A search for transiting planets around hot subdwarfs

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TRAPPIST North, Oukaïmeden, Morroco © E. Jehin.

TESS, NASA Somewhere in space.

TRAPPIST South, La Silla, Chile © E. Jehin.

Do hot subdwarfs have planets?
Can short-period planets survive the expansion phase of their host stars?
What are the consequences of a planetary engulfment?

Context

Hot subdwarf stars (sdB) are a relatively rare as only 2% of stars will become one. They are formed when Solar-like stars lose most of their enveloppe at the tip of the Red Giant Branch (RGB) (see fig. 1). Only their core remains, so they are light weight (~0.5 $M_\odot$), small (~0.2 $R_\odot$) and very hot (~40000 K) core He burning stars (see fig. 2). SdB are also short-lived (~100 Myr) and no planets have been found around them so far.

Take Home message

Hot subdwarfs
  => currently no confirmed planets
  => can inform on planet's fate during RGB
We are analysing all the observed ones
  => to find planets using the transit method
  => to compute their planetary occurrences
  => to constrain close orbiting planet's fate
So far no confirmed detection, follow-up ongoing

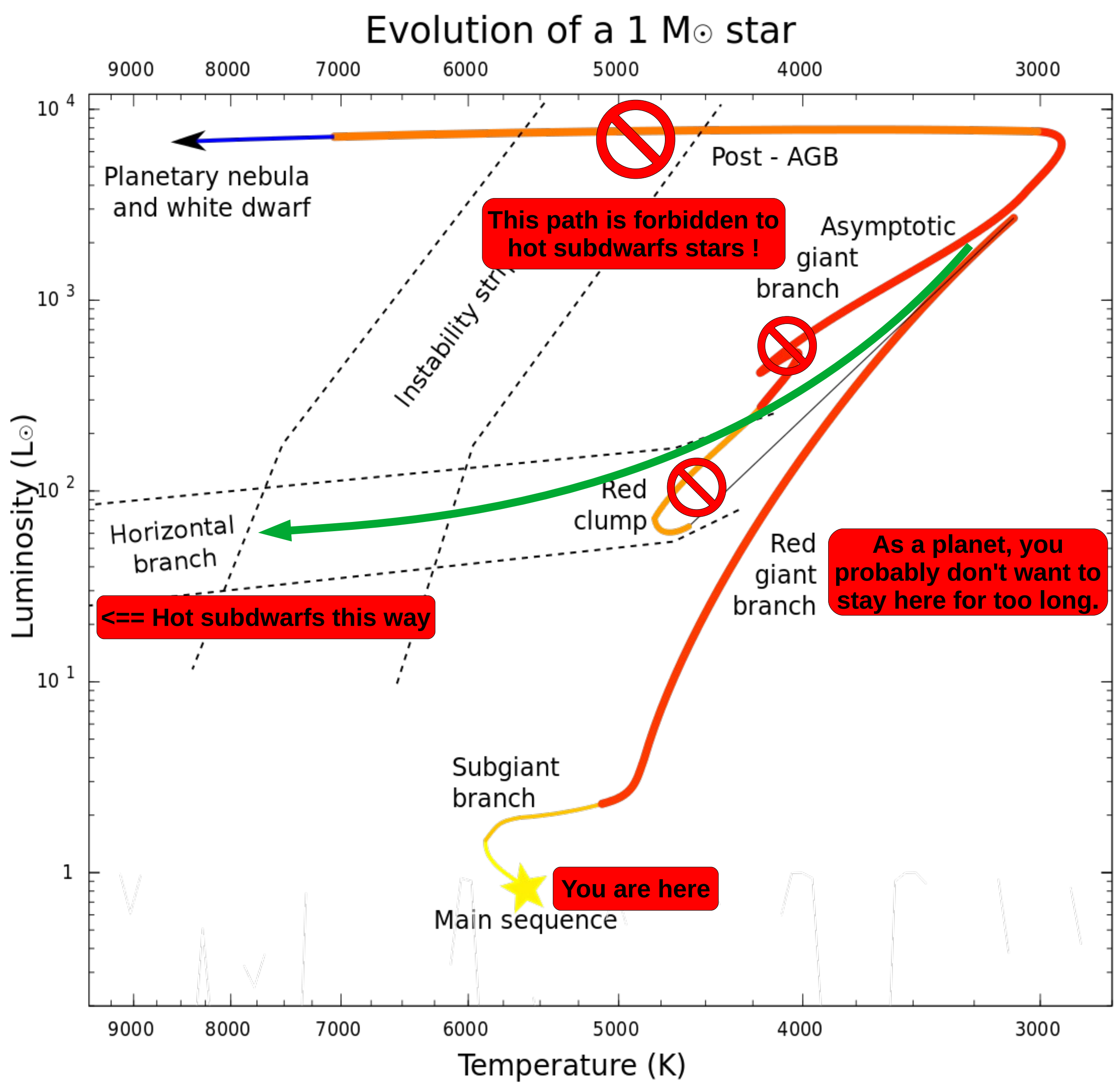

Fig. 1 : HR diagram and hot subdwarf stars. Adapted from author Lithopsian @ Wikimedia Fundation, CC BY-SA 4.0

Goals

The brief lifespan of SdB stars implies that planets have limited time to form or migrate around them. Consequently, planets in close proximity to SdB stars were most likely already present during the RGB phase and survived. Our goal is to (1) determine whether some planets made it by analysing all lightcurves from TESS primary mission. (2) Compute planetary occurrence around sdBs. (3) Investigate the potential formation of sdB through star-planet interaction at the end of the RGB.

