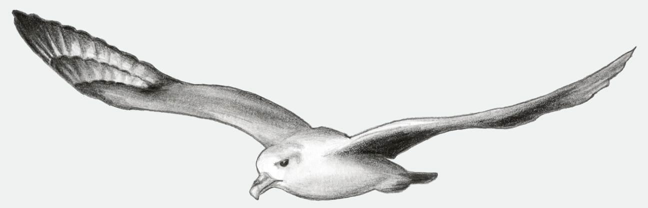
FULMAR: Follow-Up Lightcurves Multitool Assisting Radial velocities



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Introduction

We developed a modular tool called **FULMAR** for analyzing light curves in support of RV follow-up programs. It can filter the activity using different methods (such as Savitzky-Golay filtering, Gaussian Processes), compute the rotation period of the star using Gaussian Processes, search for transits in the cleaned lightcurve using the transit least-squares (TLS) algorithm [3] and probe signals that were detected with RV.

Activity Correction: Savitzky-Golay filter

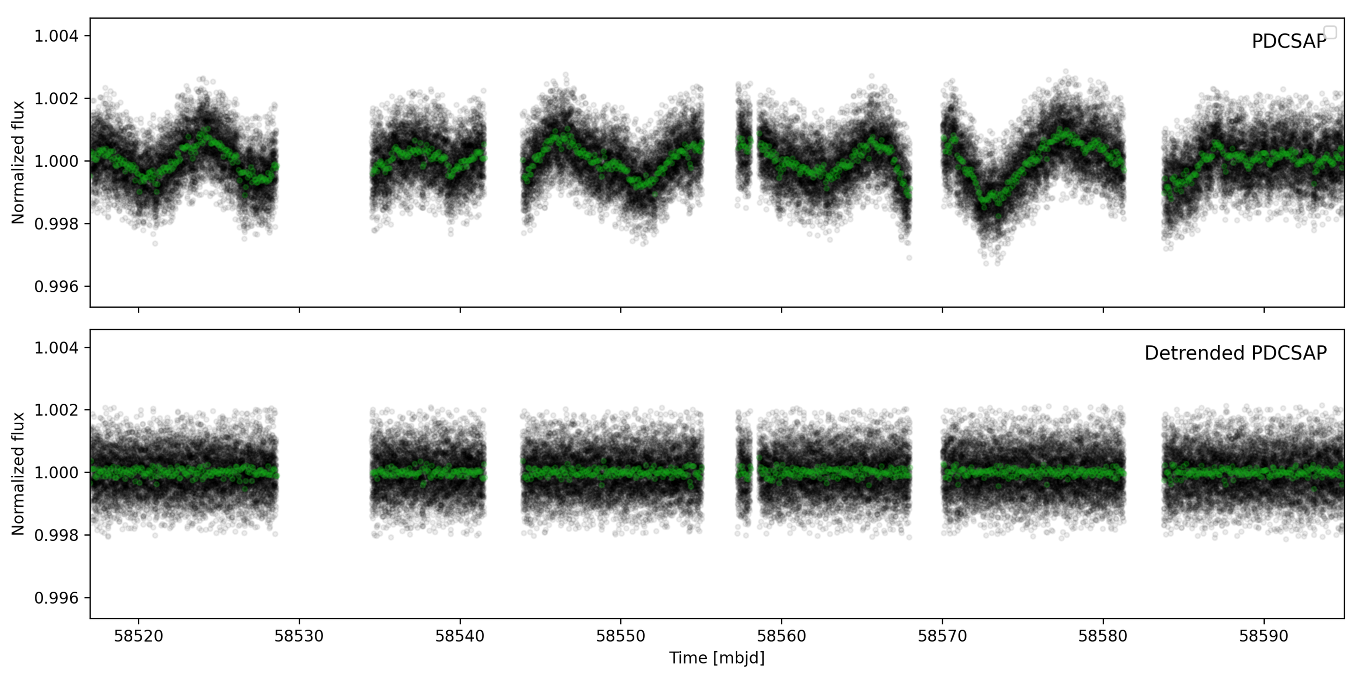

Figure 1. TOI-119 light curves: *top:* Presearch data conditioned SAP (PDCSAP), *bottom:* Detrended PDCSAP using an SG filter. Black points depict the TESS two-minute cadence flux measurements, green points are the same data binned into 2 hours intervals. Our code uses a window length between 721 and 1501, this corresponds to 24h and 50.03h, respectively. Shorter timescales are more efficient at removing unwanted variability, but have a higher risk of removing transit data as well.

