# A search for transiting planets around hot subdwarfs

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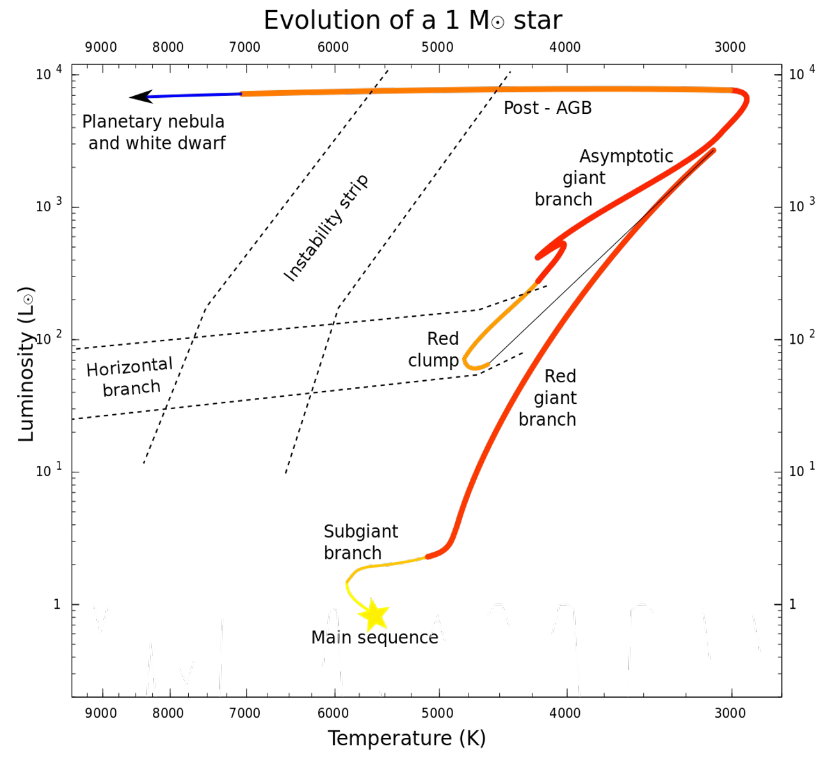
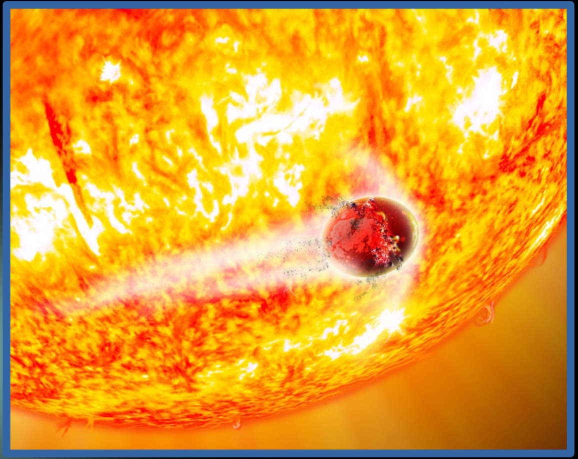
# Motivation

## Evolution of planetary systems with stellar evolution





Introduction
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Conclusion

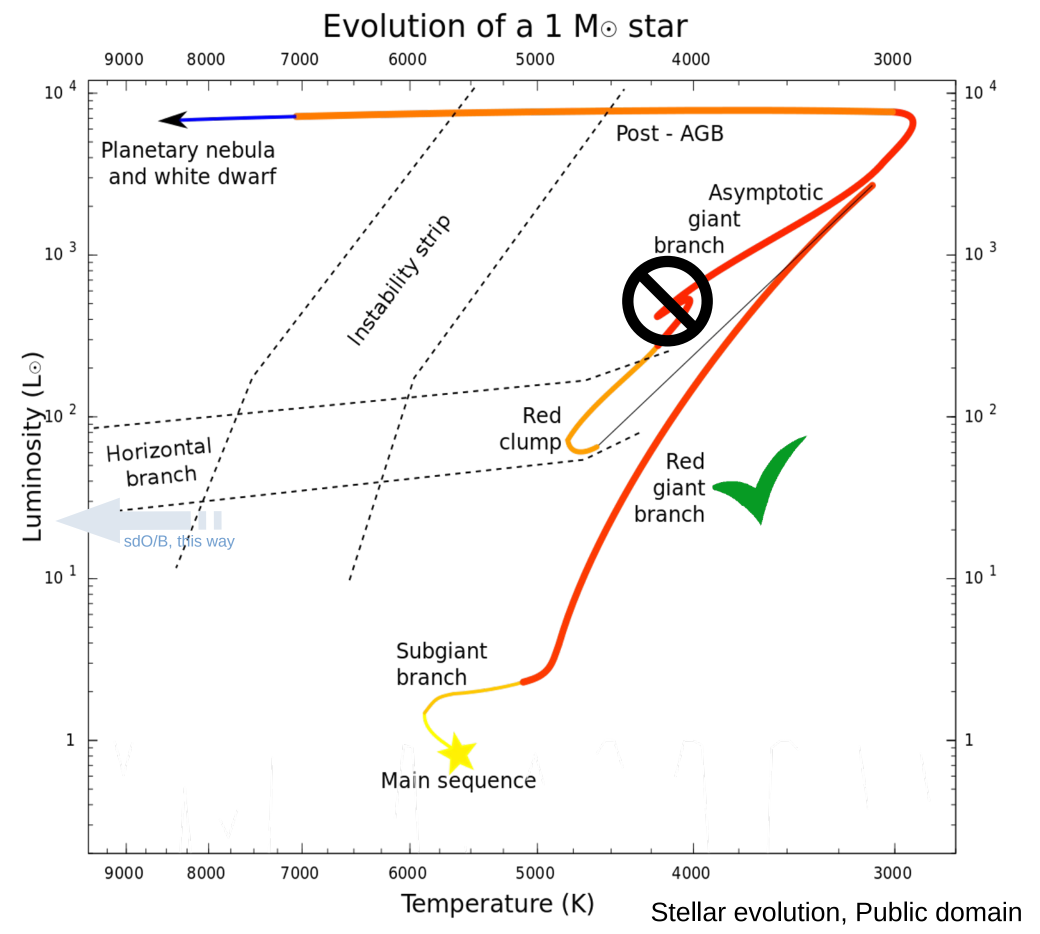
# Why hot subdwarfs?