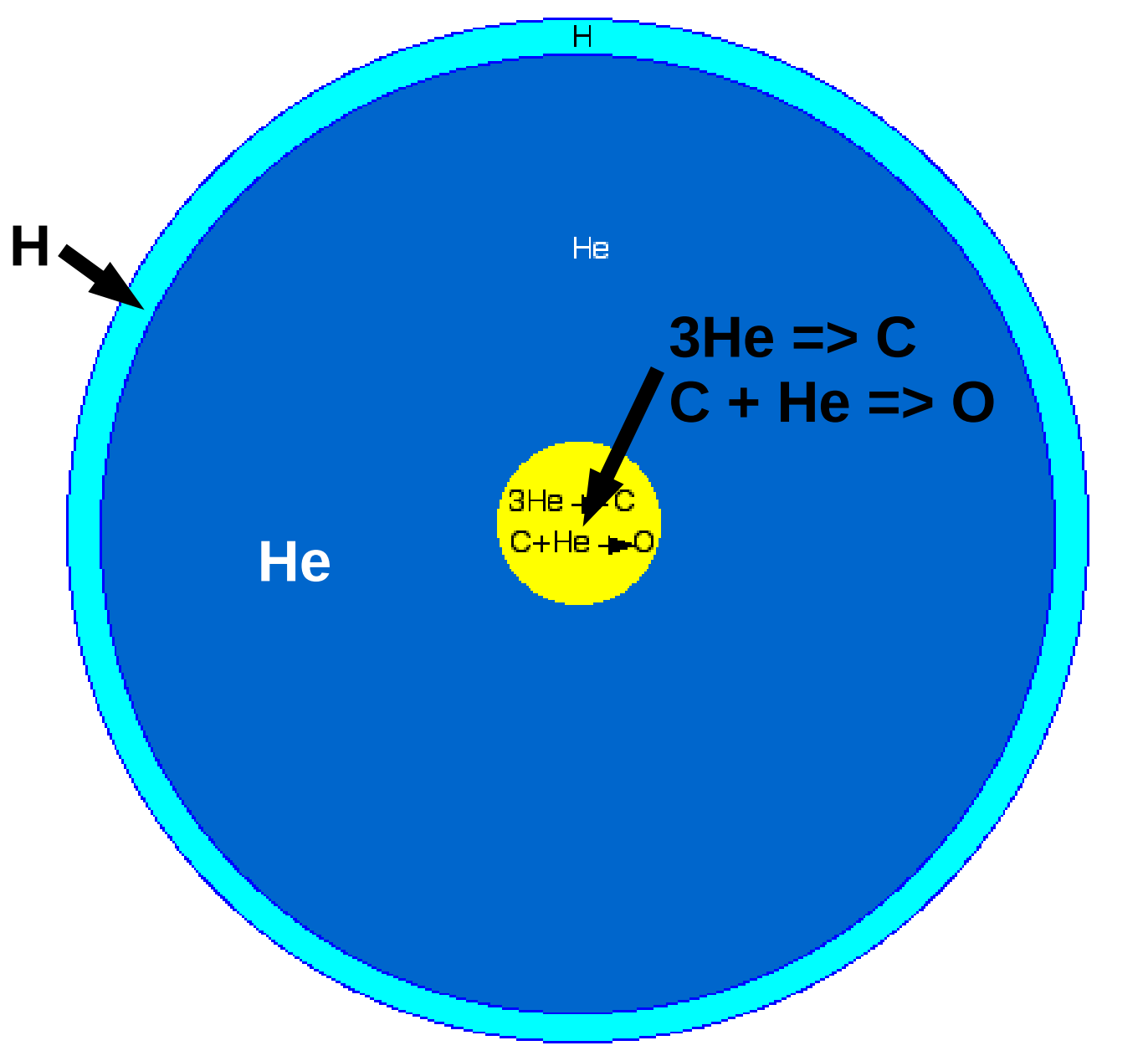

Fig. 2 : Schematic cross section of a hot subdwarf. © Uwe W. @ Wikimedia Fundation. CC BY-SA 3.0

