# MACHINE LEARNING TO IMPROVE THE CHARACTERISATION OF STELLAR ACTIVITY AND EXOPLANET TRANSITS IN NOISY LIGHTCURVES FROM TESS AND KEPLER

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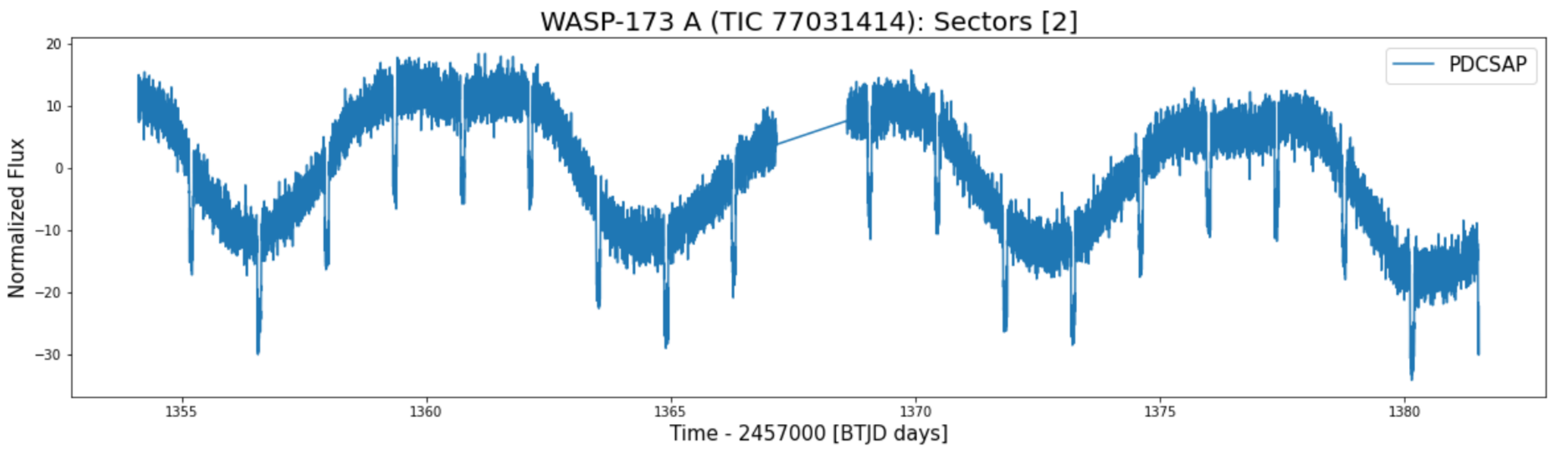
# ABSTRACT

**Gaussian Processes (GPs)** can be useful for the task of modelling stellar and instrumental systematics in lightcurves because they can identify patterns in data without knowing the detailed physical processes [1][2]. This thesis work is focusing on applying this machine learning method to TESS and Kepler lightcurves. We seek to answer the following research questions:

- **RQ1**: How accurately can we model the **stellar activity** with GPs?
- **RQ2**: How accurately can we model the **exoplanet transits** with GPs?
- **RQ3**: Does joint modelling improve the characterization of rotation and planet parameters?

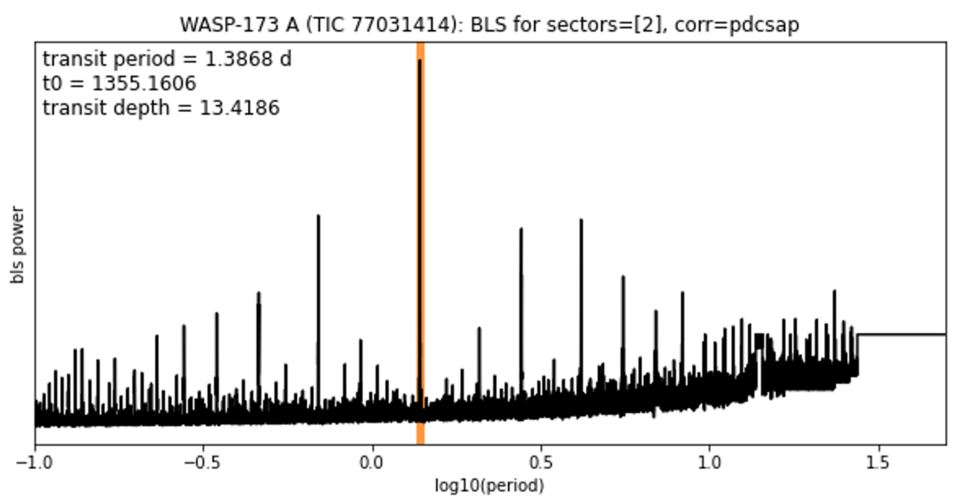
## TESS lightcurve of WASP-173 A (TIC 77031414)