Transitcheck - visual check at a given period and epoch

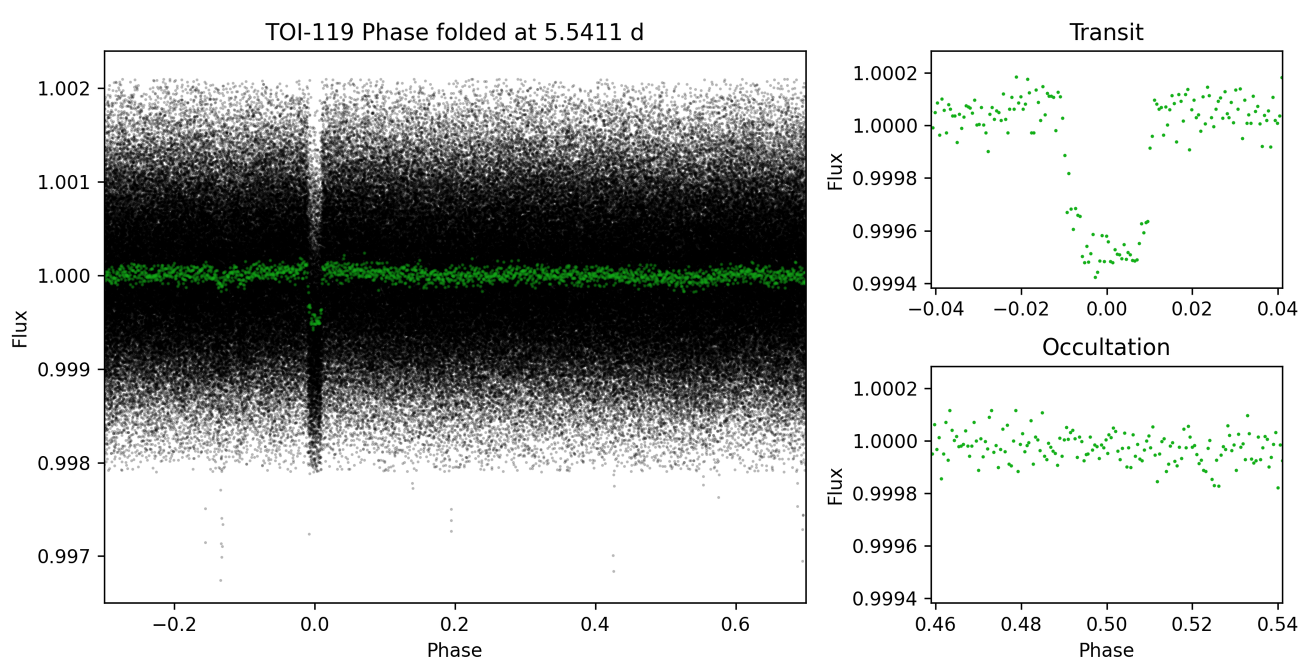

Figure 2. We provide a way for the user to do a visual check of the lightcurves at a chosen period and epoch. Transitcheck for TOI-119.01, with P=5.5411d.

