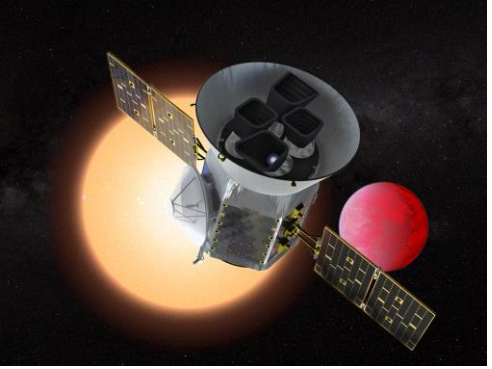

Optimizing TESS short cadence aperture for Asteroseismology of solar-like stars

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Abstract Thanks to missions such as **CoRoT** and ***Kepler*/K2**, asteroseismology has demonstrated that it is a powerful tool to determine precise stellar parameters. Now, with the NASA **TESS (Transiting Exoplanet Survey Satellite)** mission, a new opportunity arose to use this technique on a sample of more than 20,000 bright main-sequence and subgiant stars. The standard light curves provided by the TESS Science Processing Operations Center (SPOC) are optimized for exoplanet search, the main goal of this mission, and could be improved to **look for oscillations in solar-like stars**. Our experience with Kepler have shown that the ideal apertures are larger than the standard ones. These apertures increase the signal-to-noise ratio (SNR) of the oscillation modes of the stars while improving the low-frequency stability of the light curve. We developed an automatic code to determine the **optimal** aperture to look for the oscillation modes for a large sample of solar-like stars, in particular, on **planet host stars**.

Here we present the methodology and we will show examples of how we improve the SNR and detection of the modes using our apertures compared to other apertures obtained within the community.

Context of the research

- Photometric data from space missions (e.g. CoRoT, *Kepler*, K2) —> Asteroseismology is a **powerful tool** to determine stellar parameters (M, R, age) with high precision.

- Variability in Power spectrum density of a typical solar-like star (PSD): rotation, convection (or granulation), oscillations.

- Global seismic parameters (frequency of maximum power ν_{max}, frequency spacing $\Delta\nu$) combined with T_{eff} → estimate of M and R from scaling relations [$\Delta\nu$]

$$\nu_{\max} \propto g T_{\mathrm{eff}}^{-1/2} \propto M R^{-2} T_{\mathrm{eff}}^{-1/2} \qquad \langle \Delta\nu \rangle \propto \langle \rho \rangle^{1/2} \propto M^{1/2} R^{-3/2}$$

[e.g. Brown 1991; Kjeldsen & Bedding 1995]

- ***Transiting Exoplanet Survey Satellite (TESS)***: millions of lightcurves provided since 2018

- Light curves produced by *Science Processing Operations Center (SPOC)*: optimized for exoplanet search but not for asteroseismology

Goal: develop a method to automatically optimize the apertures of TESS data to look for solar-like oscillations

