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Extracting rotation rates on 27-d TESS-like light curves downgrading *Kepler* data.

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Abstract

Evolution of surface magnetic features in the star, such as stellar spots or faculae, can leave a signature in the lightcurves. These features allow us to study the surface rotation period, Prot, of stars. However, the length of the observations is an important limiting factor to determine reliable Prot. Indeed, it is commonly accepted that it is necessary to observe for a period longer than 2-3 times Prot in order to properly determine it. But even when stars are observed for this long (more easily reachable for fast-rotating stars), the observation may happen during a minimum of magnetic activity, which can hamper the Prot detection. It is then challenging to assess the reliability of the extracted Prot as well as the probability of detecting it given the 27-day observation length for the majority of TESS targets. Starting from 55,275 stars with reliable Prot observed by *Kepler* (Santos et al. 2019 & 2021, Breton et al. 2021), 2,500,000 light curves were created to mimic TESS 27-d observations. In this work preliminary results obtained on a sub-sample of 9,275 stars giving 431,087 independent subseries of 27 d are presented. Realistic limits on the longest reliable Prot depending on the method used as well as the associated probabilities for completeness and reliability of the results are given.

Observations & Data Analysis

In this work, 55-d filtered KEPSISMIC lightcurves (García et al. 2011, 2014b, available at MAST) of the original NASA *Kepler* main mission (Borucki et al. 2010) are split into independent subseries of 27 d to mimic the Transiting Exoplanets Survey Satellite (TESS, Ricker et al. 2014) one-sector observations. A total of 55,232 main-sequence and subgiant FGKM stars from Santos et al. (2019 & 2021) with reliable Prot were considered.

Each subseries is re-analised with our rotation pipeline (Mathur et al. 2010, García et al. 2014a, Ceillier et al. 2016 & Breton et al. 2021) which combines three different estimations of the Prot obtained from the autocorrelation function (ACF) of the lightcurve (e.g. McQuillan et al. 2013 & 2014), a time-period analysis, which is projected into the Period axis (GWPS) using a Morlet wavelet (Torrence & Compo 1998) and the composite Spectrum (CS) which is the product of the previous two analysis (Ceillier et al. 2016). An example of the result for the first 27-d subseries of KIC 9643215 is given in Fig.1. The distribution of Prot is shown in Fig.2.

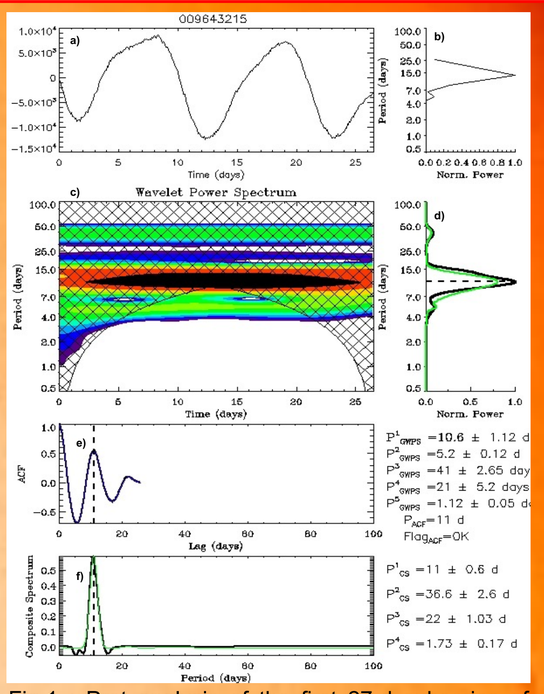


Fig.1 : Prot analysis of the first 27-d subseries of KIC 9643215. a) Lightcurve; b) PSD; c) Time-Period; d) GWPS; e) ACF; f) CS. The vertical dashed lines represent the retrieved Prot. The black crossed area of the time-period analysis delimits the cone of influence where the analysis is not reliable.

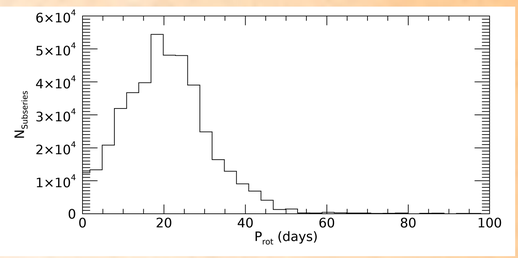
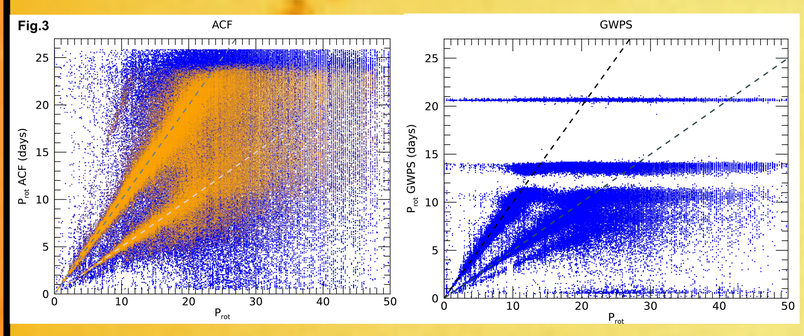
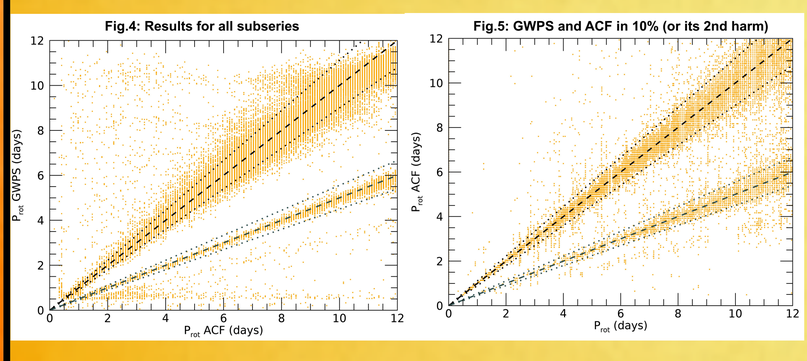


