Characterizing TESS exoplanets around M-dwarfs with ExTrA

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Introduction

During its multiple years of observations, TESS has discovered **more than 300 planetary candidates** around M-type stars. As M-dwarfs radiate most of their energy at infrared wavelengths, **near-infrared observations** are needed to confirm and characterize these candidates.

Using ExTrA for follow-up observations will allow us to **improve the precision** on the planetary radius measurement, measure possible **transit timing variations** (TTVs) and even detect **additional planets** in the systems.

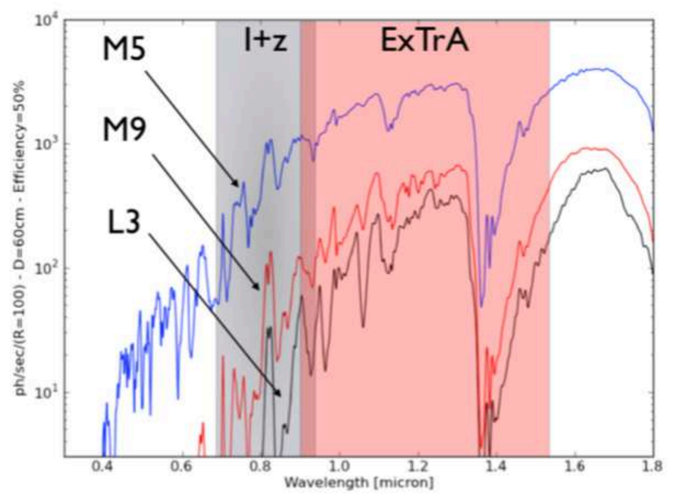

Figure 1 : Photon distribution (per R=100 resolution element) for a M5@15pc, a M9@10pc, and a L3@10pc dwarfs, as would be recorded with a telescope of 60-cm diameter, with a 50% efficiency, and through the Earth atmosphere. The light-red zone labeled ExTrA is our spectral window.

A new concept

ExTrA (***Bonfils et al. 2015***) is a new instrument composed of **three 60cm telescopes** that are located at La Silla Observatory in Chile. The ExTrA facility relies on a new approach that involves **combining optical photometry with spectroscopic information** with the aim of mitigating the disruptive effect of Earth's atmosphere, as well as effects introduced by instruments and detectors. Even though the team is still working on using the facility at its full potential, the instrument is currently observing and producing light curves for multiple M-dwarfs.

On each telescope, 5 field units (FUs) are used to collect light from **a target star and four reference stars** for comparison. This light is sent through fibers into a **near-infrared spectrograph** with low spectral resolution in order to analyze it in many different wavelengths.

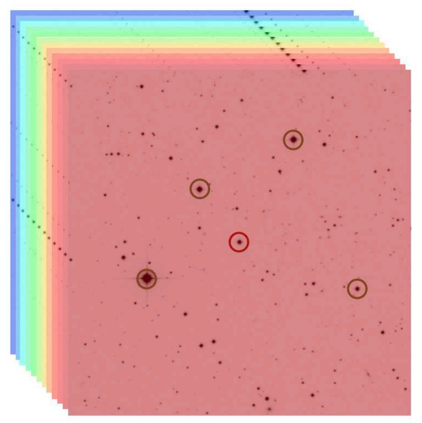

Figure 2 : The target star and 4 reference stars fluxes analyzed at different narrow bands