Activity Correction: Gaussian Processes

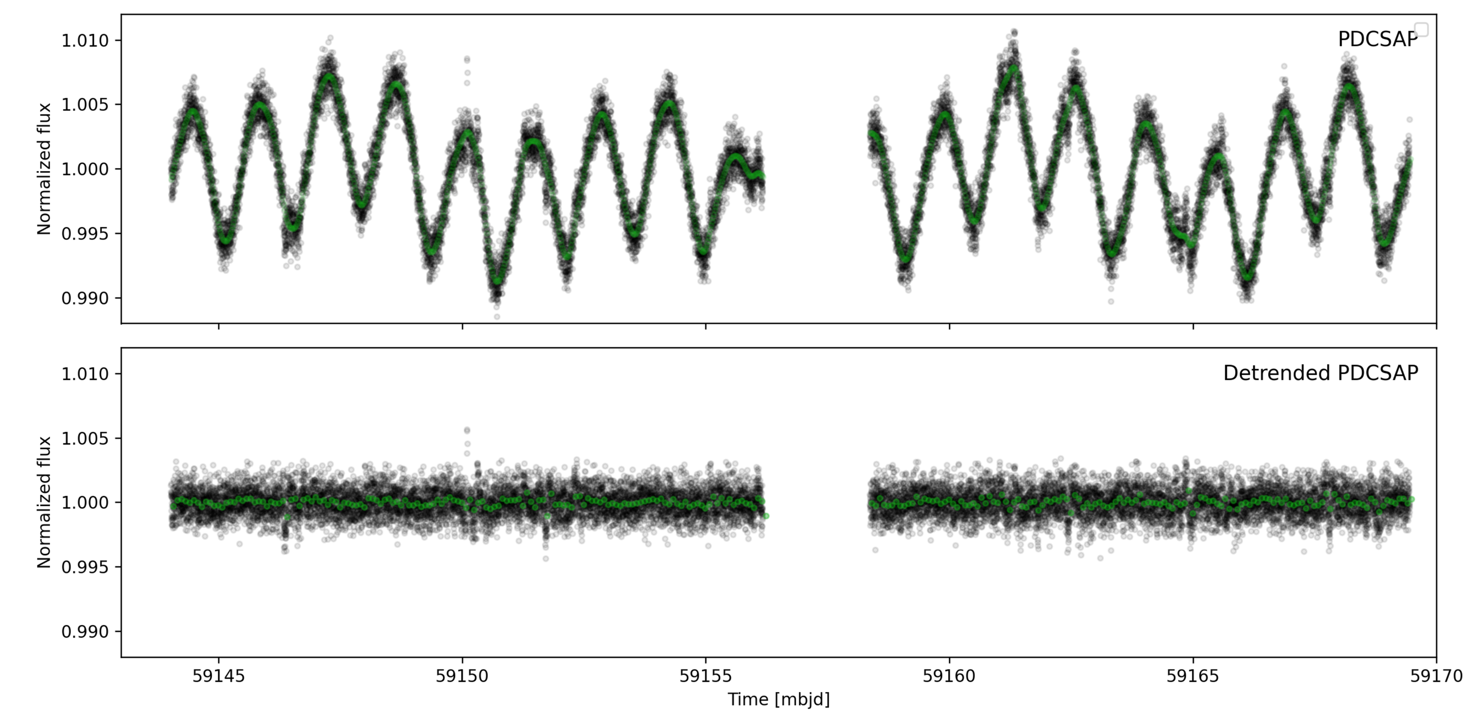

Figure 3. Light curves showing rotation: *top:* Presearch data conditioned SAP (PDCSAP) with GP model in green, *bottom:* Detrended PDCSAP. Black points depict the TESS two-minute cadence flux measurements, green points are the same data binned into 2 hours intervals. To avoid fitting short-term variations, the data used for the GP fit is a set of 20 to 60min-bins of the original data.

Real-world application: TOI 119

The host star is bright (V=10.07), yet active ($\log(R'_{HK})$=-4.6). Two transiting planets were found by TESS with periods of 10.691d and 5.541d and announced transit depths of 530ppm and 420ppm, respectively.

After running FULMAR on this system, using a Savitzky-Golay filter with a window length of 801, we retrieve the two transits with a signal detection efficiency (SDE) of 95.45 for TOI 119.01 and 80.57 for TOI 119.02. The first non detection has an SDE of 8.20, which is under the commonly used threshold of 9. The efficiency of the correction can be seen on Figure 1. Transit parameters retrieved by FULMAR are shown in Table 1.