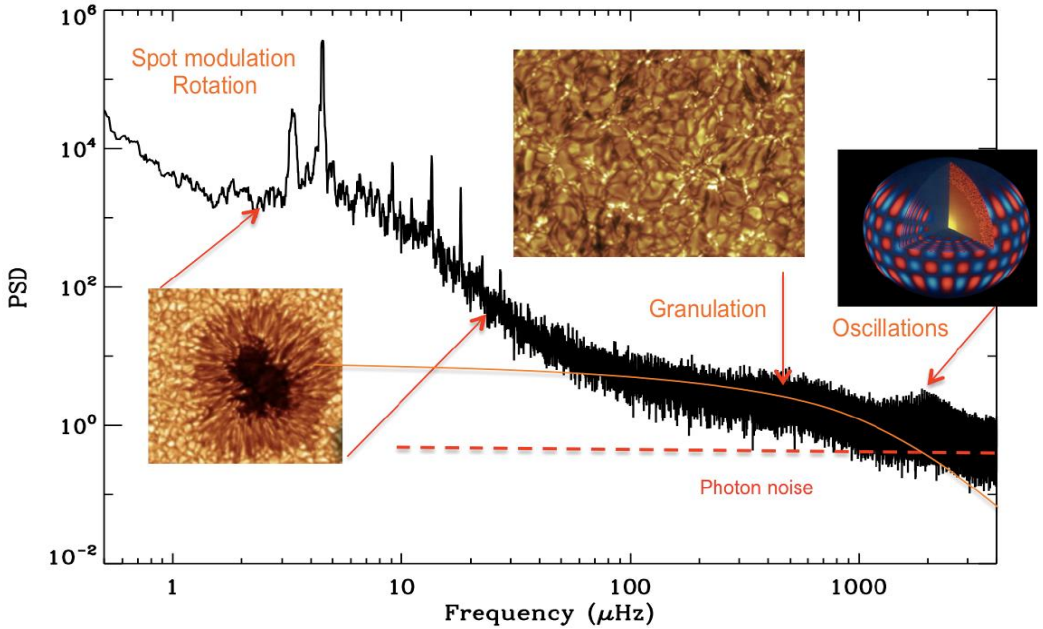


Figure 1. PSD of the *Kepler* target KIC 3733735 [from Garcia 2015]

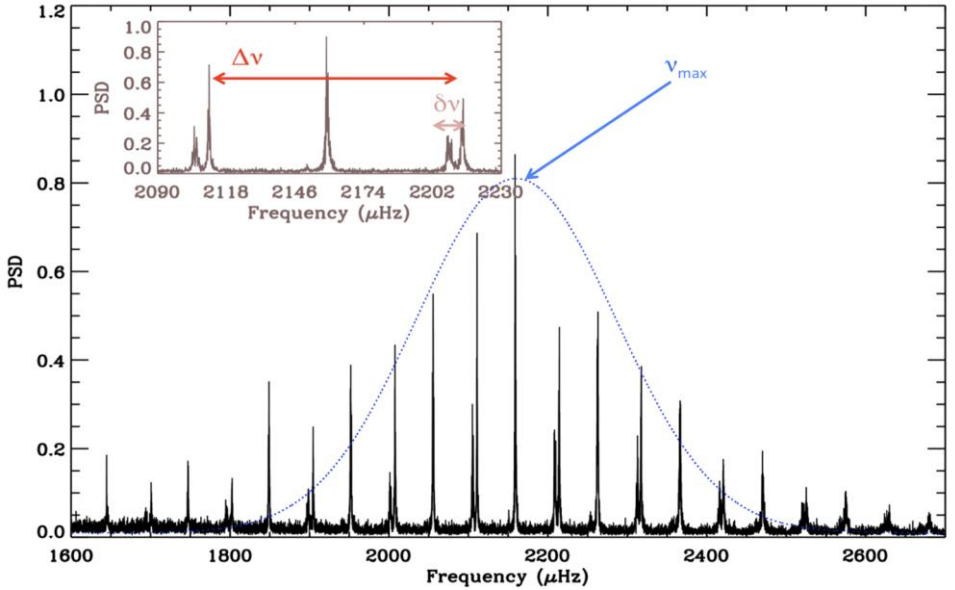


Figure 2. Typical oscillation spectrum of a solar-like star showing the frequency of maximum amplitude [from García & Ballot 2019]

Description of the methodology

1. Compute:
   - **Probability of detection** of the oscillations ($\mathbf{P_{det}}$)
   - Estimation of $\boldsymbol{\nu_{max}}$ using scaling relations
     [Campante et al. (2016), ATL from Schofield et al. (2019)]

2. Selection of **larger apertures:**
   - Start by selecting the pixel with maximum integrated flux (*flux_max*)
     - Or manually select it
   - Compute the **difference of integrated flux** (*dif_flux*) between two adjacent pixels in 2 directions (**mask A** and **mask B**)
   - To avoid nearby stars, a pixel is selected if:
     - *dif_flux* > 0 and Integrated flux of pixel > threshold (10, 100… $e^{-}s^{-1}$)
     - *dif_flux* < 0 and Integrated flux of pixel > *0.8*flux_max*