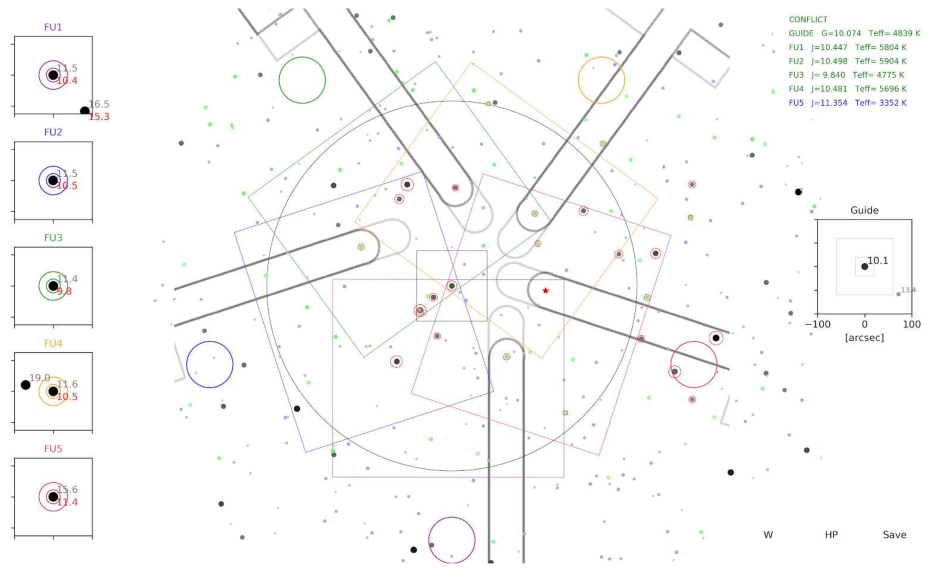

Figure 3 : Snapshot of the software for preparing observations for ExTrA. Each FU is placed over a particular comparison star (green stars) or the target (red star). On the left the location of each FU is magnified and the fiber apertures are drawn to scale (colored circles; the first circle is 4", the second circle is 8"). The guiding star is located at the center and a magnified image is shown on the right.

TOI-269 b : an eccentric sub-Neptune transiting a M2 dwarf revisited with ExTrA

In order to evaluate the capacity and precision of ExTrA, we observed multiple TOIs (**TESS Object of Interest**) to confirm the presence of exoplanets. One of them was **TOI-269 b** (***Cointepas et al. 2021***) where we were able to confirm the presence of a mini-neptune orbiting a M2 star. The planet was detected by the TESS pipeline and confirmed with radial velocity measurements with the spectrograph HARPS and ground-based photometric follow-up.

The joint photometry and radial velocity analysis lead to the characterization of a **mini-neptune exoplanet** at a period of 3.7 days with a radius of 2.77 ± 0.12 $R_\oplus$ and mass of 8.8 ± 1.4 $M_\oplus$. Some results of the joint fit are presented below.

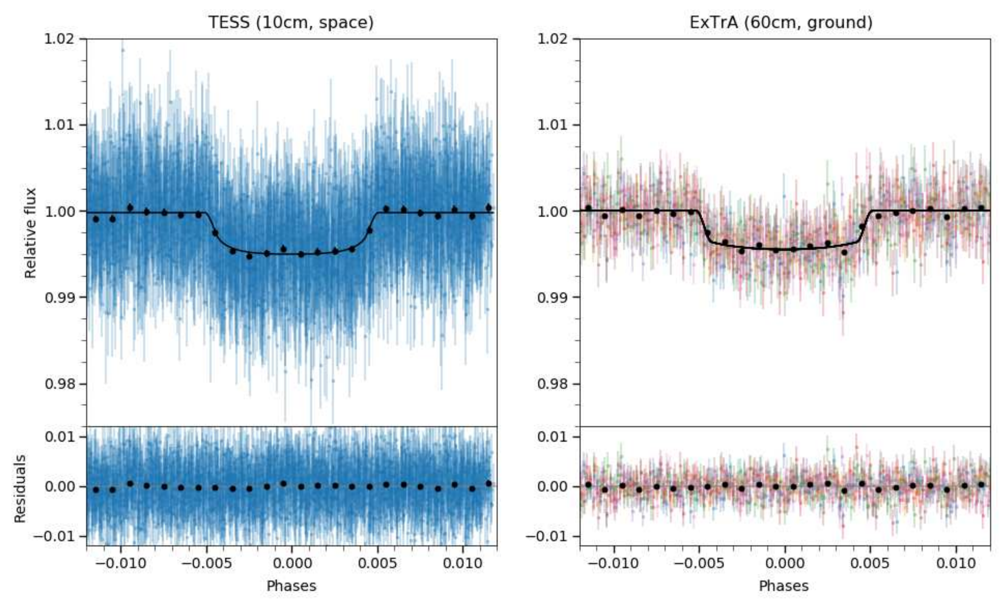

Figure 4 : Photometry data for TESS (35 transits), and ExTrA (7 transits; corrected for the GP component) phase-folded to the period of the planet. The black line is the maximum a posteriori model; the black points are ~ 5 min binned data.

