A dedicated search for young transiting planets with TESS

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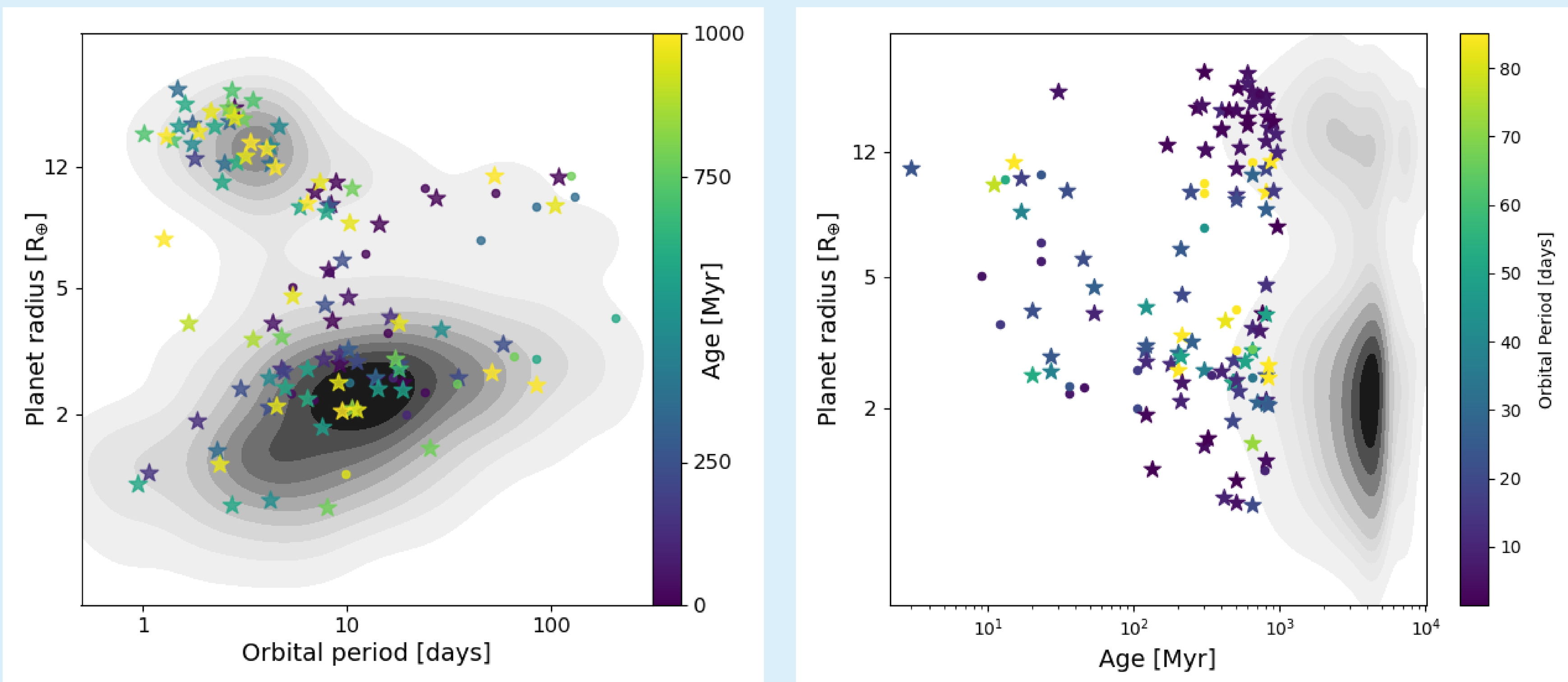
Motivation

