*SF2A 2024*
*M. Béthermin, K. Baillié, N. Lagarde, J. Malzac, R.-M. Ouazzani, J. Richard, O. Venot, A. Siebert (eds)*

# MULTI-CAMPAIGN OBSERVATIONS OF STELLAR ROTATION PERIODS IN CLUSTERS WITH TESS

M. Gilles[1, 2], D. B. Palakkatharappil[1], R. A. Garcia[1], A. Hamy[1, 3], A. Prin[1,3], S. N. Breton[4], D. Godoy-Rivera[5], S. Mathur[5] and A. R. G. Santos[6]

**Abstract.** Understanding the surface rotation of stars is essential to better constrain the physical processes in action during stellar evolution. For solar-like stars in a wide range of their lifetimes, surface rotation is indeed an age indicator. It traces the existence of coupling mechanisms in their interiors, which shape stellar evolution. Investigating stars in clusters is of major interest because stars are assumed to have a common age and initial chemical composition. In this work, we are interested in the methods to extract rotation periods longer than 10 days using the Transiting Exoplanet Survey Satellite, TESS, mission with only two 27-d sectors observed in different campaigns. If we succeed, we will be able to study for example the K-dwarf spin-down stalling using stars with rotation periods up to 20 days in stellar clusters in a range of 1-2.5 Ga.

Keywords: Stellar rotation; low mass stars; star clusters

## 1 Introduction

Long and continuous ultra-high-precision photometry from space missions such as CoRoT (Convection, Rotation, and planetary Transits), *Kepler*, K2, and TESS (Baglin et al. 2006; Borucki et al. 2010; Howell et al. 2014; Ricker et al. 2014) has revolutionise the study of stellar physics (e.g. García & Ballot 2019). Using seismology it has been possible to study different populations of stars (e.g. Epstein et al. 2014) and apply this knowledge to other disciplines such as galacto-archeology (e.g. Miglio et al. 2013; Stello et al. 2015; Tayar et al. 2017) or exoplanet characterisation, for example to determine spin-orbit alignments (e.g. Ballot et al. 2006; Campante et al. 2016). Moreover, the exquisite photometry allowed us to determine rotation periods, $P_{\rm rot}$, of tens to hundred of thousands of stars at various evolutionary stages (e.g. Ceillier et al. 2017; Santos et al. 2019, 2021; Colman et al. 2024). Using *Kepler* observations, McQuillan et al. (2013, 2014) uncovered the existence of a bimodal distribution of $P_{\rm rot}$. By studying clusters of around 1 Ga, this bimodality was associated to a stalling of the braking in the K dwarfs (e.g. Agüeros et al. 2018; Curtis et al. 2020; Santos et al. 2024). To improve our knowledge of the K-dwarf stalling it is necessary to study clusters of about 1 to 2.5 Ga. Unfortunately, only five –quite faint– clusters were targeted by *Kepler*. Therefore, to have brighter clusters and to extend the sample, we need to use TESS observations. In spite of some very promising methods using neural networks (Claytor et al. 2024), the current limit to extract reliable $P_{\rm rot}$ with TESS is around 10 days (e.g. Holcomb et al. 2022). In this work, we study if using multi-campaign observations of the same clusters by TESS could allow us to extract reliable $P_{\rm rot}$ up to 20 days.

## 2 Observations and methodology to extract reliable rotation periods

The multi-sector observations from TESS cover 85% of the sky, offering a valuable opportunity to study open clusters in the Milky Way. We selected open clusters from the Milky Way Star Clusters Catalog (MWSC

---

[1] Université Paris Cité, Université Paris-Saclay, CEA, CNRS, AIM, 91191, Gif-sur-Yvette, France
[2] ESTACA Paris-Saclay, Montigny-le-Bretonneux, France
[3] École Centrale-Supélec, Université Paris-Saclay, France
[4] INAF - Osservatorio Astrofisico di Catania, Via S. Sofia, 78, 95123 Catania, Italy
[5] Instituto de Astrofísica de Canarias (IAC) & Universidad de La Laguna, E-38205 La Laguna, Tenerife, Spain
[6] Instituto de Astrofísica e Ciências do Espaço, Universidade do Porto, CAUP, Rua das Estrelas, PT4150-762 Porto, Portugal

Kharchenko et al. 2012, 2013; Schmeja et al. 2014; Scholz et al. 2015) that have ages between 1 and 2.5 Ga and radii greater than 16′. This radius limit helps reduce nearby source contamination due to the TESS large pixel size (21″) and densely populated stars towards the cluster centre. For cluster member stars, we choose those with a Tmag $< 15$ and a membership probability greater than 0.5 from the Cantat-Gaudin et al. (2018) catalogue. There are total of 18 clusters, each with at least three sectors of TESS observations.