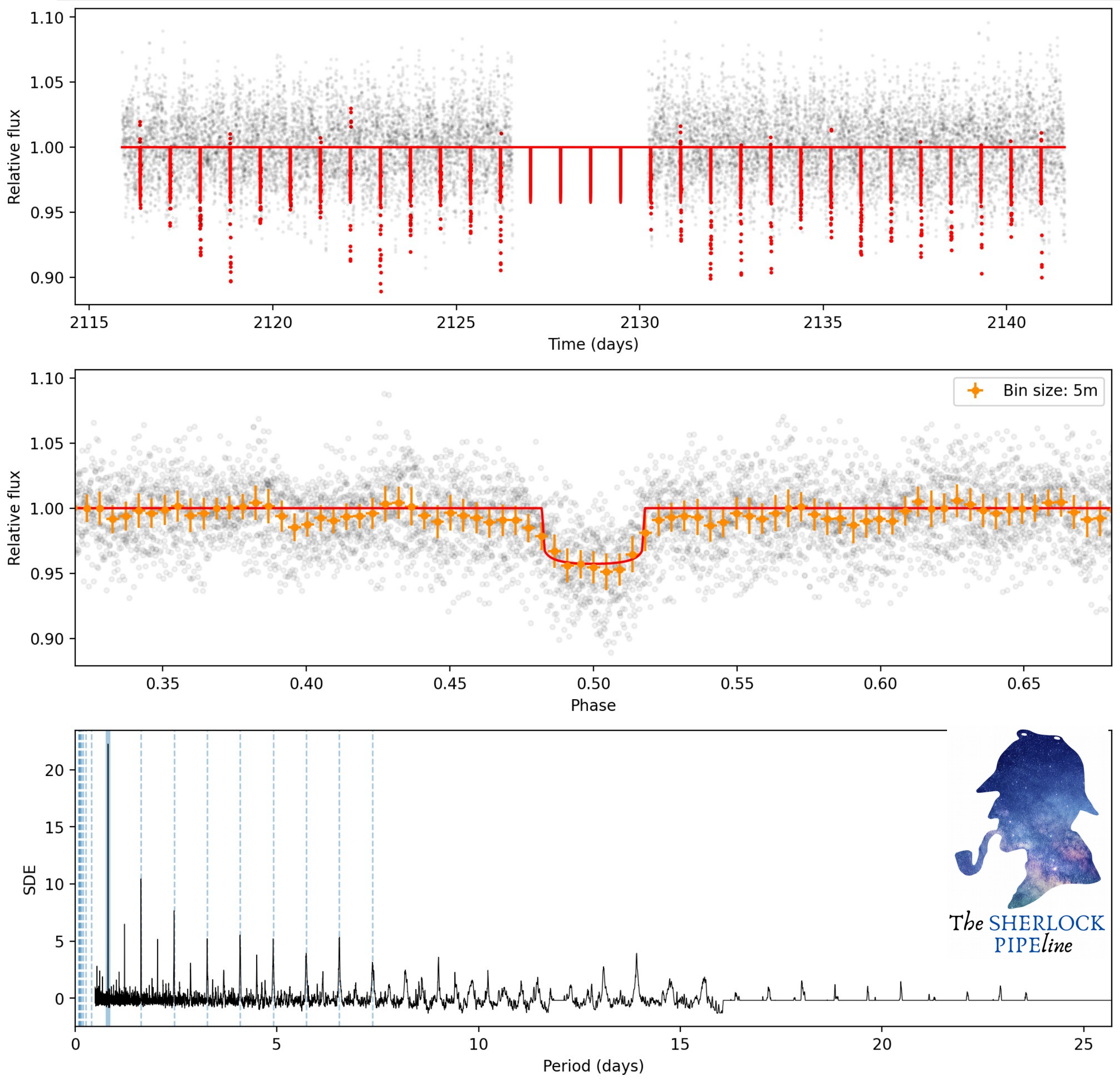

Fig. 3 : Example of a signal detected with Sherlock in both primary and extended mission of TESS. This particular transit is not a planet, but rather a small star orbiting a bigger one (eclipsing binary). Own work.

Method

We analysed the ligtht curves with the open-source Sherlock Pipeline that retrieves the data from online databases, detrends them according to user defined parameters (fig. 4), searches for transits and provides nice graphs and figures to assess the validity of the detection (fig. 3). Then, for any of the 1302 targets displaying a potential signal, we analysed its lightcurve from TESS extended mission. If the same signal is detected, it goes through a vetting check, then follow-up observations with the TRAPPIST telescopes.The occurrence rates are computed by using the result of our analysis with Sherlock and accounting for detection bias by doing injection-recovery tests (fig. 5). Then, formula 1 is used to get the unbiased occurrences.