Fig.2 : Distribution of the number of subseries as a function of the Prot from Santos (2019 & 2021) for the 9,275 stars used in this work.

Results & Discussion



- **Fig.3 shows the retrieved Prot for each 27-d subseries for the ACF (in Orange those with H_ACF > 0.3) and the GWPS as a function of Prot.**
- **By construction, reliable GWPS Prot can only be obtained up to ~11 days due to the degradation of the Period resolution to allow a time evolution.**
- **For both methods, the 2nd harmonic is retrieved for a lot of 27-d subseries.**



- **Fig.4 shows Prot GWPS as a function of Prot ACF for all the subseries in the range [0-11] days where Prot GWPS is reliable.**
- **Fig.5 shows Prot ACF as a function of Prot for stars selected because Prot ACF = Prot GWPS at 10% or with Prot ACF = 2 x Prot GWPS at 10% (to take into account "double dip" stars).**

Prot range	Number of 27-d series Completeness, Reliability	ACF = GWPS (within 10%)	ACF = GWPS (10%, 2nd Harmonic)	ACF (H_ACF>0.3)
0 < Prot < 5 (d)	Total Selected Correct Prot (10%) Completeness, Reliability	19128 15695 14813 77.44%, 94.38%	19128 16691 15691 82.03%, 94.08%	19128 16961 16130 84.32%, 95.10%
0 < Prot < 11 (d)	Total Selected Correct Prot (10%) Completeness, Reliability	63906 50479 43010 67.30%, 85.20%	63906 54419 46294 72.44%, 85.07%	63906 54854 47340 74.08%, 86.30%
11 < Prot < 15 (d)	Total Selected Correct Prot (10%) Completeness, Reliability			46882 36628 24912 53.14%, 68.01%
0 < Prot < 15 (d)	Total Selected Correct Prot (10%) Completeness, Reliability			110788 91482 72252 65.21%, 78.98%

The Table provides the results for different ways of selecting reliable Prot by comparing Prot Acf with Prot GWPS ans selecting those that agree within 10% (including or not the 2nd harmonic), as well as using only the Prot ACF and selecting those where the amplitude of the ACF peak, H_ACF > 0.3. The completeness corresponds to the percentage of correct retrievals from the total of subseries in the given Prot range, while the reliability represents the percentage of correct retrievals from the selected ones.

Conclusions & Perspectives

- **This preliminary analysis shows the limits of detecting Prot from 27-d long lightcurves**
- **Although the time-period analysis was a powerful method to disentangle between real stellar Prot and perturbations due to instrumental problems at the beginning of the *Kepler* mission, it limits the retrieval of Prot to about 40% of the length of observations.**
- **The use of the ACF with a lower limit in the amplitude of the ACF peak to 0.3 (as described in Ceillier et al. 2016) is a good compromise when using only this method.**
- **Considering only the last two selection methods given in the table:**
  - **For short rotation periods < 5 days, completeness and reliability are above 94 and 82% respectively**
  - **For Prot up to 11 days, those values are still acceptable (> 85% and >72% respectively).**
- **Beyond 11 days and up to 15 days (approximately half of the length of the subseries) the results drop drastically to 68% completeness and a poor 53% of reliability.**
- **Current efforts are focused in improving longer Prot.**

References

•Borucki, W. J., Koch, D., Basri, G., et al. 2010, Sci, 327, 977
•Breton, S. N., Santos, A. R. G., Bugnet, L., et al. 2021, A&A, 647, A125
•Ceillier, T., van Saders, J., García, R. A., et al. 2016, MNRAS, 456, 119
•García, R. A., Ceillier, T., Salabert, D., et al. 2014a, A&A, 572, A34
•García, R. A., Mathur, S., Pires, S., et al., 2014b, A&A, 568, 10
•García, R. A., Hekker, S., Stello, D., et al. 2011, MNRAS, 414, L6
•Mathur, García, Régulo et al., 2010, A&A 511, A46
•McQuillan, A., Mazeh, T., & Aigrain, S. 2013, ApJ, 775, L11
•McQuillan, A., Mazeh, T., & Aigrain, S. 2014, ApJS, 211, 24
•Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2014, Proc SPIE, 9143, 914320
•Santos, A. R. G., García, R. A., Mathur, S., et al. 2019, ApJS, 244, 21
•Santos, A. R. G., Breton, S.N., Mathur, S., García, R.A., 2021, ApJS, 255, 17
•Torrence & Compo 1998, Bulletin of the American Meteorological Society, 79, 61

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