To study the best methodology to extract reliable $P_{\rm rot}$ with at least two 27-d TESS sectors separated with at least 1 year using Auto Correlation Functions (ACF, e.g. McQuillan et al. 2014) and Lomb-Scargle Periodograms (LS, Lomb 1976; Scargle 1982), we simulate pure sine waves in a range of periods up to 30 days.

For the ACF, if we keep the gap, there is no advantage to analyse multi-sector campaigns. As the gaps are longer than the continuous data, the ACF for periods longer than 27 days will be zero, and $P_{\rm rot} > 10$ days would be not reliable. To avoid this limitation we suggest to re-attach the sectors by removing the long gap. Depending on the phase difference between the two segments $|\Phi_1 - \Phi_2|$, it would be possible to measure $P_{\rm rot} > 10$ days. Indeed, when the phase shift is closer to 180°, both sectors would be closely anti correlated and no $P_{\rm rot}$ would be extracted. Therefore, by re-attaching the observed sectors, it would be possible to obtain reliable $P_{\rm rot}$ up to $\sim 15$ days, while in the range 15-22 days the extracted periodicity could be a higher harmonic of the real value. Zero padding, ZP, has no effect in the measurement of the ACF.

For a sine wave with an amplitude $A$, its Fourier transform, $X$, as a function of $|\Phi_1 - \Phi_2|$ can be written as:

$$|X| = A\sqrt{2(1 + \cos(\Phi_1 - \Phi_2))} \tag{2.1}$$

The power of the sine wave becomes minimum when the phase difference is multiples of $\pi$. This leads to power leakage into nearby bins and could make them higher than the true period. Thus, the rotation pipeline could select a wrong $P_{\rm rot}$ when using the LS periodogram. ZP at the end of the signal reduces this problem by increasing the resolution (see Fig. 1). On the contrary, removing the gaps has no effect in the results with LS.

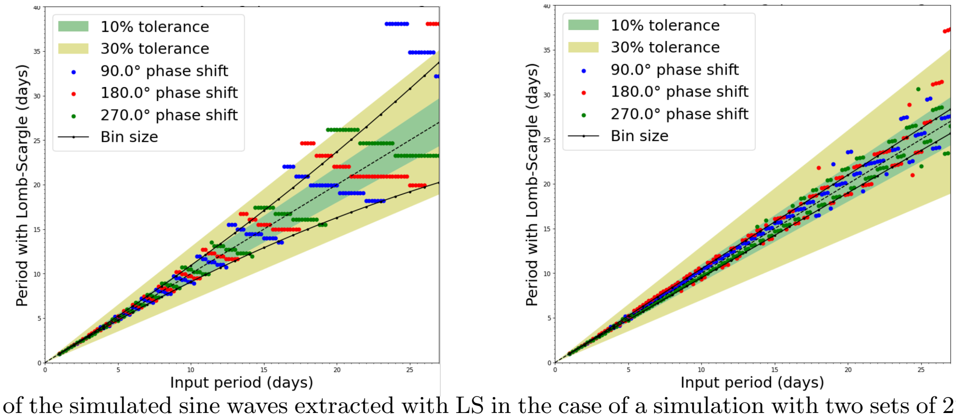

**Fig. 1.** Period of the simulated sine waves extracted with LS in the case of a simulation with two sets of 27-d observations separated by a 1-a gap without (left) and with (right) ZP. Shaded green regions represent the tolerance (10-30%). Horizontal lines represent the resolution in period. Colours depict the phase shift between the two sets of observations.

## 3 Conclusions

We have identified stellar clusters in TESS with ages in the range 1-2.5 Ga. Preliminary results with pure sine waves show that, on one hand, the ACF should be computed from a reattached signal without zero padding. On the other hand, LS periodograms provide better results with zero padding and keeping the gaps. We have shown that it is possible to obtain reliable $P_{\rm rot}$ up to 20 days with a 10% tolerance in simulations of pure sine waves in the conditions of multi-campaign TESS observations.