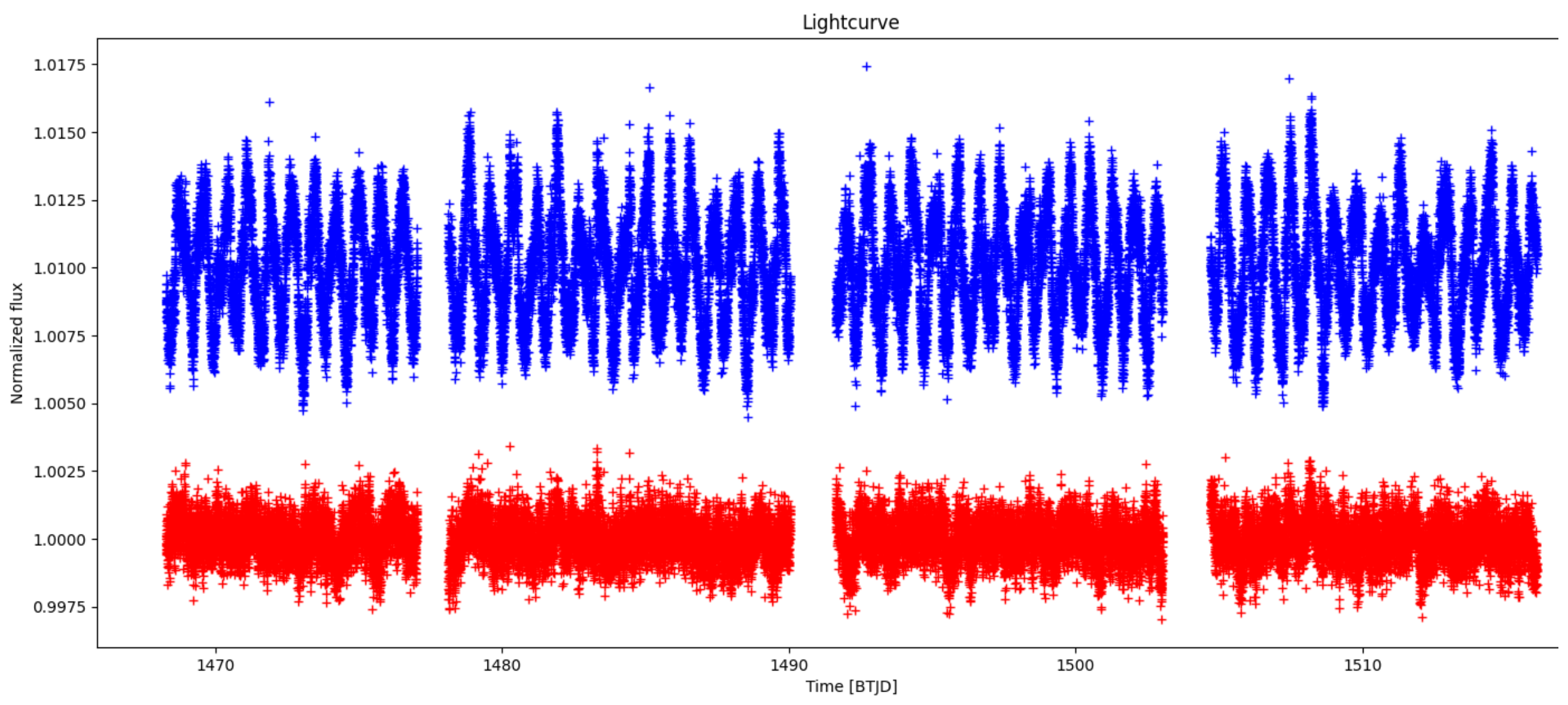

Fig. 4 : A light curve before (blue) and after (red) cleaning by Sherlock, using a pre-whitening method. Own work.