## (sdB/O stars)

- Post-Red Giant Branch (RGB) stars, do no ascend Asymptotic Giant Branch

- Small stars (0.1-0.3 $R_{sun}$)
=> well-suited for the **transit** method: small stars brings small planets !

- Short-lived (~100 Myr)
=> Migration or 2nd generation planets unlikely



Stellar evolution, Public domain

# Scientific questions

## I. Do hot subdwarfs have planets?

- No occurrence rates for planets around hot subdwarf stars
  => Do they have planets? If yes, which type and in which proportions?

## II. Can planets survive an engulfment?

- No observational constraints for engulfed planets
  => Can planet survive this process?
  => If yes, what are the remnants?

# Data

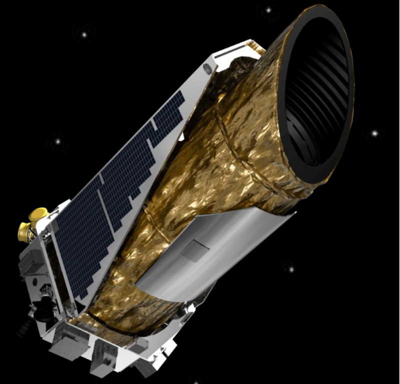
**Light curves available**

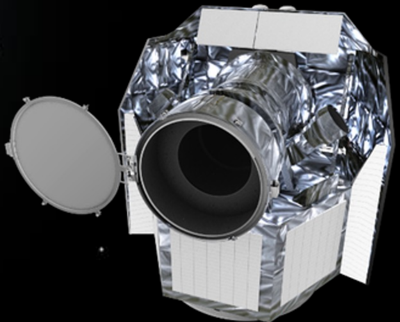
- Kepler+K2: 72 + 174 targets at 1-min cadence

- TESS: ~3300 targets at 2-min and 20s cadence at Sector 51

- CHEOPS: 61 targets, not observed by TESS neither by Kepler, 1-min cadence

"*CHaracterizing ExOPlanet Satellite*"
ESA class S mission
Heliosynchronous orbit of Earth at 700km altitude





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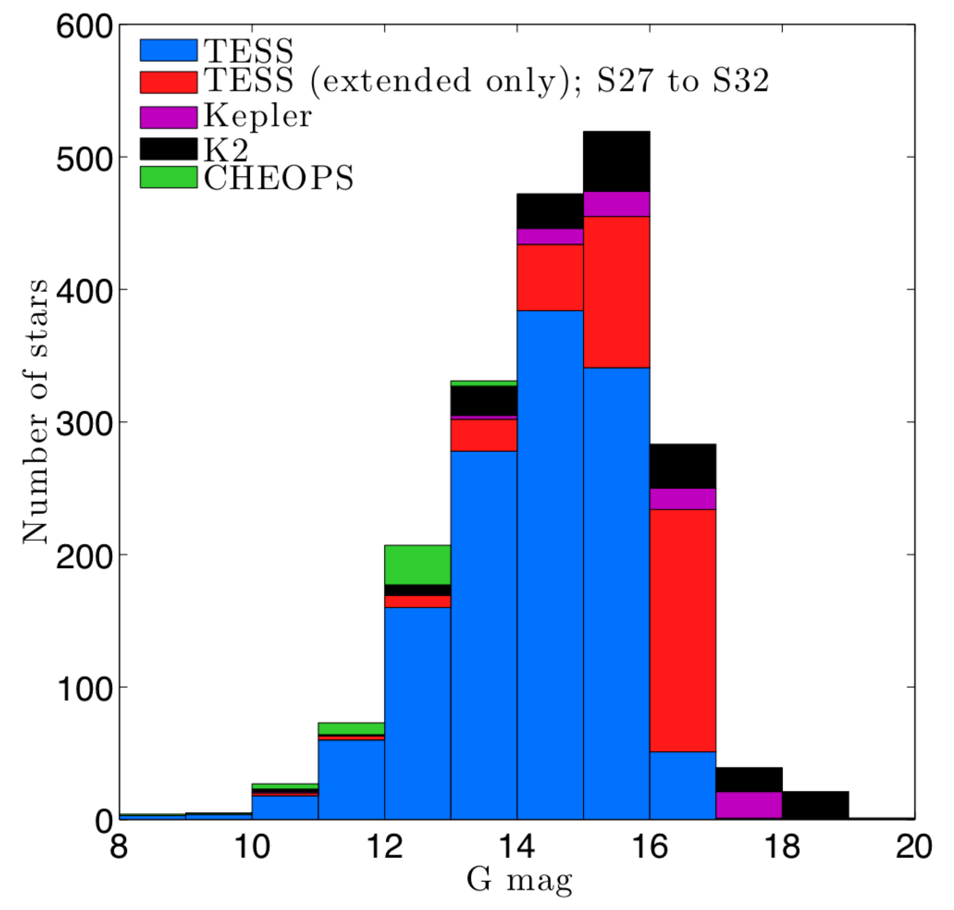
# Data