- **Figure 1:** TESS lightcurve of WASP-173 A Sector 2 (~27 days) with 2 minute cadence [9].
- WASP-173 A exhibits rotational modulation and has a large planet with 1.2 Jupiter radius orbiting around it every 1.38 days.

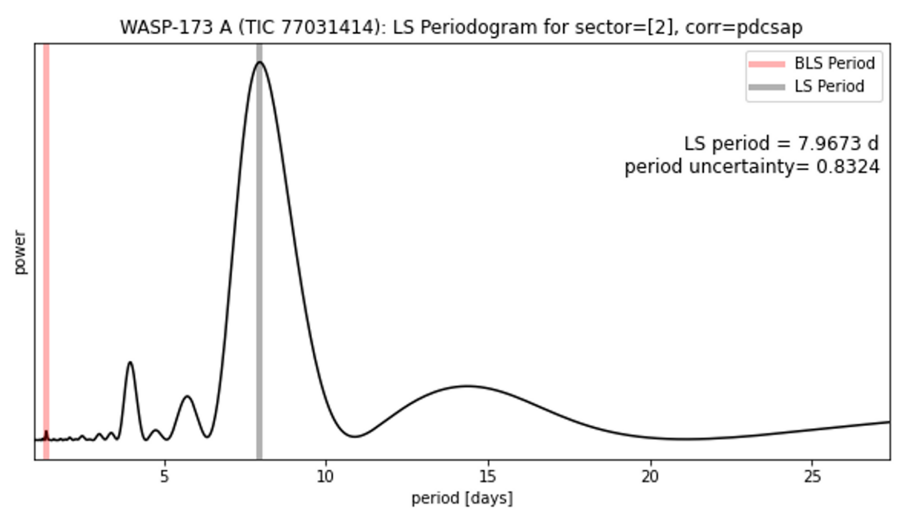
### Initializing the parameters of the GP

Box Least Squares (BLS)




- **Figure 2a (top):**
- **BLS** is applied to the lightcurve to get the initial estimates of the transit parameters [3]:
  - Transit period = 1.38 days
  - First transit time = 1355
  - Transit depth = 13.42

Lomb-Scargle (LS) Periodogram




- **Figure 2b (bottom)**:
- **LS** is applied to the lightcurve to get the initial estimate of the rotation period [3]:
  - Rotation period = 7.96 days