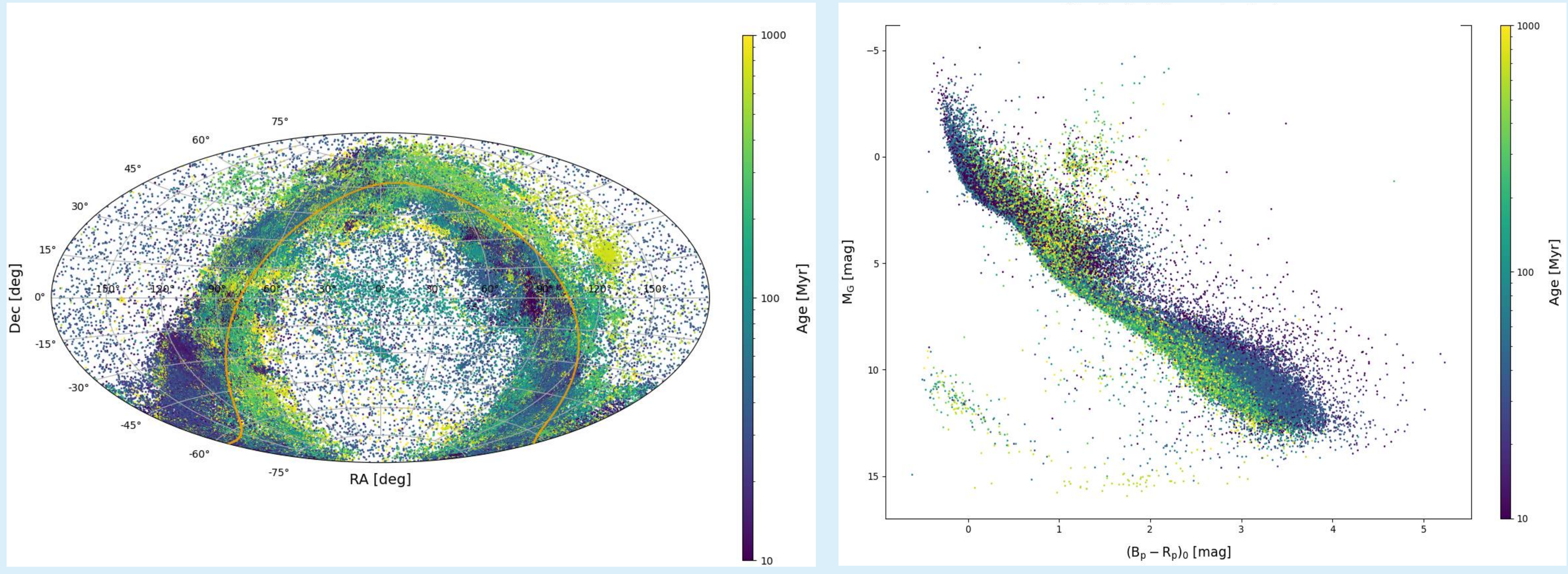
Young transiting planets are keystone objects to understand the early evolution of planetary systems. During their early (< 1 Gyr) evolution, planets actively undergo processes like orbital migration, thermal contraction, and atmospheric loss. By detecting and characterizing them while they are actively evolving, we can constrain crucial parameters such as the migration time scale, cooling and atmospheric loss rates for different planet types, all of which are essential for deeper understanding of how planetary systems form and evolve. However, young host stars are typically active and display significant photometric and spectroscopic variability resulting from star spots, plages and flares, so detecting planetary transits remains a challenge. Combining our curated young star catalogue with dedicated detection algorithms, we are searching for young transiting planets in TESS data and present the current status of our investigation.



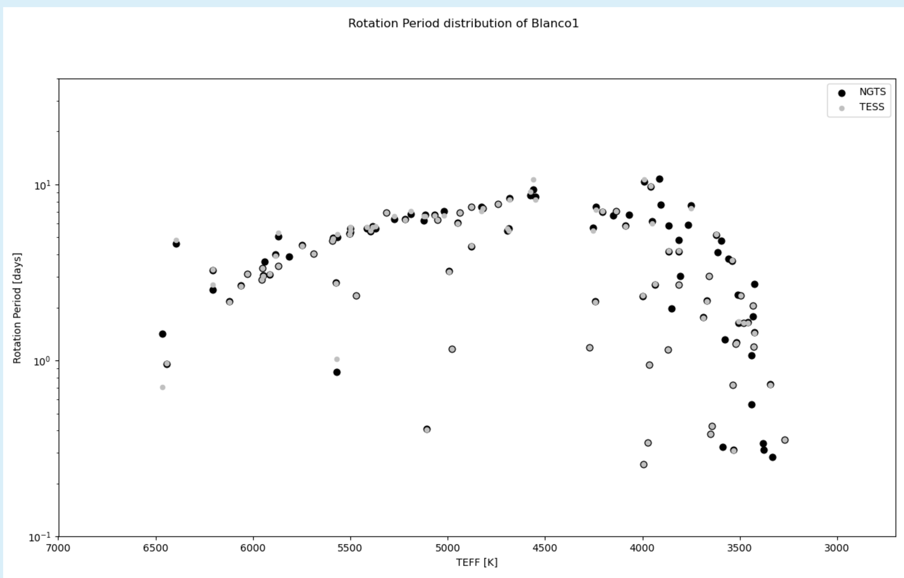
Left: planet radius – orbital period distribution of young planets highlighting that young planets occupy interesting regions of parameter space between the main older sub-populations. The dashed red line marks the *radius valley*. *Right:* planet radius – age distribution of young planets. [Stars from TESS, points from Kepler and K2]. The contour plots are defined from the current list of confirmed mature transiting planets in the *NASA exoplanet data base.*