600
500
400
300
200
100
0
Number of stars
🟦 TESS
🟥 TESS (extended only); S27 to S32
🟪 Kepler
⬛ K2
🟩 CHEOPS
8
10
12
14
16
18
20
G mag

# Method

## 1) Looking for transits with the SHERLOCK PIPEline

**S**earching for **H**ints of **E**xoplanets f**R**om **L**ightcurves **O**f spa**C**e-based see**K**ers

*Pozuelos et al., A&A 641, A23, 2020*

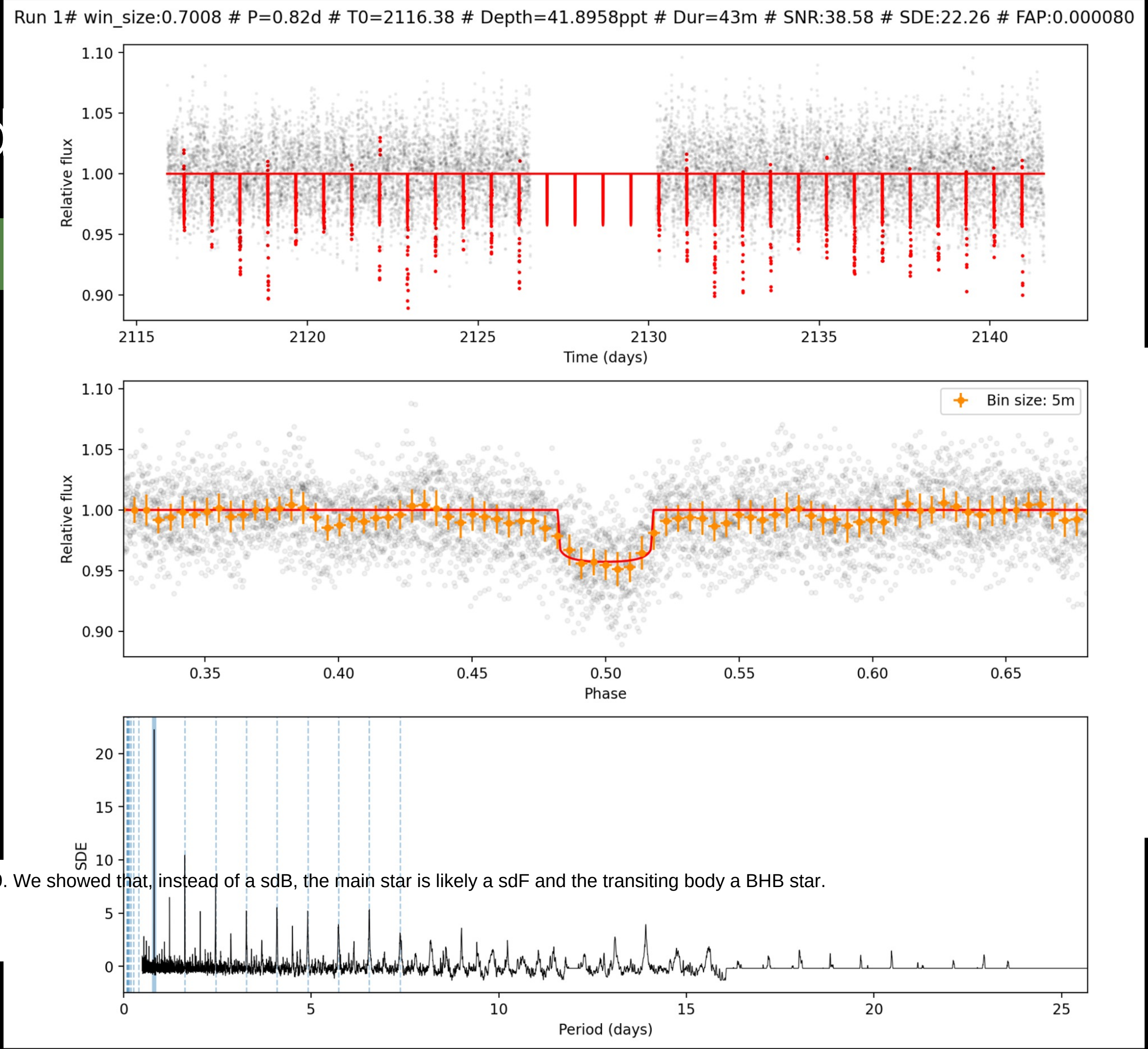
Available on open access on Github:
[https://github.com/franpoz/SHERLOCK](https://github.com/franpoz/SHERLOCK)

Gathering and detrending data, search for transits (with TLS; Hippke & Heller 2019),
Vetting process (background variation, location and brightness of nearby stars, etc.)

The SHERLOCK PIPEline

# Method

## 1) Looking



0.82 days signal on TIC 397833009. We showed that, instead of a sdB, the main star is likely a sdF and the transiting body a BHB star.