### Optimizing the GP to find the MAP parameters

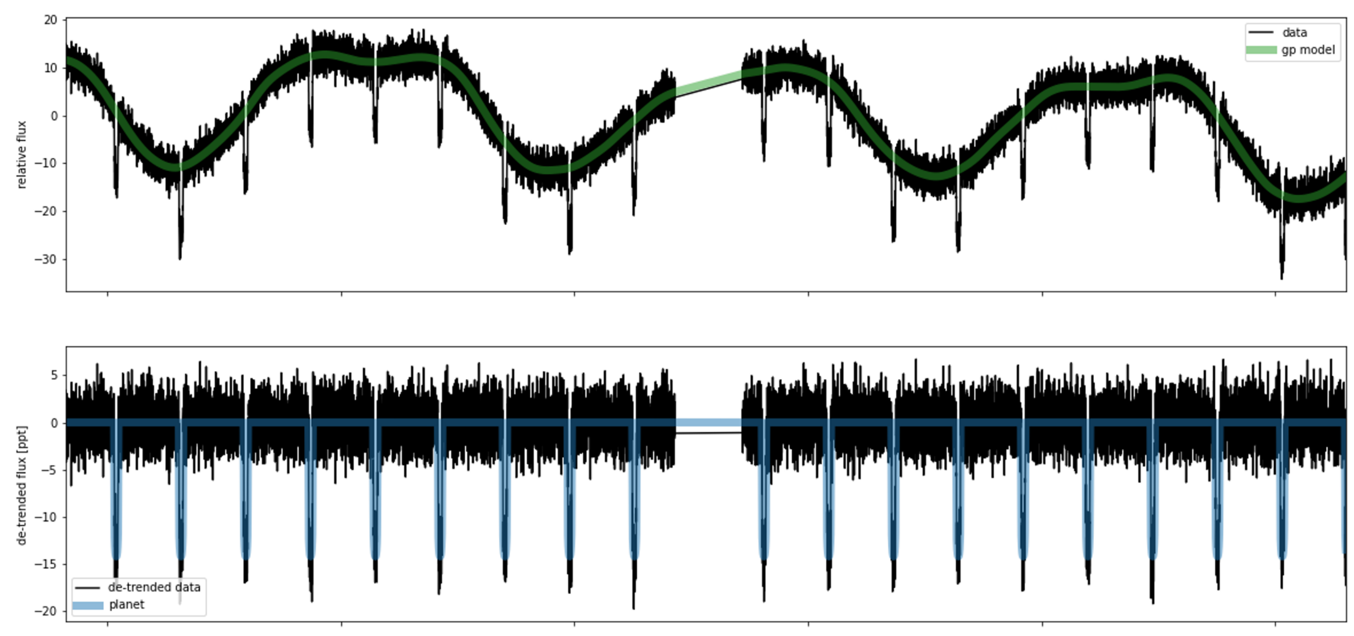
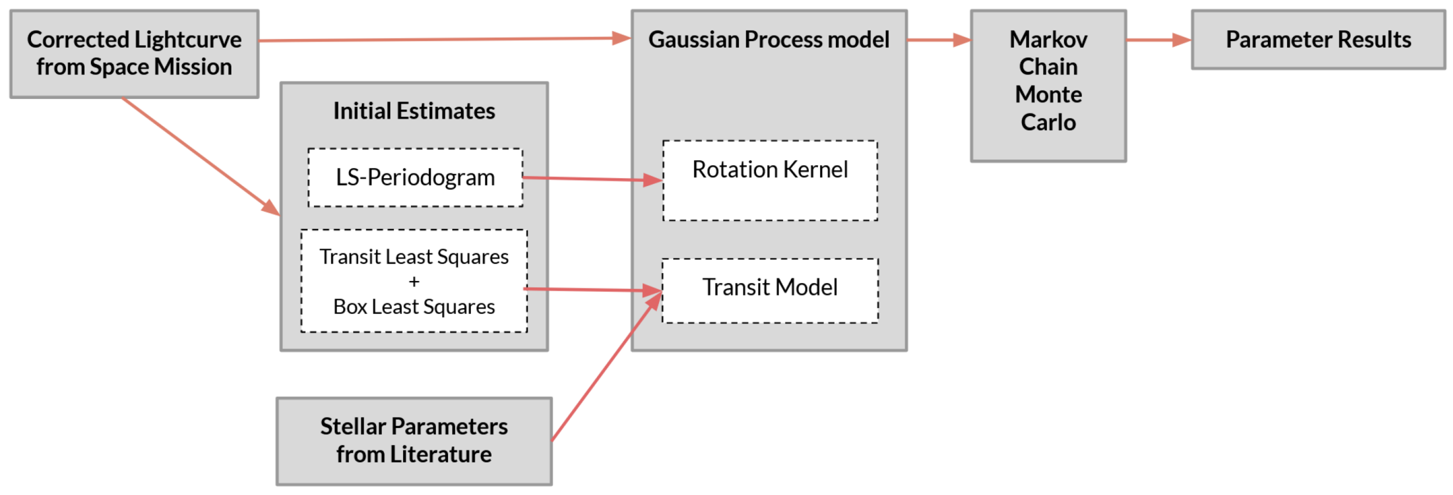