3. Correction of instrumental problems in the **light curves (LC)**
   - Correct TESS **flags** and instrumental effects (jumps, trends, angular momentum dump, etc)
     [García et al. 2011]
   - Fill gaps with inpainting methods
     [García et al. 2014, Pires et al. 2015]

4. Compute signal-to-noise ratio (SNR) in a region around estimated $\boldsymbol{\nu_{max}}$

5. **Optimal Aperture:** Select the aperture that maximizes the SNR of the oscillation modes

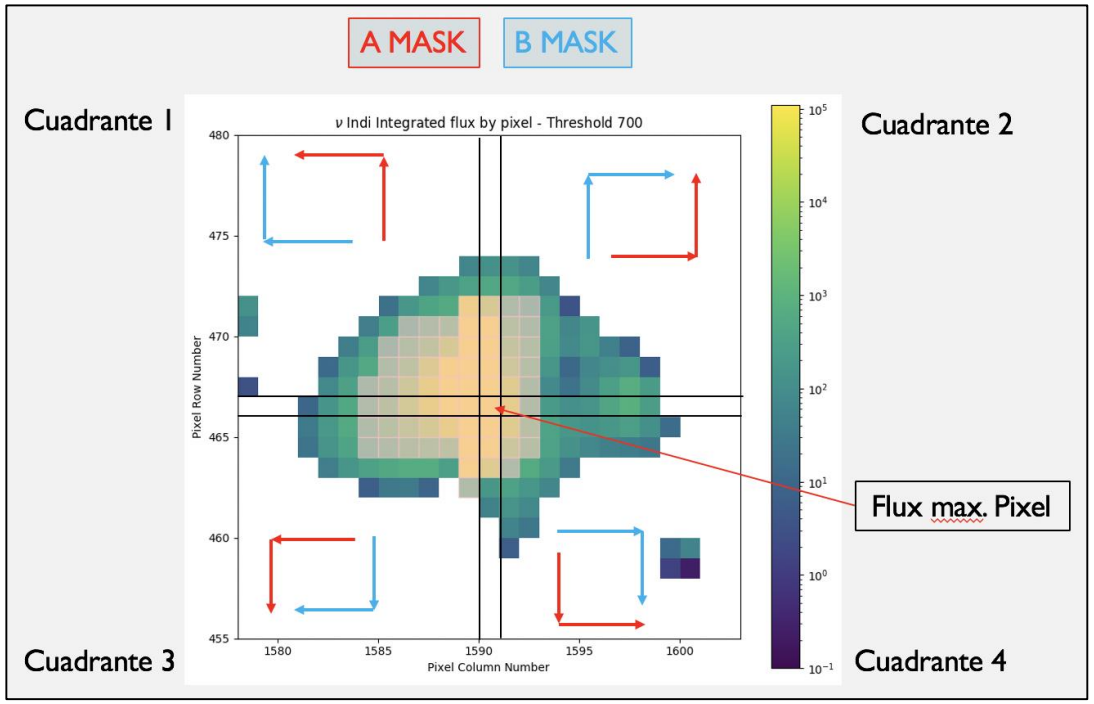
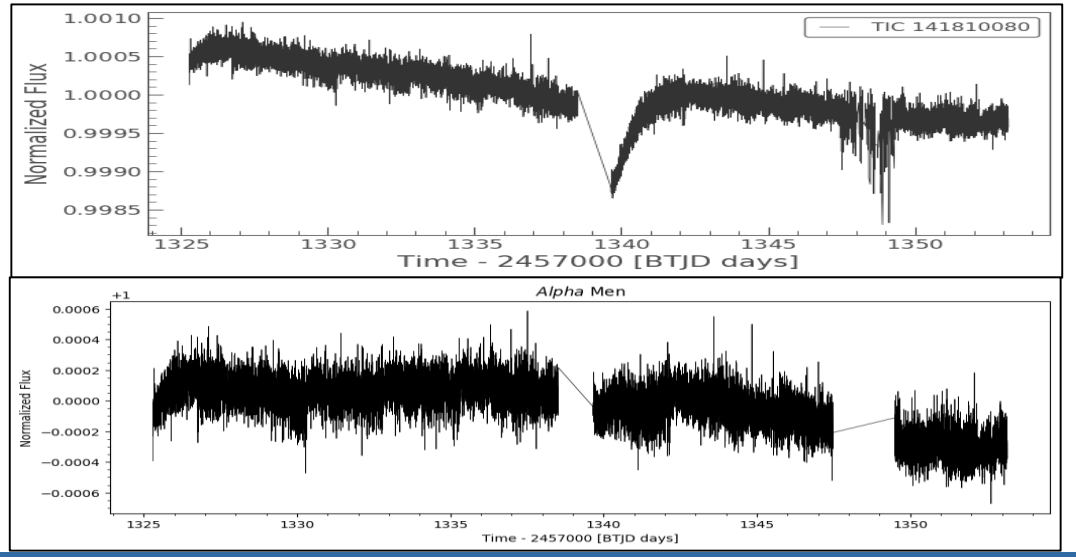