The SHERLOCK PIPEline

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# Method

## 2) Confirming the transit by follow-up observations

TRAPPIST ULiège 0.6m telescopes

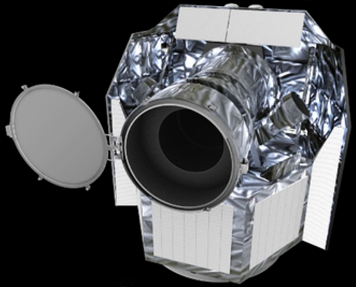
"*TRAnsiting Planets and PlanetesImals Small Telescope*"

Oukaimeden observatory (Morocco)

La Silla observatory (Chile)

Targets up to G~15: we can confirm a transit to ~2500 ppm depth

CHEOPS: Targets up to G~13, ~500 ppm transit depth



## 3) Characterizing the transiting body

Radial Velocity data to constrain the transiting body's mass:

- ESO archives
- Large surveys: SDSS, LAMOST,…
- Hot subdwarf community
- Write proposals…

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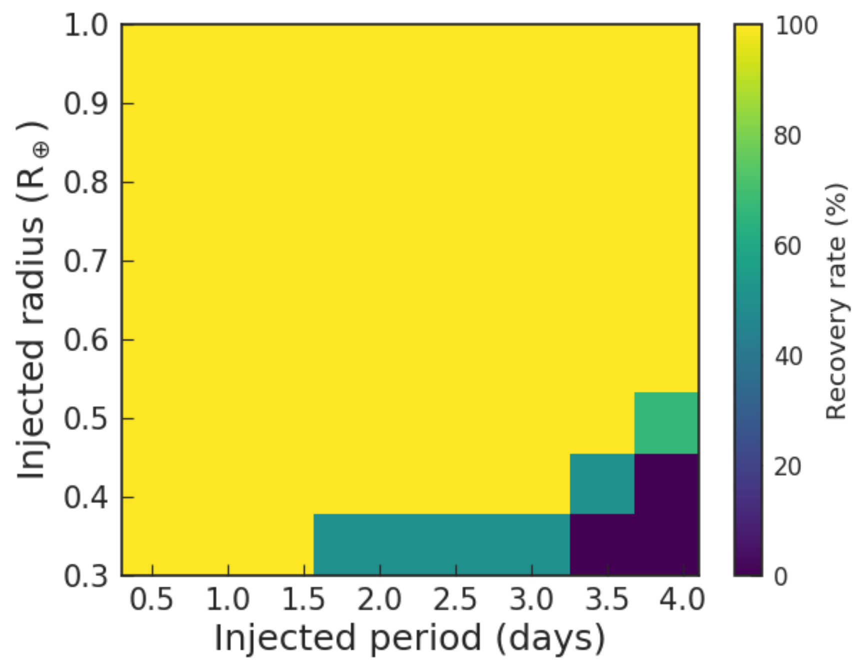
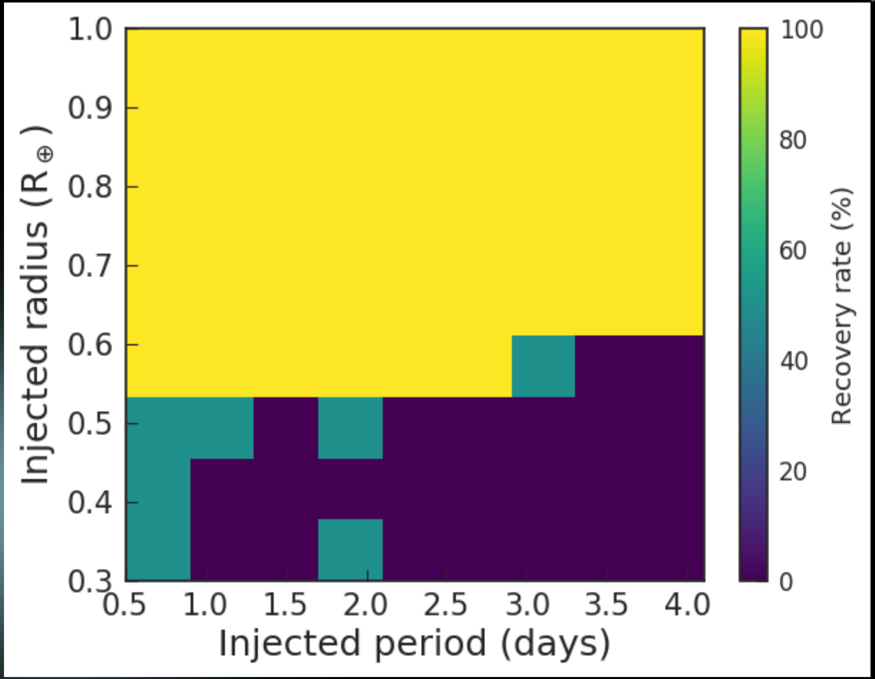
# Results

## 1. Injection-and-recovery tests: Kepler/K2 data



KIC 8054179 (Gmag 14.3), 90 days of data (Q6 Kepler).