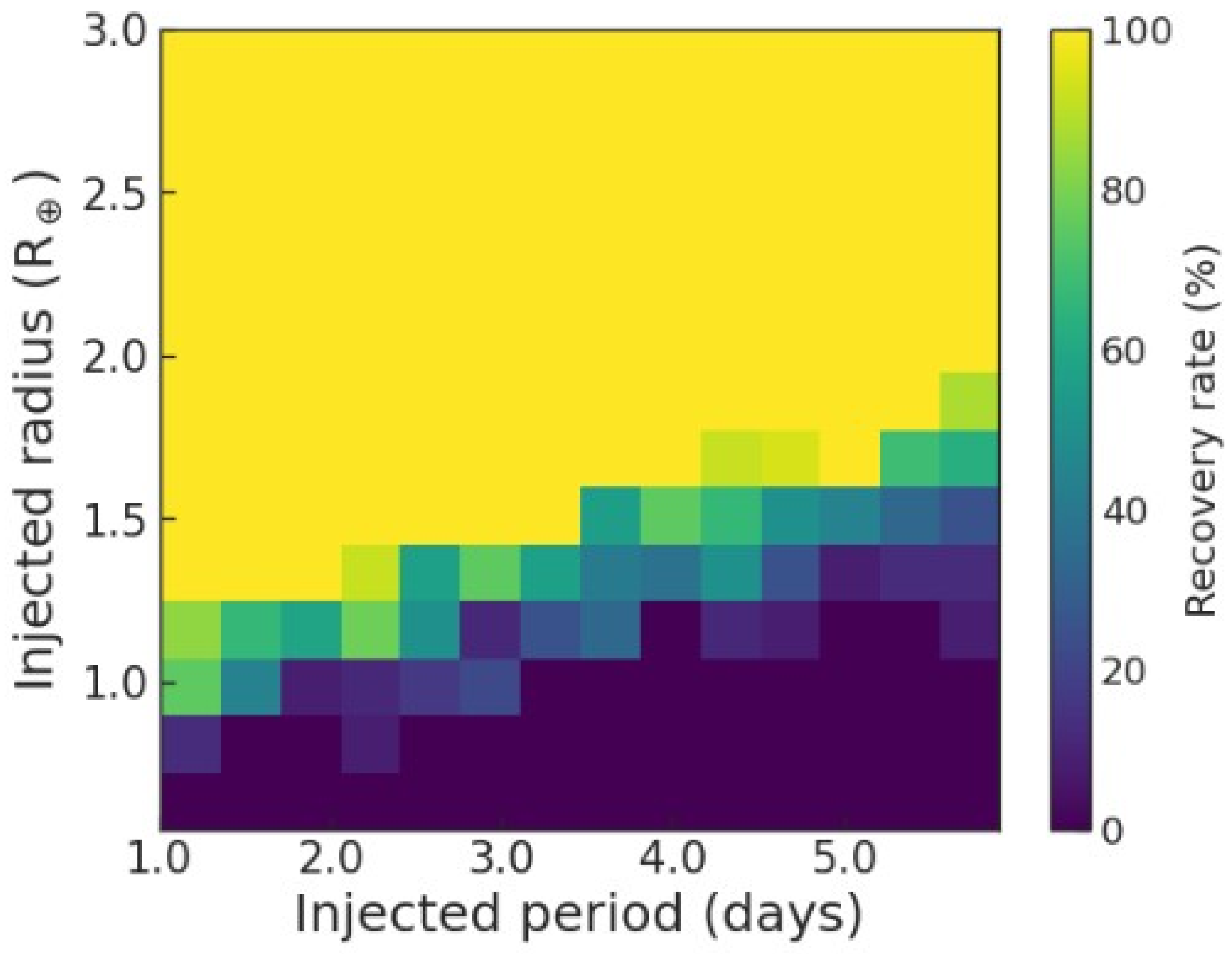

Fig. 5 : Result of injection and recovery tests to infer our capability to detect small planets with our method. This is done by injecting synthetic planets in real light curves, and then trying to recover it. This target has a G magnitude of 13.3 and was observed in a single sector of TESS. From Van Grootel et al., 2021.

Formula 1 : upper limit for the occurrence of planets:

$$f_{max} = 1-\left(1-\boxed{C}\right)^{\frac{1}{\left(\boxed{N}*\boxed{P_{transit}}*\boxed{P_{detection}}\right)+1}}$$

Confidence level

Number of star

Transit probability, constrained by geometry.

$$P_{transit} = \frac{R_* + R_p}{a}$$

R_p : Planet's radius
R_* : Star's radius
a : Semi-major axis

Detection probability, determined through injection & recovery tests (see fig. 7)

Results

While several signals are still under investigation, so far no trace of close-in planets was detected (fig. 7). From this result over so many targets we were able to compute the maximum occurrence rate for close-in planets around sdBs with strong statistical significance (see fig. 6 for cycle 1 occurrences). This result implies that short period planets are, at best, rare around sdBs. Once all the signals are investigated, we will update the occurrence rates with even more stringent constraints.