Figure 3. Example of apertura selection avoiding pixels with flux from nearby stars



Figures 4 Examples of two TESS light curves

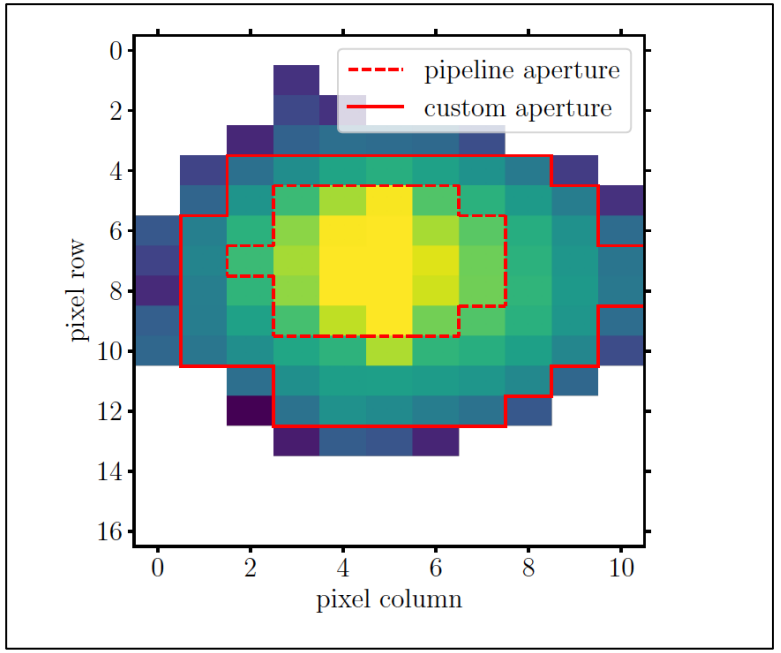
HD 38529 bright G4 subgiant star

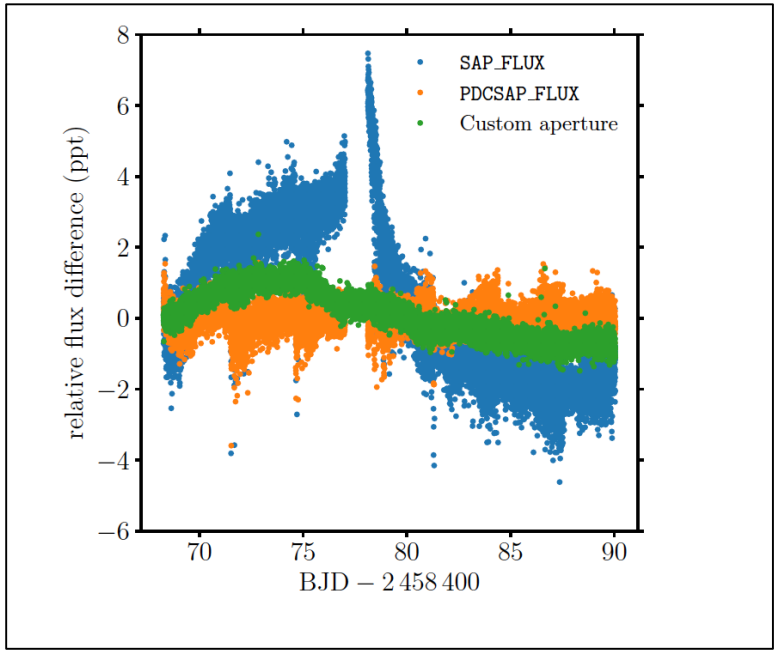
- Is the topranked target for asteroseismic detection in the *TESS's Asteroseismic Target List (ATL, Schoeld et al. 2019)*
- ATL predicted the oscillations would peak around $\sim 400 \mu Hz$
- **2 planets:**
  - *HD 38529b (*Jupiter-mass planet on a 14.3d orbit)
  - *HD 38529c (*2136d orbit*)*