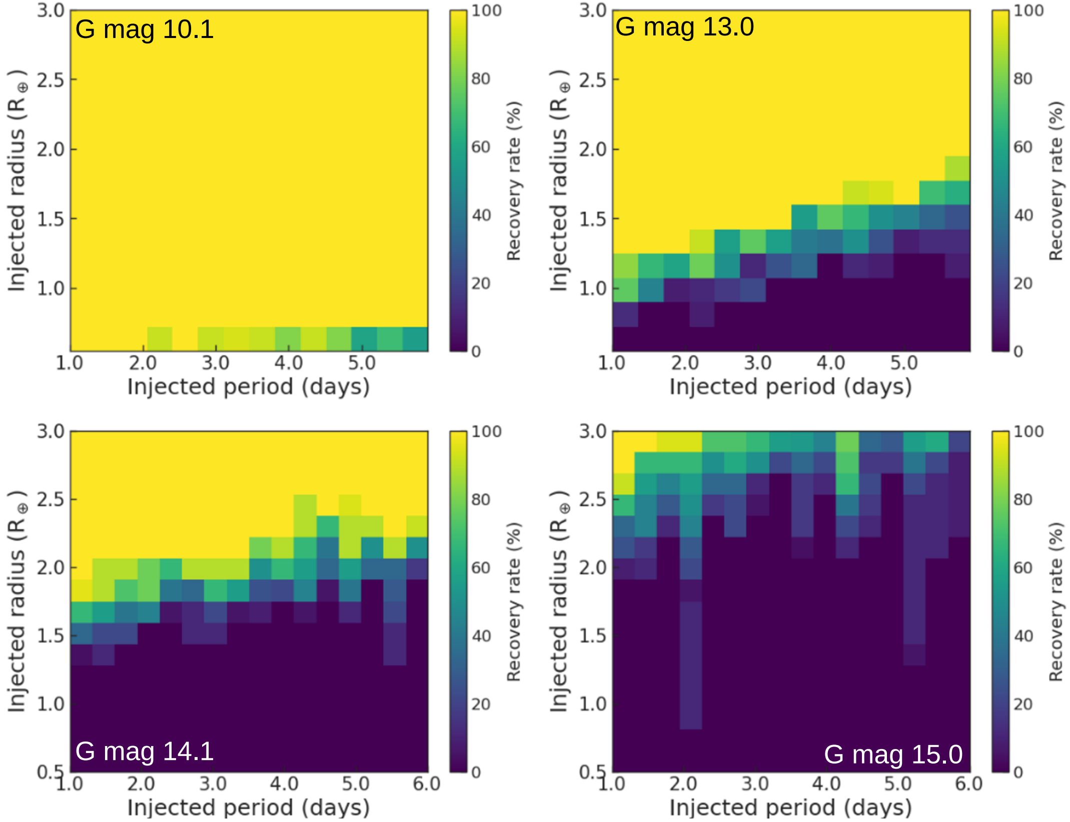


EPIC 206535752 (Gmag=14.0), 81 days of data (C3 K2)

# Results

## 1. Injection-and-recovery tests: TESS data

1-sector data, increasing magnitudes
(Gmag in 12-15=90% targets)

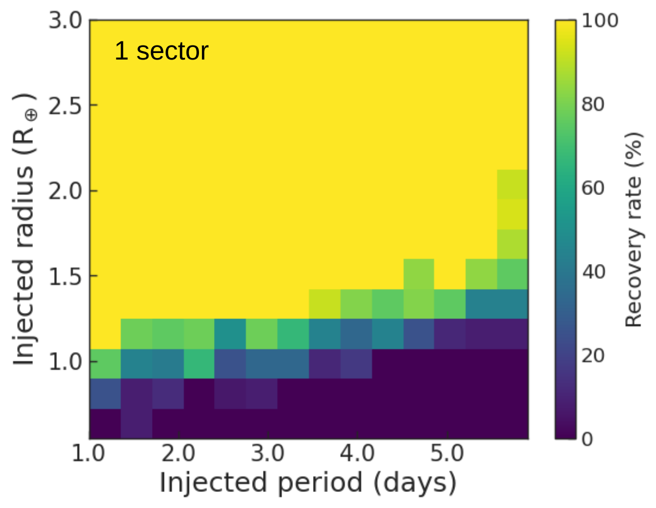


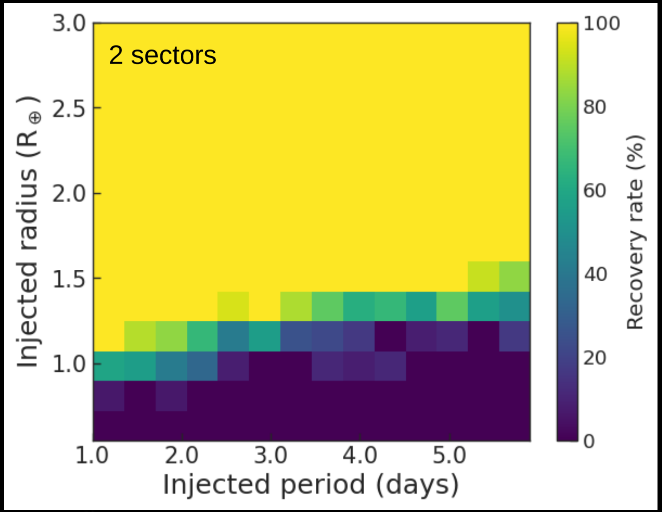
Injection-recovery test of four different hot subdwarfs having various magnitude.
Top left : TIC 147283842 (Gmag 10.1), top right TIC 96949372 (Gmag 13.0),
bottom left : TIC 85400193 (Gmag 14.1), bottom right : TIC 372681399 (Gmag 15.0).
From Van Grootel et al. 2021 (A&A, 650, 205).