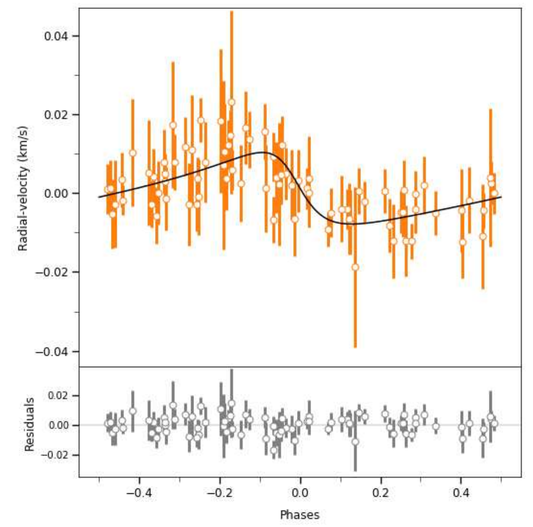

Figure 5 : HARPS RVs phase-folded to the period of the transiting planet. The black line is the best-fit model from the joint fit.

In our joint fit of photometric and velocimetric data, we derived **a non-zero eccentricity of 0.425 ± 0.086**. TOI-269 b has a remarkable eccentricity with almost the highest value for small planets with periods shorter than 10 days.
In addition, TOI-269 b lies among the best targets of its category (sub-Neptunes around M dwarfs) for **atmospheric characterization**.

In order to assess the precision we can obtain with ExTrA light curves, and compare it with TESS, we binned the residuals of the modeling for different bin width and measured the RMS to infer the error on our measurements.
We can see that 7 combined ExTrA transits is similar to 35 combined TESS transits to obtain the same **precision on the dispersion of the residuals**, potentially correlated to the precision on the radius ratio.

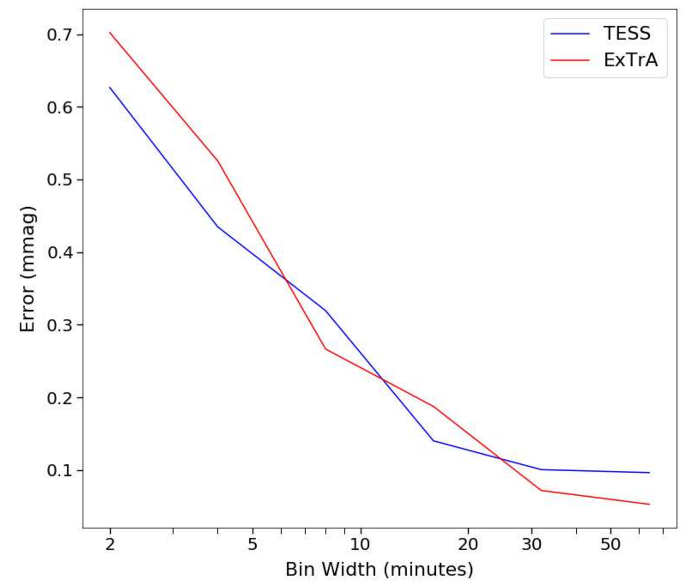

Figure 6 : Dispersion of the residuals for TESS (35 combined transits) and ExTrA (7 combined transits) data for different bin sizes.

Prelimary results on TOI-654 : another confirmation for ExTrA

As part of our WP1, consisting in refining the planetary radius measurement of TOIs, we also observed **TOI-654** multiple times with ExTrA. We did a similar analysis to that of TOI-269 using TESS and ExTrA photometry and confirmed the presence of a mini-neptune at a period of 1.53 days with a radius of 2.29 ± 0.10 $R_\oplus$.