Using **2-minute cadence** images from TESS's **Sector 6** observations:

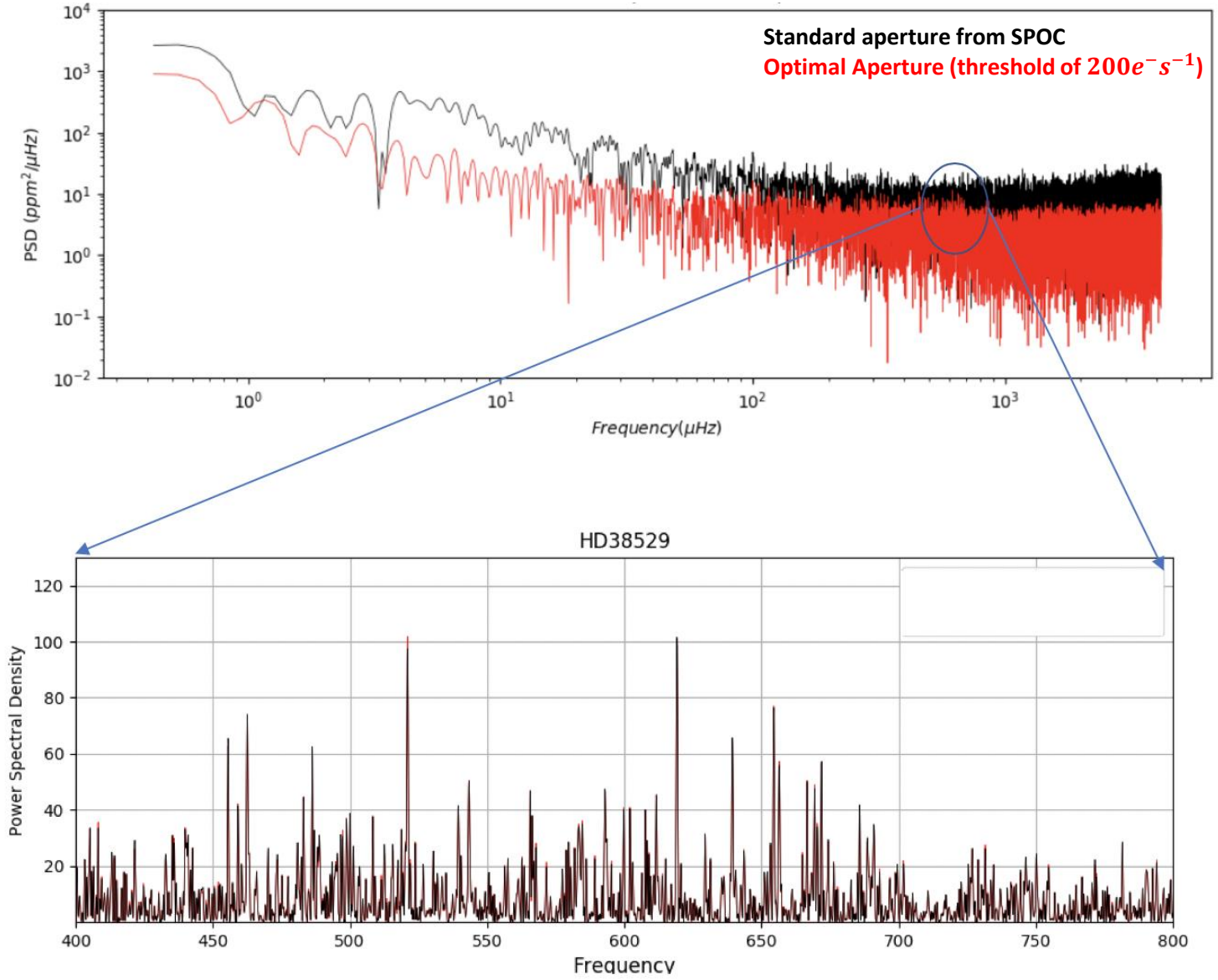
- Image and apertures:
  - Median image of HD 38529 with a logarithmic color scale
  - White regions had negative median fluxes → SPOC pipeline´s background subtraction
  - Default **pipeline aperture** (dashed line)
  - **Optimal asteroseismic aperture** (solid red line)