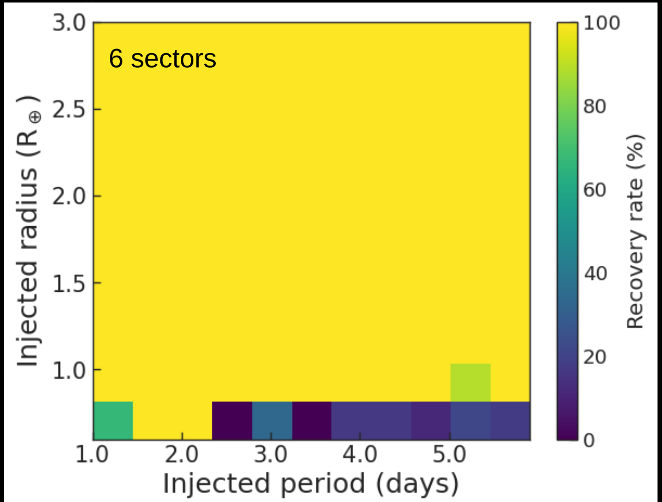
# Results

## 1. Injection-and-recovery tests: TESS data

Increasing observation duration:
(TIC362103375, Gmag=13.0)
1 -> 2 -> 6 sectors



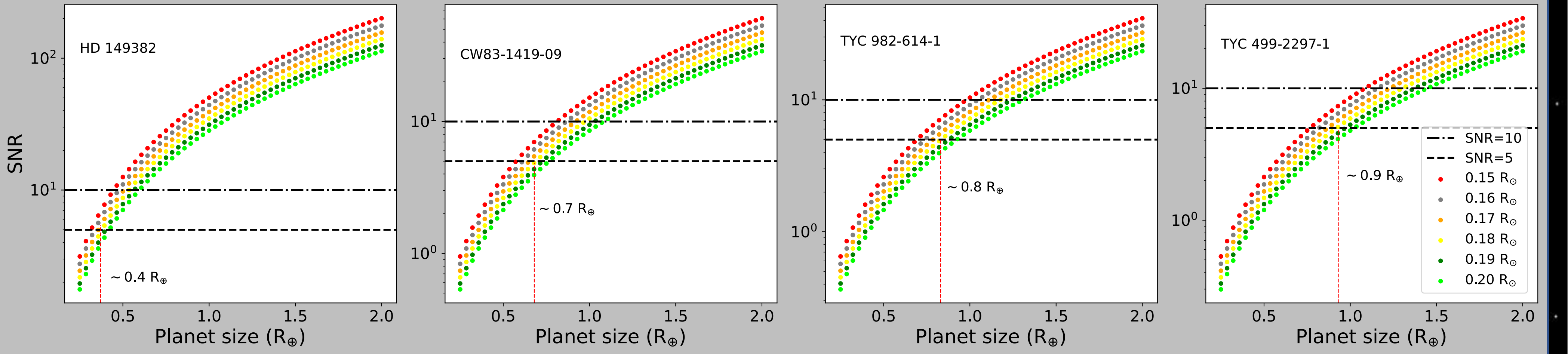




# Results

**CHEOPS data**

≲ 1 R_Earth planets can be detected in the 61 targets



# Results

## 1. Injection-and-recovery tests

Full results on Van Grootel et al. 2021
(A&A, 650, 205)

**Main conclusions:**

- TESS data will allow us to measure the planet occurence rate around hot subwarfs

- Best TESS targets, Kepler/K2 targets, and CHEOPS  targets will allow us to detect ≲ 1 R_E planets and small, possibly disintegrating objects

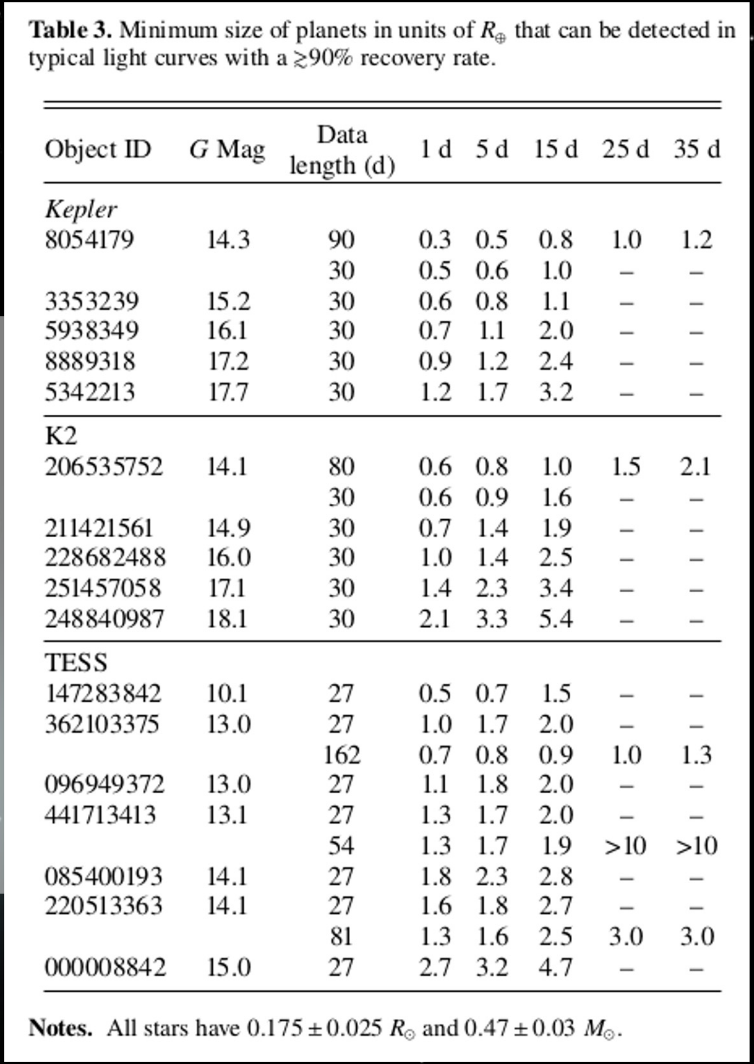


**Table 3.** Minimum size of planets in units of $R_\oplus$ that can be detected in typical light curves with a ≳90% recovery rate.