Stellar Sample

Our young star catalogue includes ~5.5 million confirmed and candidate young stars with ages between 1Myr –1Gyr, which were selected from a comprehensive literature study. For our initial search of TESS data, we have defined a *prime sample* of 100 thousand stars (any Tmag for d < 250pc and Tmag < 13.5 for d < 500pc) that are amenable to detailed transit searches and photometric and spectroscopic follow-up observations to validate and confirm detected candidates.



Left: distribution of the prime sample on the sky, coloured by age where the orange line indicates the Galactic plane. Most young stars are found close to the Galactic plane. *Right:* colour-magnitude diagram of the prime sample coloured by age, where the different colour progressions highlight various evolutionary stages.



We are also conducting a deeper study of the young stars in our catalogue. Using TESS light curves, we have calculated the rotation periods (P_{rot}) of stars that are members of a cluster as additional constraint of age and cluster membership.

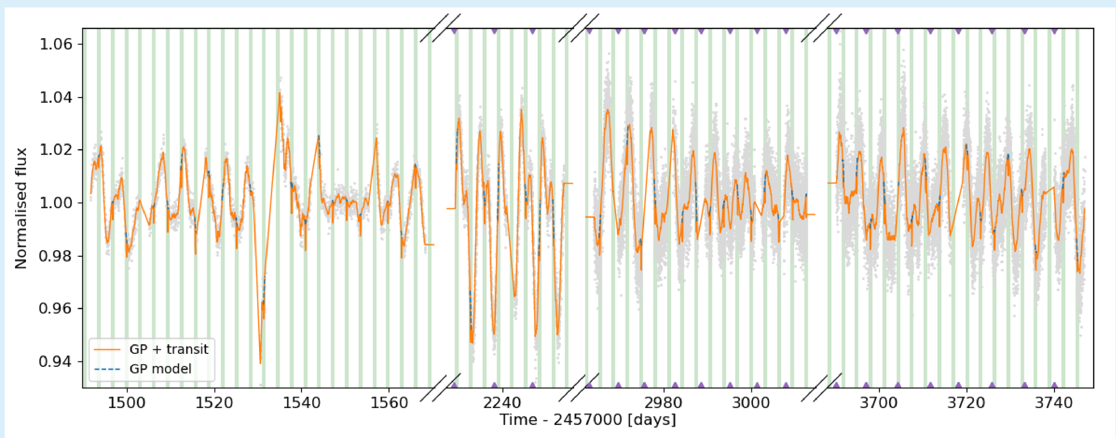
Left: rotation period distribution of the open cluster *Blanco1*, where data shows a good agreement between TESS P_{rot} and NGTS P_{rot}. (Gillen, E. et al. 2020)

[1]Gillen, E. , 2020, MNRAS, 492, 1008–1024.

Detection Strategy

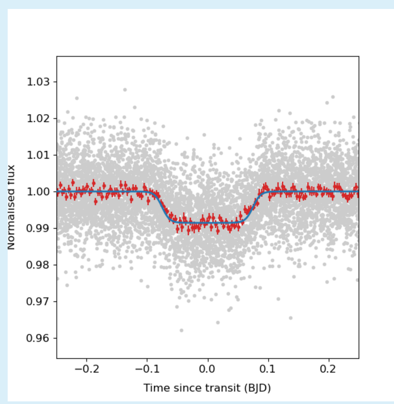
Light curves of young stars are dominated by stellar activity, most notably spot modulation and sporadic flare events (see light curves below), making planet detection challenging. To detect planet transits around such young, active stars, we adopted the following strategy:

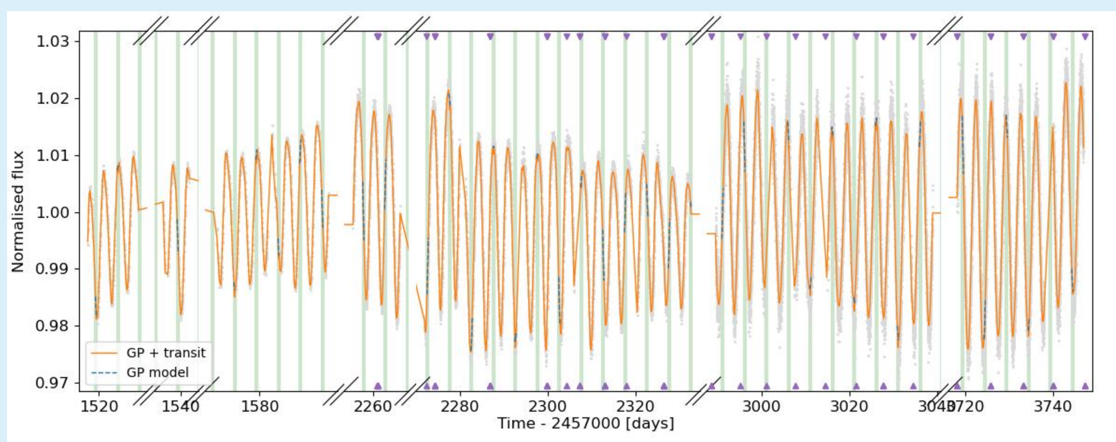
1. We developed a cleaning routine that, for each TESS sector, accounts for: bad data times based on the Moon's position; TESS quality flags; scattered light based on the TESS momentum center; and flare events.
2. We search for planet transits using two independent detection pipelines, which we have further optimized for TESS data and young stars: *YSD* (Battley et al. 2020) and *Nuance* (Garcia et al. 2024). With *YSD*, we detrend young stellar light curves using an algorithmic LOWESS-based pipeline for efficient planet searches and adapt the smoothing parameters depending on the activity period of the star. With *Nuance*, we simultaneously model the stellar variability (and instrumental signals) using Gaussian process (GP) regression while searching for the planet transits.
3. *Below* some of our new detections, presented with light curve, stellar parameters, planet parameters and phased folded transit:



$M_* = 0.85\ M_\odot$
$R_* = 0.88\ R_\odot$
Age ~ 30 Myr

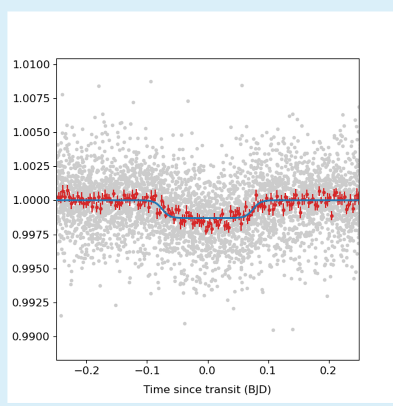
$P_p = 3.1$ d
$R_p \sim 8.9\ R_\oplus$

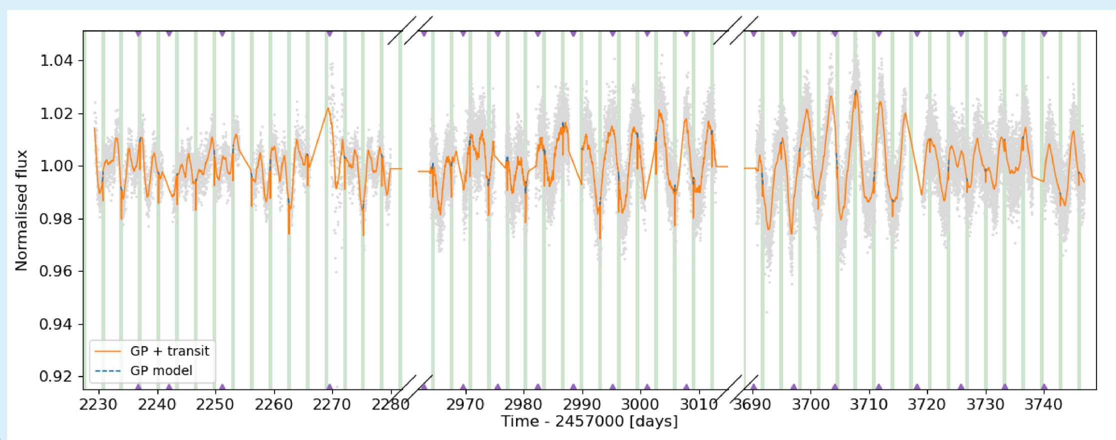




$M_* = 0.93\ M_\odot$
$R_* = 1.03\ R_\odot$
Age ~ 25 Myr

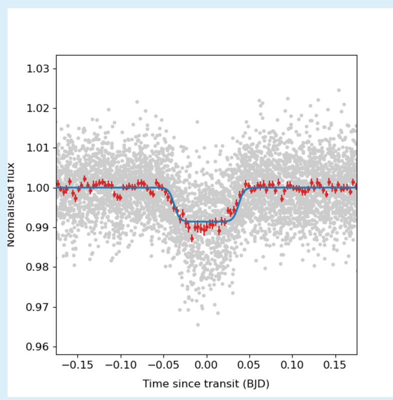
$P_p = 4.9$ d
$R_p \sim 3.7\ R_\oplus$





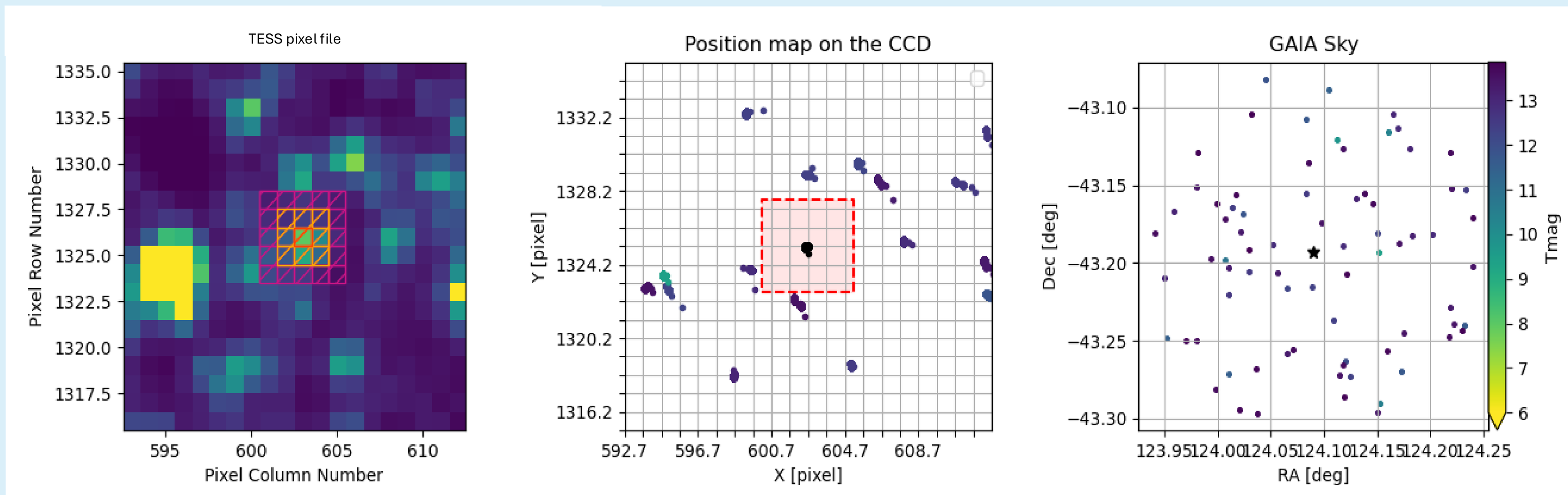
$M_* = 1.67\ M_\odot$
$R_* = 0.91\ R_\odot$
Age ~ 45 Myr