- Lightcurves of HD 38529:
  - Default pipeline´s SAP_FLUX data (**blue**) or PCSAP_FLUX data (**orange**)
  - Corrected lightcurve (**green**) from Optimal Aperture





Results. ***Planet host star HD 38529*** *[Ball et al. (2020)]*



Comparation of PSD from the **standard aperture** light curve (SPOC) and from our **optimal aperture** after correcting the light curve:

- No oscillations are detected the SPOC lightcurves *(Jenkins et al. 2016)*
- Higher background at high frequencies
- *B*y applying our methodology → Optimal aperture with threshold of $200\ e^{-}s^{-1}$
- **We found oscillations around $\sim 600\mu Hz$**

Zoom of the power excess region:

- Oscillation modes between 450-700 μHz
- *problem* → with only one month of TESS data (1 sector) not all the modes are excited.

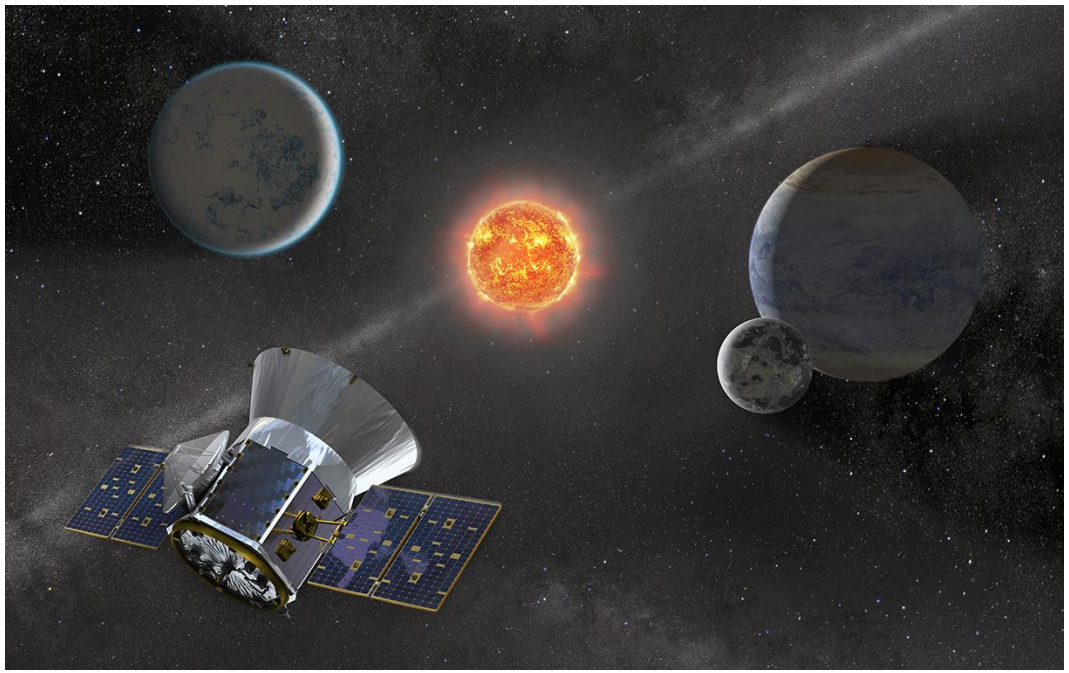
Asteroseismic modelling results for this star are :