| Object ID | *G* Mag | Data length (d) | 1 d | 5 d | 15 d | 25 d | 35 d |
|---|---|---|---|---|---|---|---|
| *Kepler* | | | | | | | |
| 8054179 | 14.3 | 90 | 0.3 | 0.5 | 0.8 | 1.0 | 1.2 |
| | | 30 | 0.5 | 0.6 | 1.0 | – | – |
| 3353239 | 15.2 | 30 | 0.6 | 0.8 | 1.1 | – | – |
| 5938349 | 16.1 | 30 | 0.7 | 1.1 | 2.0 | – | – |
| 8889318 | 17.2 | 30 | 0.9 | 1.2 | 2.4 | – | – |
| 5342213 | 17.7 | 30 | 1.2 | 1.7 | 3.2 | – | – |
| K2 | | | | | | | |
| 206535752 | 14.1 | 80 | 0.6 | 0.8 | 1.0 | 1.5 | 2.1 |
| | | 30 | 0.6 | 0.9 | 1.6 | – | – |
| 211421561 | 14.9 | 30 | 0.7 | 1.4 | 1.9 | – | – |
| 228682488 | 16.0 | 30 | 1.0 | 1.4 | 2.5 | – | – |
| 251457058 | 17.1 | 30 | 1.4 | 2.3 | 3.4 | – | – |
| 248840987 | 18.1 | 30 | 2.1 | 3.3 | 5.4 | – | – |
| TESS | | | | | | | |
| 147283842 | 10.1 | 27 | 0.5 | 0.7 | 1.5 | – | – |
| 362103375 | 13.0 | 27 | 1.0 | 1.7 | 2.0 | – | – |
| | | 162 | 0.7 | 0.8 | 0.9 | 1.0 | 1.3 |
| 096949372 | 13.0 | 27 | 1.1 | 1.8 | 2.0 | – | – |
| 441713413 | 13.1 | 27 | 1.3 | 1.7 | 2.0 | – | – |
| | | 54 | 1.3 | 1.7 | 1.9 | >10 | >10 |
| 085400193 | 14.1 | 27 | 1.8 | 2.3 | 2.8 | – | – |
| 220513363 | 14.1 | 27 | 1.6 | 1.8 | 2.7 | – | – |
| | | 81 | 1.3 | 1.6 | 2.5 | 3.0 | 3.0 |
| 000008842 | 15.0 | 27 | 2.7 | 3.2 | 4.7 | – | – |

**Notes.** All stars have $0.175 \pm 0.025\ R_\odot$ and $0.47 \pm 0.03\ M_\odot$.

# 2. Results from TESS Cycle 1

TESS cycle 1 fully analyzed (792 stars):

- 352 signals (belonging to 243 stars)
but only 46 retrieved Cycle 3 (12 stars not re-observed)

- 7 stars with signals are now followed-up (2 signals retrieved thus far); 23 signals will be followed-up in coming weeks/months

- 0 planetary body confirmed

Thuillier et al., accepted to A&A
[https://doi.org/10.1051/0004-6361/202243554](https://doi.org/10.1051/0004-6361/202243554)

All targets (792 stars)

Detection of a signal above thresholds and visually credible.

**Stage 0** 352 signals

Signal recovered in TESS cycle 3.

**Stage 1** 46 signals

Positive to our vetting process.