Name	Period [d]	Epoch [mjdb]	Duration [h]	Depth [ppm]
TOI 119.01	5.54111 ± 0.00001	58327.11488 ± 0007	$2.739^{+0.031}_{-0.024}$	$459.3^{+36.8}_{-16.6}$
TOI 119.02	10.69173 ± 0.00002	$58327.54459^{+0.0011}_{-0.0012}$	$3.254^{+0.044}_{-0.042}$	$433.2^{+45.6}_{-23.8}$

Table 1. Parameters retrieved by FULMAR for TOI 119.01 and TOI 119.02

Acknowledgements

This research made use of `exoplanet` [2] and its dependencies.
This work was supported by FCT through national funds (PTDC/FIS-AST/28953/2017) and by FEDER - Fundo Europeu de Desenvolvimento Regional through COMPETE2020 - Programa Operacional Competitividade e Internacionalização (POCI-01-0145-FEDER-028953) and through national funds (PIDDAC) by the grant UID/FIS/04434/2019.

Transit Fitting using MCMC

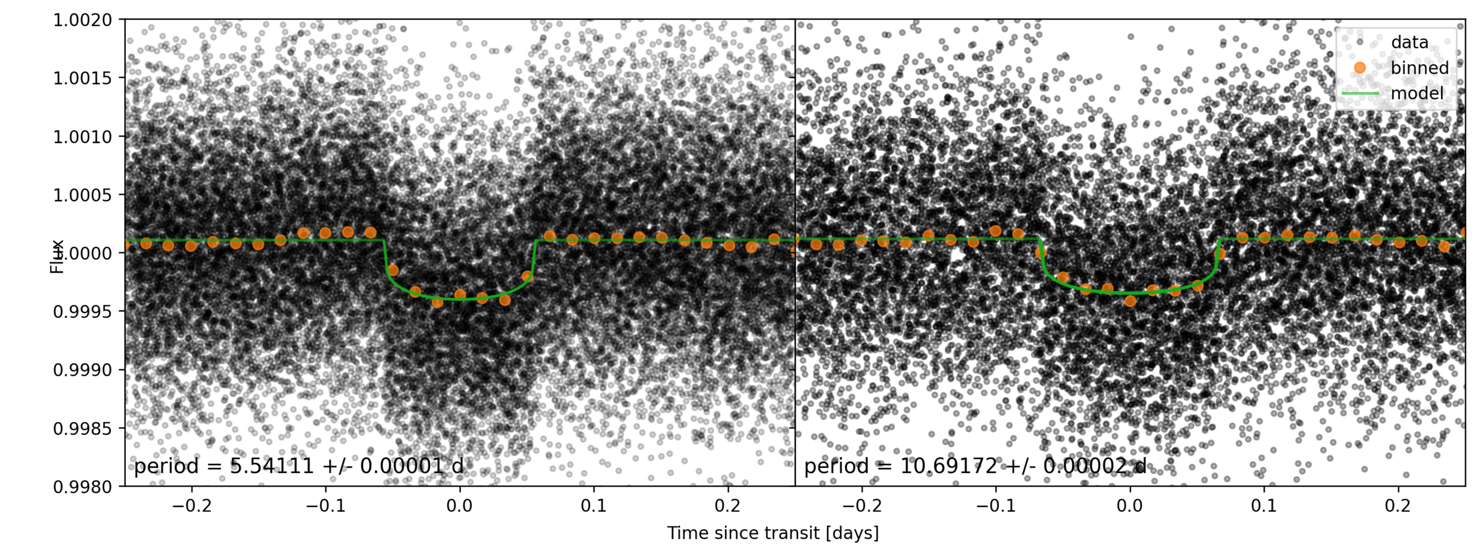

Figure 4. Phase folded transits of TOI 119.01 and TOI 119.02. Green curve is the best-likelihood model.

Take home message

FULMAR aims at selecting suitable RV follow-up targets more effectively and making their analysis easier. It was build in a modular way, making new features easier to implement.

Currently, the following features are available:

- **Activity correction** It can filter the activity using different methods, namely a Savitzky-Golay filter or Gaussian Processes.
- **Transit finding** FULMAR looks for transits in the lightcurve using the transit least-squares (TLS) algorithm.
- **Transit fitting** Transit parameters can be optimized using MCMC.
- **Rotation period** The rotation period of the star can be computed using Gaussian Processes.
- **Probing signals detected in RV** The tool can output a *Transitcheck* image for a visual check before running the transit fitting module.

Routinely conducting such analysis during follow-up targets selection will allow for a more efficient use of instrument time on high-precision spectrographs, and ultimately lead to the characterization of more systems with a given instrument.

References

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