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Long-term stellar activity of M dwarfs: Combining K2 and TESS

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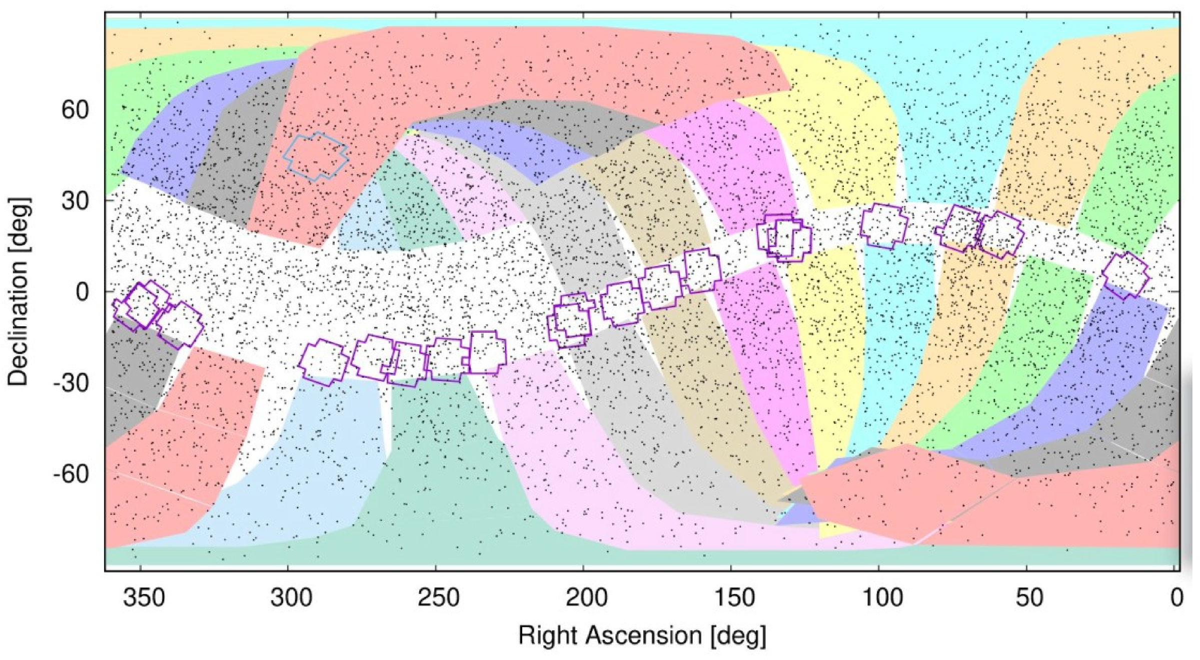
1 Abstract

Studies of the rotation and activity of M type stars are essential to enhance our understanding of stellar dynamos and angular momentum evolution.
Using the outstanding photometric capabilities of space telescopes rotation signals even with low amplitudes can be investigated in up to now unrivaled detail. By combining data of Kepler/K2 and TESS the star spot activity of M dwarfs can be monitored on a decade timescale.
In the framework of our study on the rotation-activity relation for M dwarfs that is based on the Lepine and Gaidos (2011) catalog we also aim at an investigation of the long-term activity.
While K2 was observing fields distributed around the ecliptic plane, the TESS prime mission was oriented along a line of ecliptic longitude with one camera centered on an ecliptic pole. Due to these different observing strategies, the overlap between K2 and TESS is marginal. However, 45 stars from our sample were observed with both missions of which four targets were analyzed in more detail.
Here, I present our results of the combined K2 and TESS stellar activity studies for two targets of our sample. Furthermore, we will show that combining missions like K2 and TESS are a promising method for detecting stellar activity cycles.

2 The sample

The sample was selected from the Superblink proper motion catalog by Lépine & Gaidos (2011), which includes ~9000 bright M dwarfs (J < 10 mag) with spectral types from K7 to M7.



Target Selection

1) Variability amplitude > standard deviation of the flat and cleaned light curve (S_{flat}, see Stelzer+16, Raetz+20)