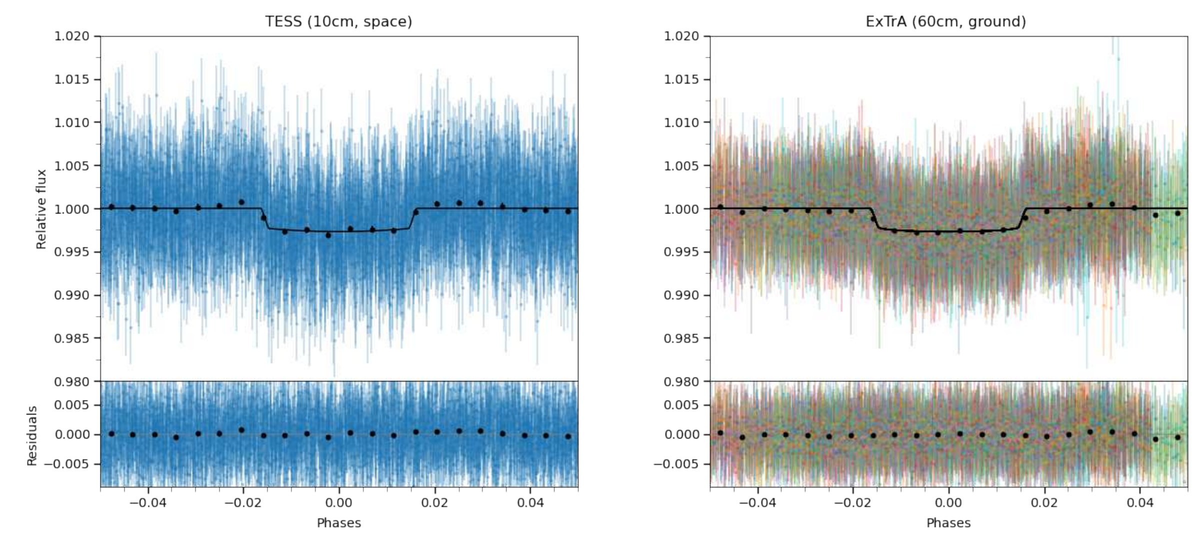

Figure 7 : Photometry data for TESS (28 transits), and ExTrA (20 transits) phase-folded to the period of the planet. The black line is the maximum a posteriori model; the black points are ~10 min binned data.

Adding the ExTrA transits to the TESS data improves by 20% the precision on the radius ratio measurement of TOI-654.01, demonstrating once again that ExTrA is the perfect instrument to follow-up TESS planetary candidates around M-dwarfs.

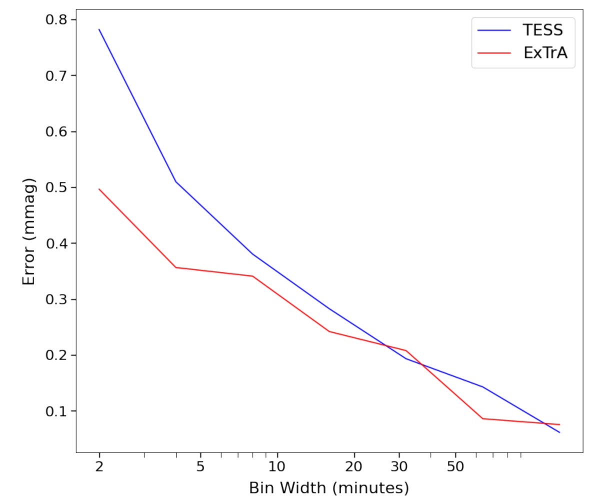

Figure 8 : Dispersion of the residuals for TESS (28 combined transits) and ExTrA (20 combined transits) data for different bin sizes.

Synergies with other missions

Besides running its own survey, ExTrA is a valuable resources to **follow-up M dwarfs** with candidates found by both **K2 and TESS** missions. With ExTrA, we will obtain a better precision for the coolest stars (late M) because of near-infrared photometry.

Planet candidates detected in transit need follow-up observations. **NIRPS** will be an **infrared spectrograph** designed to detect Earth-like rocky planets around the coldest stars. NIRPS is the "red arm" of HARPS, extending its capability into the infrared and allowing astronomers to characterize planetary systems. ExTrA and NIRPS will work in tandem to fully characterize exoplanets orbiting M-dwarfs with near-infrared observations.

The exoplanets detected by ExTrA will be amenable to **atmospheric characterization** with instruments such as the **VLT**, and future instruments like the **JWST**, and **ELT**.

ExTrA

TOI-269 b