RAG & DBP acknowledge the support from GOLF & PLATO CNES grants. SNB acknowledges support from PLATO ASI-INAF agreement 2015-019-R.1-2018. SM & DGR acknowledge support by the Spanish Ministry of Science and Innovation with the grant PID2019-107061GB-C66 and with the Juan de la Cierva program under contract JDC2022-049054-I, respectively. ÂRGS acknowledges the support from the FCT through national funds and FEDER through COMPETE2020 (UIDB/04434/2020, UIDP/04434/2020 & 2022.03993.PTDC) and the support from the FCT through the work contract 2020.02480.CEECIND/CP1631/CT0001. We acknowledge the use of TESS High Level Science Products (HLSP) produced by the Quick-Look Pipeline (QLP) at the TESS Science Office at MIT from the MAST. Funding for the TESS mission is provided by NASA's Science Mission directorate.

## References

Agüeros, M. A., Bowsher, E. C., Bochanski, J. J., et al. 2018, ApJ, 862, 33

Baglin, A., Auvergne, M., Boisnard, L., et al. 2006, in COSPAR, Plenary Meeting, Vol. 36, 36th COSPAR Scientific Assembly, 3749

Ballot, J., García, R. A., & Lambert, P. 2006, MNRAS, 369, 1281

Borucki, W. J., Koch, D., Basri, G., et al. 2010, Science, 327, 977

Campante, T. L., Lund, M. N., Kuszlewicz, J. S., et al. 2016, ApJ, 819, 85

Cantat-Gaudin, T., Jordi, C., Vallenari, A., et al. 2018, 618, A93

Ceillier, T., Tayar, J., Mathur, S., et al. 2017, A&A, 605, A111

Claytor, Z. R., van Saders, J. L., Cao, L., et al. 2024, ApJ, 962, 47

Colman, I. L., Angus, R., David, T., et al. 2024, AJ, 167, 189

Curtis, J. L., Agüeros, M. A., Matt, S. P., et al. 2020, ApJ, 904, 140

Epstein, C. R., Elsworth, Y. P., Johnson, J. A., et al. 2014, ApJ, 785, L28

García, R. A. & Ballot, J. 2019, Living Reviews in Solar Physics, 16, 4

Holcomb, R. J., Robertson, P., Hartigan, P., Oelkers, R. J., & Robinson, C. 2022, ApJ, 936, 138

Howell, S. B., Sobeck, C., Haas, M., et al. 2014, PASP, 126, 398

Kharchenko, N. V., Piskunov, A. E., Schilbach, E., Röser, S., & Scholz, R. D. 2012, 543, A156

Kharchenko, N. V., Piskunov, A. E., Schilbach, E., Röser, S., & Scholz, R. D. 2013, 558, A53

Lomb, N. R. 1976, Ap&SS, 39, 447

McQuillan, A., Aigrain, S., & Mazeh, T. 2013, MNRAS, 432, 1203

McQuillan, A., Mazeh, T., & Aigrain, S. 2014, ApJS, 211, 24

Miglio, A., Chiappini, C., Morel, T., et al. 2013, MNRAS, 429, 423

Ricker, G. R., Winn, J. N., Vanderspek, R., et al. 2014, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 9143, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, 20

Santos, Â. R. G., Breton, S. N., Mathur, S., & García, R. A. 2021, ApJS, 255, 17

Santos, Â. R. G., García, R. A., Mathur, S., et al. 2019, ApJS, 244, 21

Santos, Â. R. G., Godoy-Rivera, D., Finley, A. J., et al. 2024, Frontiers in Astronomy and Space Sciences, 11, 1356379

Scargle, J. D. 1982, ApJ, 263, 835

Schmeja, S., Kharchenko, N. V., Piskunov, A. E., et al. 2014, 568, A51

Scholz, R. D., Kharchenko, N. V., Piskunov, A. E., Röser, S., & Schilbach, E. 2015, 581, A39

Stello, D., Huber, D., Sharma, S., et al. 2015, ApJ, 809, L3

Tayar, J., Somers, G., Pinsonneault, M. H., et al. 2017, ApJ, 840, 17