**Stage 2** 30 signals

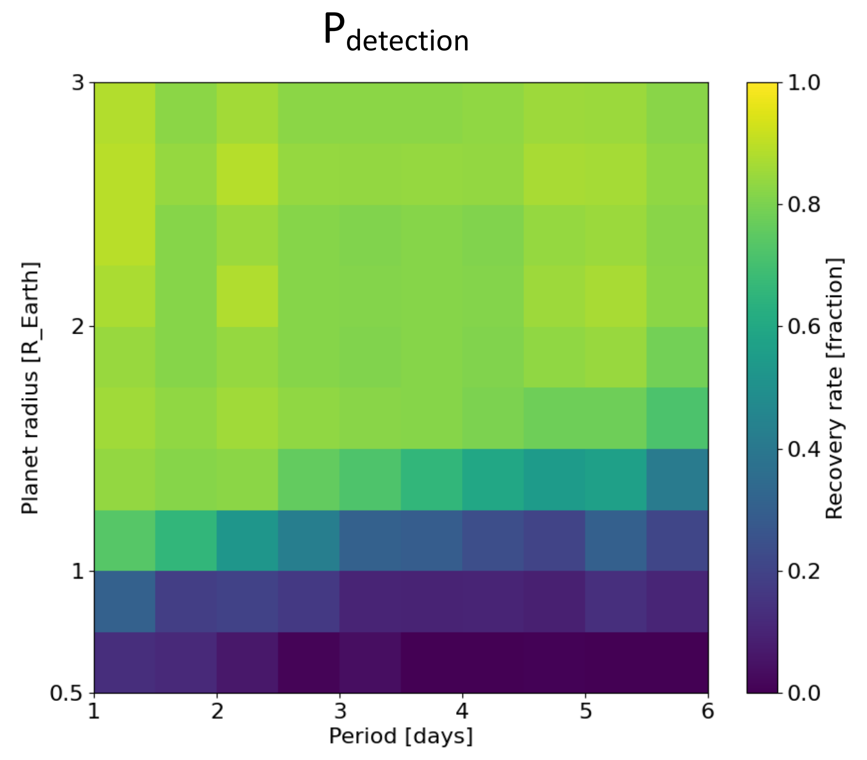
Recovered in follow-up observations

**Stage 3** 2 signals

Planetary nature confirmed

**Stage 4** 0 signal

# First statistics on planet occurrence around hot subdwarfs



With C=0.95, assuming the 549 targets are Gmag=13-13.5 and R*=0.175Rsun

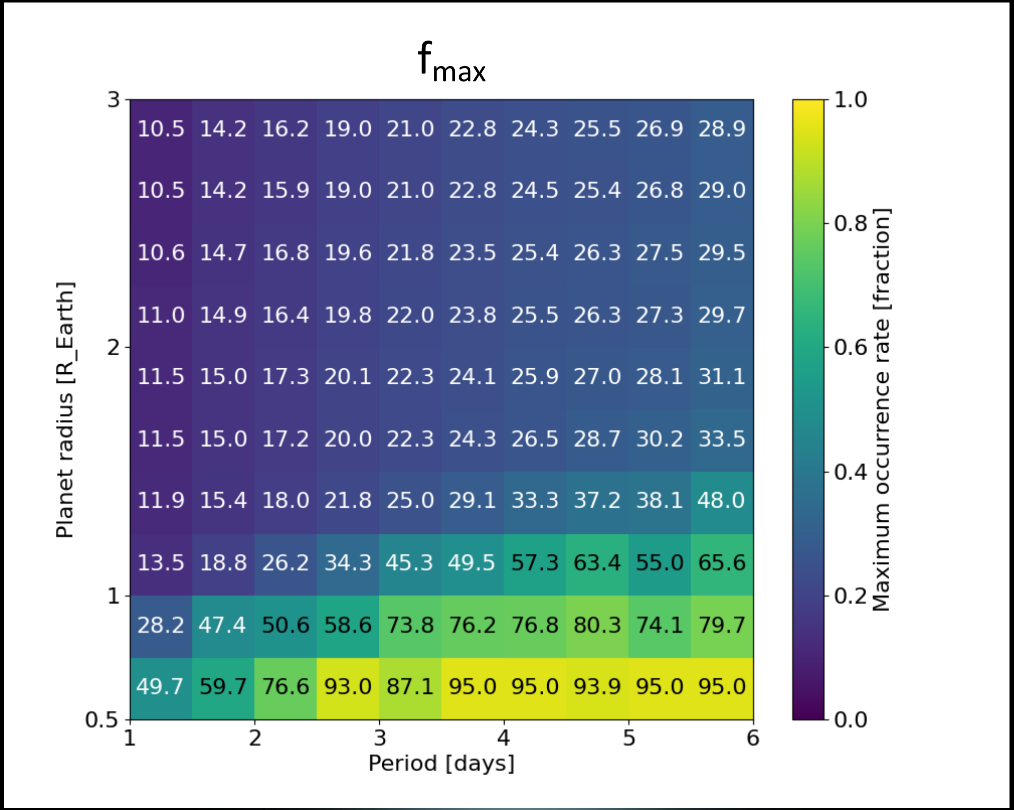
Based on 549 stars displaying no signal (list in Thuillier et al.). The upper limit $f_{max}$ of the occurrence rate based on this non-detection is:

$$f_{max} = 1 - (1 - C)^{\frac{1}{N'+1}}$$

(Faedi et al. 2011)

$$N' = N \times P_{\text{transit}} \times P_{\text{detection}}$$

# First statistics on planet occurrence around hot subdwarfs



| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 10.5 | 14.2 | 16.2 | 19.0 | 21.0 | 22.8 | 24.3 | 25.5 | 26.9 | 28.9 |
| 10.5 | 14.2 | 15.9 | 19.0 | 21.0 | 22.8 | 24.5 | 25.4 | 26.8 | 29.0 |
| 10.6 | 14.7 | 16.8 | 19.6 | 21.8 | 23.5 | 25.4 | 26.3 | 27.5 | 29.5 |
| 11.0 | 14.9 | 16.4 | 19.8 | 22.0 | 23.8 | 25.5 | 26.3 | 27.3 | 29.7 |
| 11.5 | 15.0 | 17.3 | 20.1 | 22.3 | 24.1 | 25.9 | 27.0 | 28.1 | 31.1 |
| 11.5 | 15.0 | 17.2 | 20.0 | 22.3 | 24.3 | 26.5 | 28.7 | 30.2 | 33.5 |
| 11.9 | 15.4 | 18.0 | 21.8 | 25.0 | 29.1 | 33.3 | 37.2 | 38.1 | 48.0 |
| 13.5 | 18.8 | 26.2 | 34.3 | 45.3 | 49.5 | 57.3 | 63.4 | 55.0 | 65.6 |
| 28.2 | 47.4 | 50.6 | 58.6 | 73.8 | 76.2 | 76.8 | 80.3 | 74.1 | 79.7 |
| 49.7 | 59.7 | 76.6 | 93.0 | 87.1 | 95.0 | 95.0 | 93.9 | 95.0 | 95.0 |

Thuillier et al., accepted

Ex: At 1d orbital period, we can exclude the presence of a 3 R_E (resp. 0.5 R_E) planets in 89.5% (resp. 50.3%) of hot subdwarfs

# Conclusion

**- Do hot subdwarf stars have planets?**
**- What happens when a planet is engulfed by its star when it evolves?**

=> Data from Kepler/K2, TESS, CHEOPS missions (~3600 sdO/B)
=> Tools to perform the analysis (Sherlock Pipeline)
=> Access to follow up observations (TRAPPIST, CHEOPS)

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**-** TESS cycle 1 analyzed / several interesting signals under follow-up / first occurrence rates of planets around hot subdwarfs

=> no detection : strong observational constraints for the survival of planets !
=> detection : 1st planet around a hot subdwarf + potential survivor of an engulfment !

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**THANKS FOR YOUR ATTENTION !**