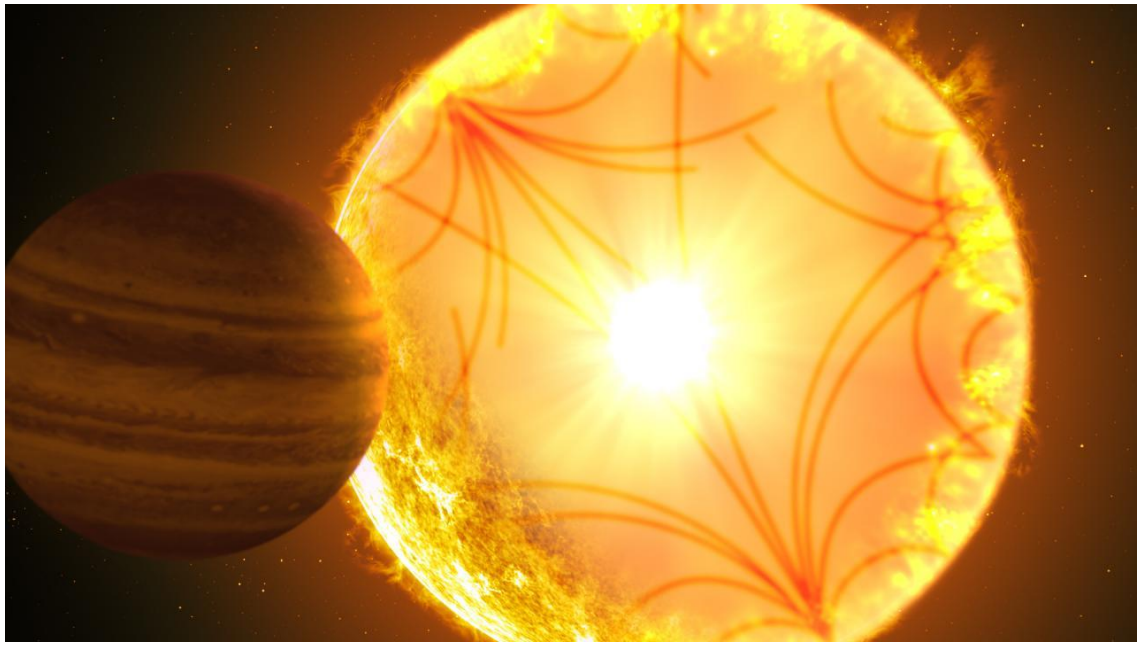
[Ball et al. 2020]

$$M = 1.48 \pm 0.04\,\mathrm{M}_{\odot}$$
$$R = 2.68 \pm 0.03\,\mathrm{R}_{\odot}$$
$$t = 3.07 \pm 0.39\,\mathrm{Gyr}$$

*Impact and prospects for the **future***

- Improve the pipeline (González-Cuesta et al. in prep.)
- TESS will provide millions of light curves:
  - Apply the code to a large sample of **main-sequence** and **subgiant stars** to look for oscillation modes
  - Specially for ***TESS Object of Interest (TOI)*** within ***KESPRINT*** AND ***TASC*** consortiums





Synergy between Exoplanet research and Asteroseismology:

- Special interest on **planet's host stars**
- **Asteroseismic improved** stellar parameters → **More precise** *exoplanet* parameters
- Look for changes in the architecture of these **planetary systems**
- Up to now, **only ~10 new** TESS stars harbouring planets with detected oscillations

Much work remains to be done in the coming years…