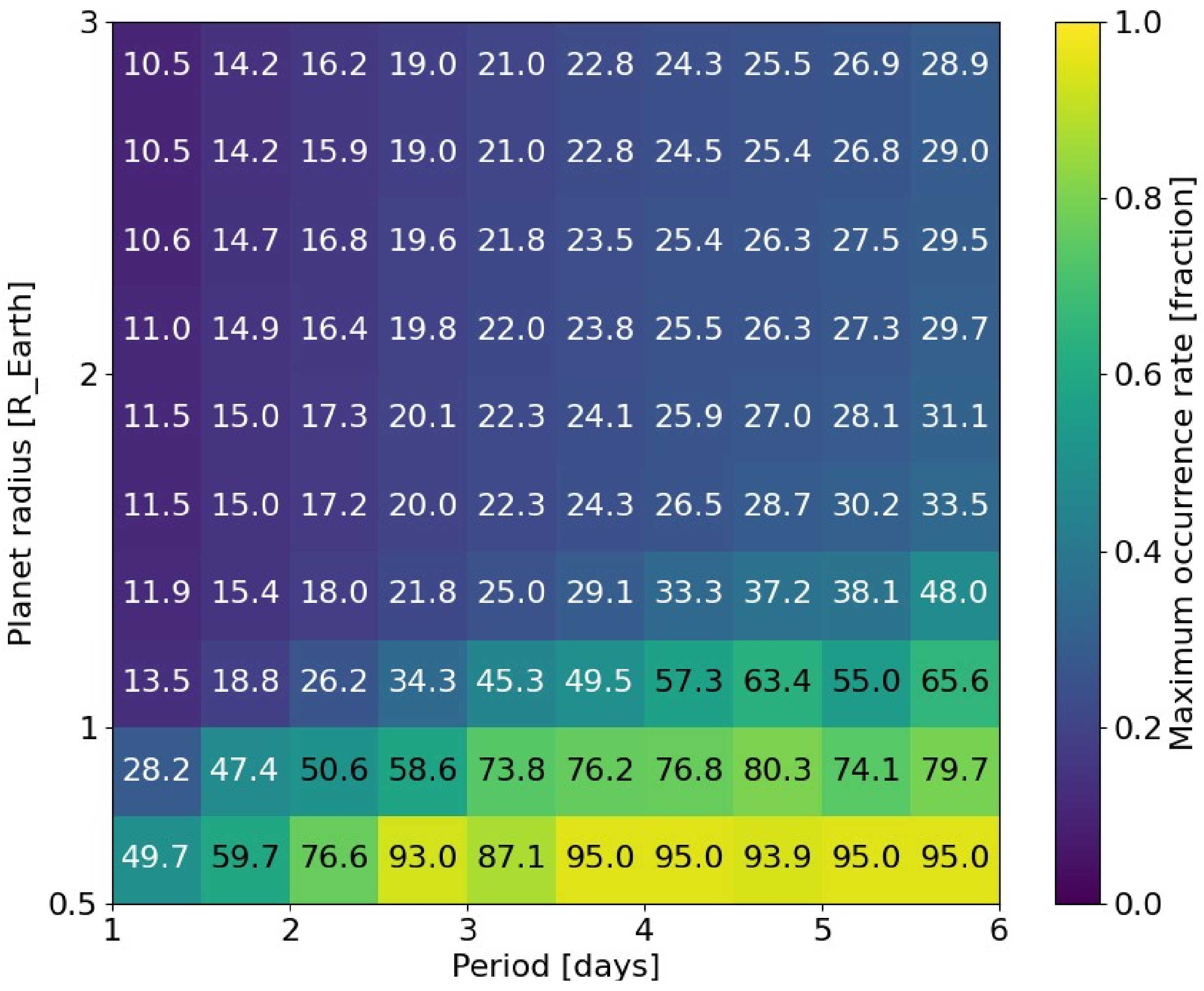

Fig. 6 : Upper limit for the occurrence rates of planets around hot subdwarf stars as a function of their period and radius. This figure shows results for the 792 sdBs from the cycle 1 of TESS. This figure is read as "there is at most 10.5 % of sdBs that have a 3 $R_\oplus$ planet with a 1 day period". Confidence level in formula 1 is set to 95%. From Thuillier et al., 2022.