$P_p = 3.2$ d
$R_p \sim 9.2\ R_\oplus$

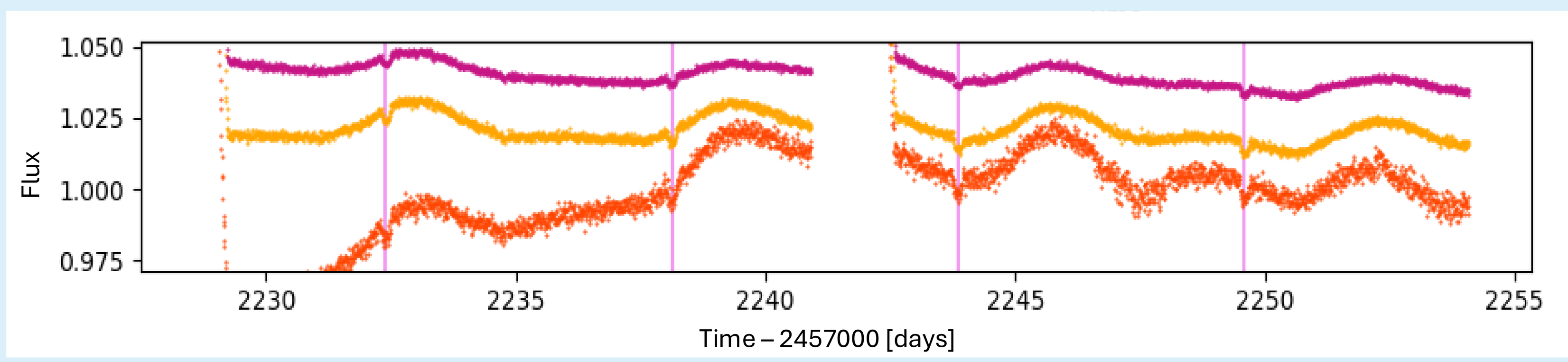


Vetting Strategy

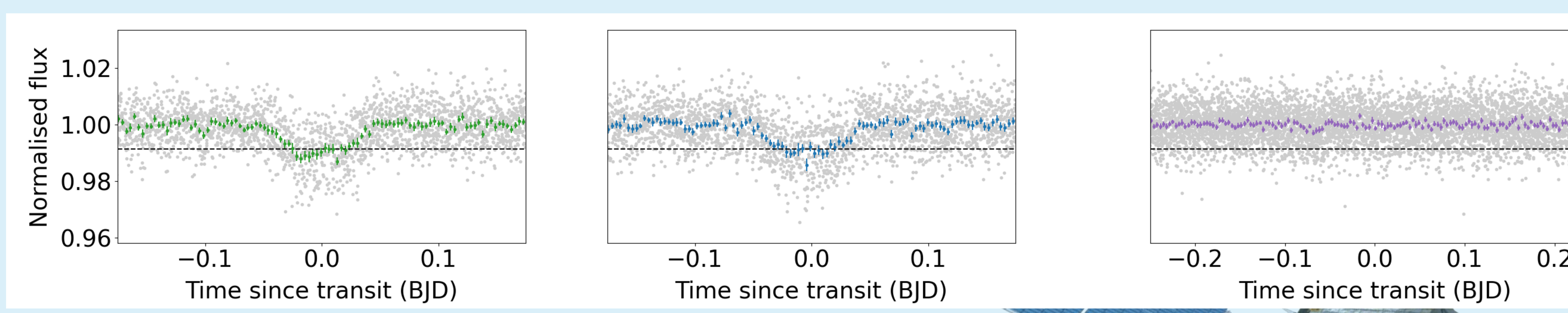
TESS has a relatively large ~21 arcsecond pixel scale, which means than contaminating light from nearby sources can introduce signals into the light curves of our target stars. Below: TESS pixel file (*left*), target position map along the time window of a sector (*middle*), and the *Gaia* sky map centered on the target (*right*).



The combination of these give insight into the on-sky stellar neighborhood and help us to reject blended `transit' signals originating on contaminating stars. We define small (1x1; **orange**), medium (3x3; **yellow**) and large (5x5; **purple**) customized masks from the TESS pixel file that are centered on our target. The apparent depths of transits in the corresponding light curves can be used to distinguish between on-target vs. blended signals from neighboring stars.



As additional vetting step we compare odd – even transits and check for secondary eclipses for exclude eclipsing binaries.



[1]Battley, M. P., Pollacco, D., and Armstrong, D. J., 2020, MNRAS, 496, 1197–1216. [2] Garcia, L. J., Foreman-Mackey, D., Murray, C. A., Aigrain, S., Feliz, D. L., and Pozuelos, F. J., 2024, The Astronomical Journal, 167, Art. no. 284.

Next steps

- Continue the search for transiting planets.
- Conduct radial velocity and photometric follow-up for the most interesting and promising targets to determine their radii and masses.
- Analyze and confirm the nature of the best candidates to increase our sample of **new young exoplanets.**

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