**Figure 3:** After optimization, the model can separate stellar activity (green) and transit signals (blue) [3][4].

# METHODOLOGY

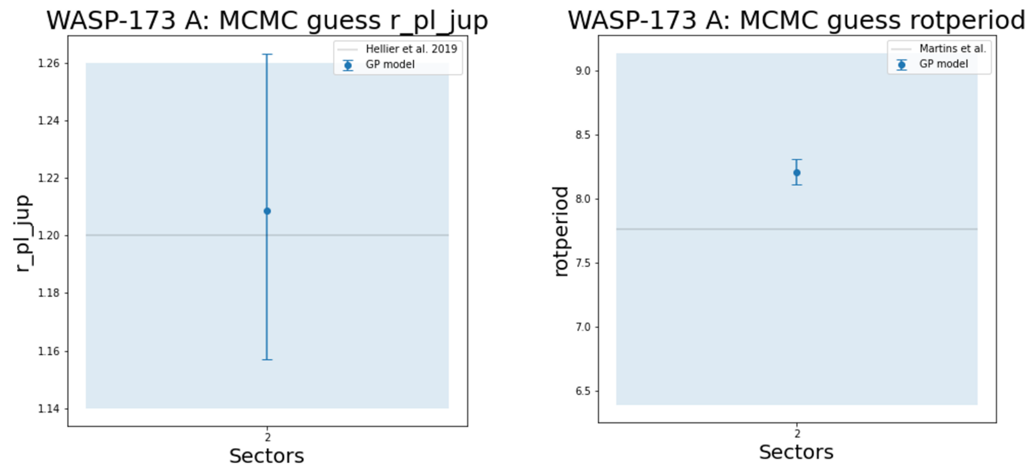
- A **Gaussian Process (GP)** is used to model the **stellar activity**, **background noise**, and **exoplanet transits** simultaneously.
- The GP is implemented using software exoplanet and PyMC3 --> fast computation [3][4][5].
- The GP consists of:
  - A **RotationTerm kernel** to describe rotational modulation [1][2][3].
  - A **SHOTerm kernel** to describe background noise [1][2][3].
  - A **mean transit model** to describe transit signals [6][7][8].
- **Initialization:** GP parameters are initialized with traditional methods (see Fig. 2).
- **Optimization**: GP is optimized to find the MAP parameters (see Fig. 3).
- **Markov Chain Monte Carlo (MCMC):** sampling to approximate the posterior distributions of the parameters of interest (see Fig. 4) [4]:
  - **Rotation parameters:** rotation period, amplitude, quality factor
  - **Planet parameters:** transit period, radius of planet, first transit time, impact parameter, eccentricity