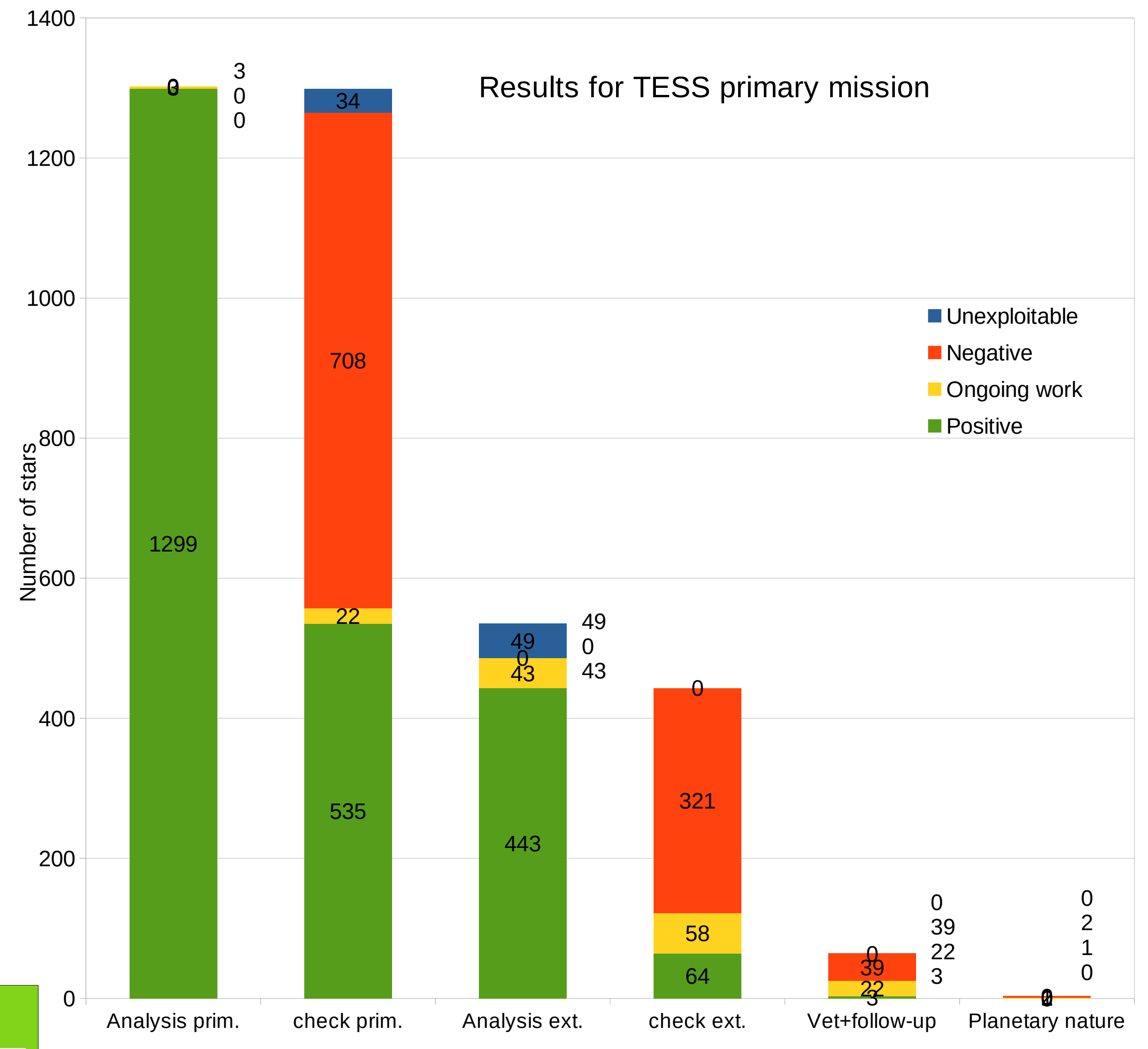

Fig. 7 : Number of targets passing each step of the analysis (green) for the full primary mission (792 stars from cycle 1 and 510 from cycle 2). "Analysis prim." = star's data from TESS primary mission was analysed using Sherlock. "Check prim." = the results (curves and numbers) were above our thresholds. "ext." = extended mission (TESS cycles >= 3). "Vet + follow-up" = the signal was confirmed to be a real object. "Planetary nature" = the object nature has been confirmed as a planet. Targets were labelled as "Unexploitable" when their light curves were too chaotic to be used. The ones labelled with "ongoing work" are still under investigation.

Relevant papers

Van Grootel et al. 2021 :

A search for transiting planets around hot subdwarfs

I. Methods and performance tests on light curves from *Kepler*, K2, TESS, and CHEOPS★

Thuillier et al. 2022 :

A search for transiting planets around hot subdwarfs

II. Supplementary methods and results from TESS Cycle 1

A.Thuillier, V. Van Grootel, L. Siess, F.J. Pozuelos, M. Devora-Pajares, S. Charpinet

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