workflow that would allow us to operate under these conditions. We observed for over a month at the end of 2020, but closed for the winter and COVID. We reopened in March 2021, and have been operating continuously since then, weather permitting. This would have been impossible without support of the OAN-SPM staff.

3. VALIDATED PLANETARY SYSTEMS WITH SAINT-EX

As our first science results, we have contributed photometric time-series data to the TESS (Ricker et al. 2014) follow up efforts in order to validate the planetary nature of planet candidates identified from their space light curves, highlighting the observing capabilities of the facility.

The first planetary system validated with SAINT-EX light curves was TOI-1266 and was published in Demory et al. (2020). This newly identified planetary system orbits a bright M3V dwarf star ($K = 8.8$ mag) and is composed of a sub-Neptune-size planet ($2.37^{+0.16}_{-0.12}$ $R_\oplus$; ΔF ∼0.003) in a 10.9 day period, and a super-Earth-size planet ($1.56^{+0.15}_{-0.13}$ $R_\oplus$; ΔF ∼0.0017; shown below on the right) in an 18.8 day period. The planet masses where constrained using TTVs to be $13.5^{+11.0}_{-9.0}$ $M_\oplus$ for planet b and $2.2^{+2.0}_{-1.5}$ $M_\oplus$ for c. Figure 1 shows the SAINT-EX transit light curves that were analyzed with additional photometric and spectroscopic data to validate the planets and derive their physical properties.

The second system validated to be a transiting exoplanet with SAINT-EX light curves is a sub-

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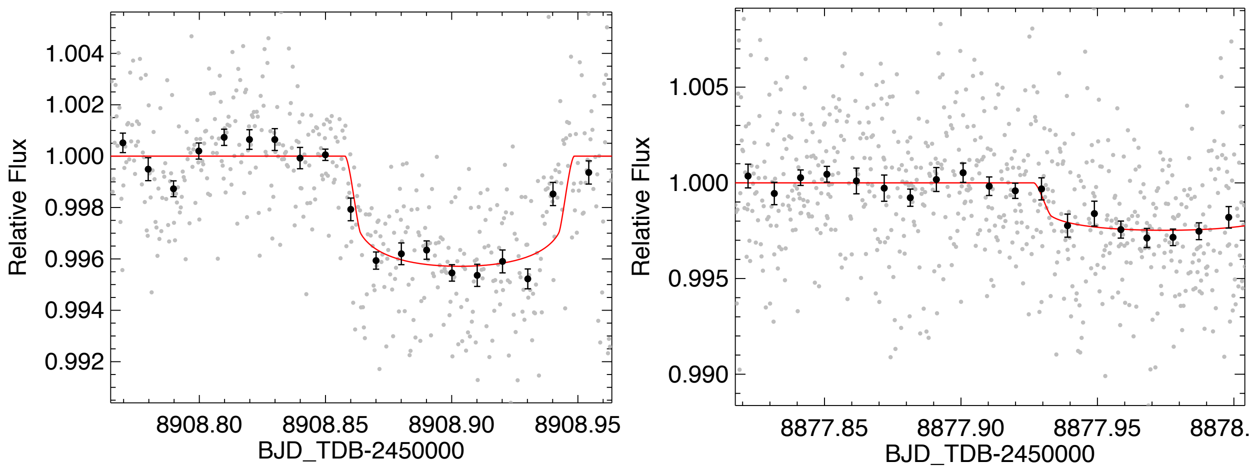

Fig. 1. SAINT-EX z' light curves for the two TOI-1266 transiting planets. The grey points show the 12 s exposures while 15-min bins are shown in black and in red, the best-fit model of Demory et al. (2020). On the left, the TOI-1266 b transit observed on 29 Feb 2020, and on the right, is the TOI-1266 c transit observed on 29 Jan 2020.

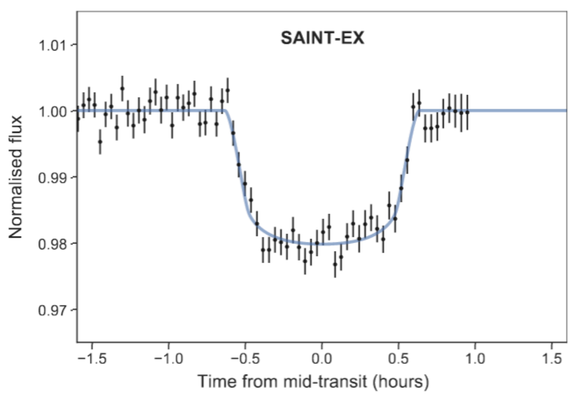

Fig. 2. SAINT-EX z' transit light curve of TOI-2406 b. The observations were acquired on 02 Dec 2020 with 120s exposure times. The best fit model from Wells et al. (2021) is shown in blue.

Neptune orbiting the thick-disk M4V dwarf star TOI-2406 in a 3.077 d period (Wells et al. 2021). The SAINT-EX light curve has a 30-minute rms of $\sim$500 ppm (Fig. 2), which in addition to other light curves allows the measurement of the planet radius to be 2.94 ± 0.17 $R_\oplus$ (ΔF $\sim$0.0175). We found two surprising things: (1) the orbit is found to be eccentric ($0.26^{+0.27}_{-0.12}$) despite its close-in orbit indicative of a complex formation or additional companions, and (2) a planet this large is not expected to be able to form around such a low-metallicity star ([Fe/H] = -0.38 dex), posing a challenge to planet formation theory.

4. SUMMARY

SAINT-EX is a 1-m telescope dedicated to the study of exoplanets through the acquisition of precise light curves. Its observing capabilities have been demonstrated in the two TESS planetary systems that have been validated with SAINT-EX photometry (Demory et al. 2020; Wells et al. 2021). We will continue searching for transits around the coolest, lowest mass stars in the solar neighborhood and supporting the science from the TESS (e.g., Schanche et al. 2022) and CHEOPS space missions.

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