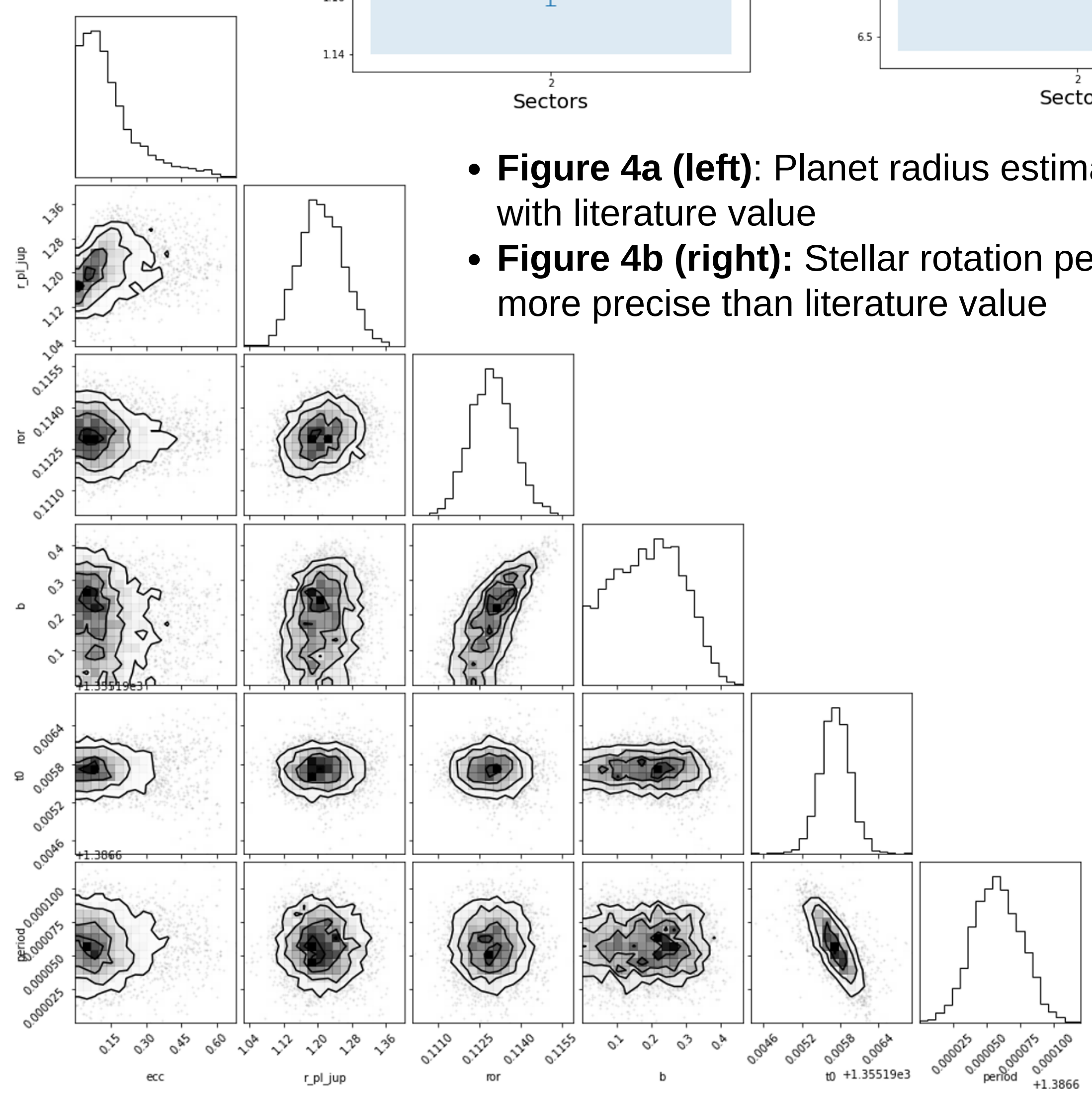

# RESULTS

### Parameter results after MCMC sampling

| Parameter | GP mean | GP error | Reference mean | Reference error | Reference |
|---|---|---|---|---|---|
| Rotation Period (rotperiod) | 8.2067 | (-0.10, +0.10) | 7.765 | (-1.37, +1.37) | Martins et al. 2020 |
| Amplitude (amp) | 55.14132 | (-2.08, +2.46) | | | |
| Quality factor (Q0) | 293.22826 | (-3.93, +1371.46) | | | |
| Transit Period (period) | 1.38666 | (-2e-05, +2e-05) | 1.38665318 | 0.0 | Hellier et al. 2019 |
| Planet Radius (r_pl_jup) | 1.20871 | (-0.05, +0.05) | 1.2 | (-0.06, +0.06) | Hellier et al. 2019 |
| First Transit Time (t0) | 1355.19572 | (-0.00024, +0.00022) | | | |
| Impact Parameter (b) | 0.18695 | (-0.12, +0.10) | 0.4 | (-0.08, +0.08) | Hellier et al. 2019 |
| Eccentricity (ecc) | 0.147 | (-0.08, +0.14) | 0.0 | | Hellier et al. 2019 |




- **Figure 4a (left)**: Planet radius estimate consistent with literature value
- **Figure 4b (right):** Stellar rotation period estimate more precise than literature value




- **Figure 4c**: Planet parameters after MCMC sampling [3][4][10].
- Good convergence for transit period, planet radius, and first transit time.
- Weaker convergence for impact parameter and eccentricity.

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**Acknowledgements**: I thank my supervisors at the ESA and the UvA (Patrick Forre) for their support;