2) χ^2 of the light curve > 1.5

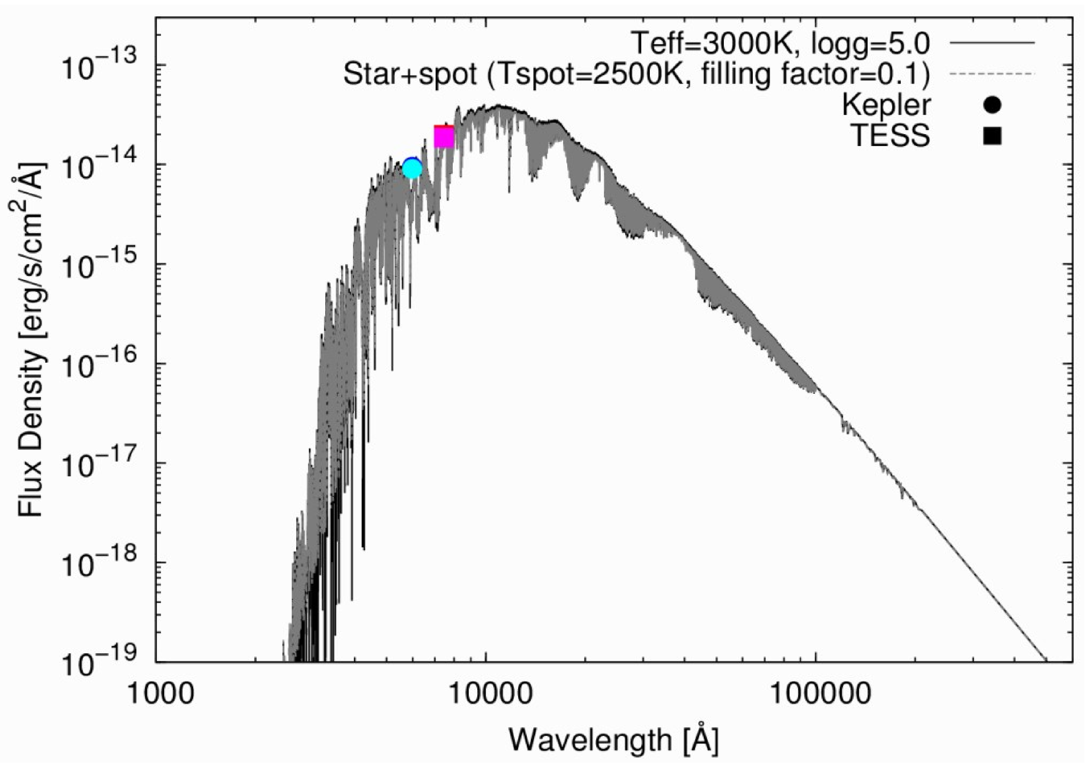
3) Rotation period reliably identified in TESS data
- $P_{rot,K2}$ < 1/2*ObsTimeTESS
- $P_{rot,K2}$ is detectable with TESS

→ 4 targets were analysed
(results for 2 stars shown in box 5)

Fig.: All Lépine & Gaidos M-dwarfs with the K2 campaign fields and the TESS prime mission sectors overplotted. Although the overlap between K2 and TESS is marginal, 45 stars are in common.

3 Simulation of the amplitudes of spot induced variability

(Scholz et al. 2005)



- The **amplitude** of the light curve is defined as peak-to-peak magnitude difference
- For the simulations, we used NextGen model spectra (Allard et al. 1997)
- The spectrum of the star is convolved with transmission curves of Kepler and TESS

$$S_{min} = (1.0 - f) \times S_0 + f \times S_S(T_S)$$

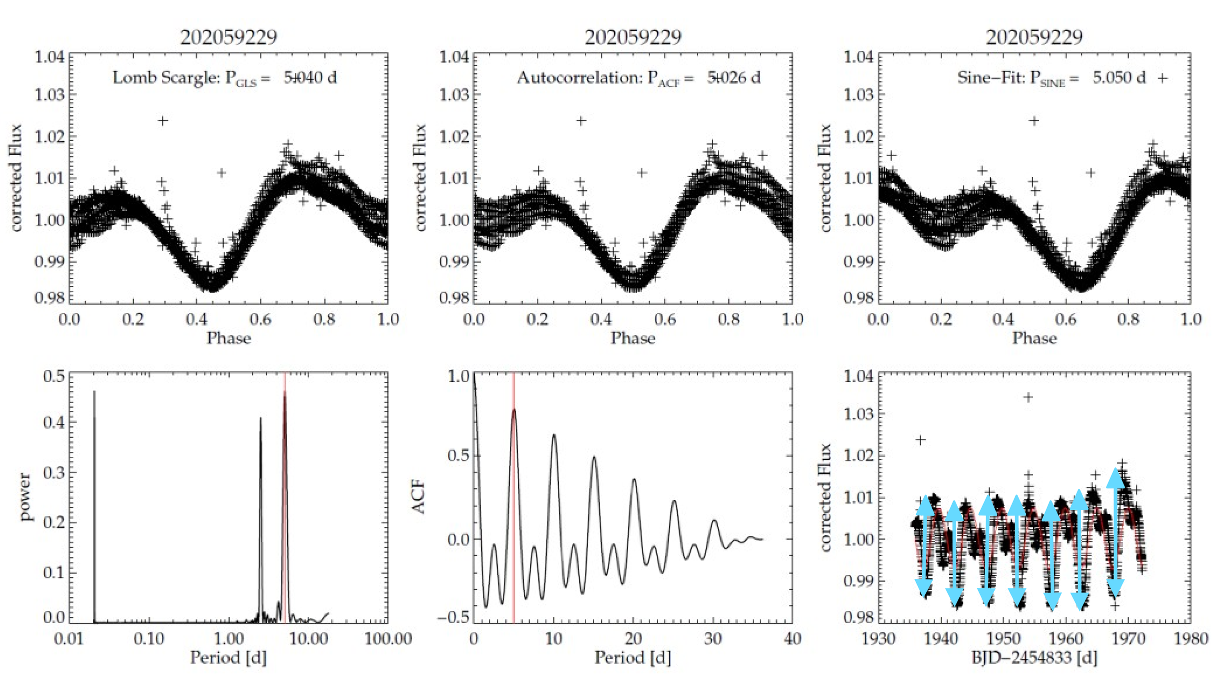
S_0: Spectrum of star without spots
f: filling factor (FF)
$S_S(T_S)$: Blackbody spectrum of T_{spot}
S_{min}: Spectrum with spots

- By integrating over the synthetic spectra with/without spots, we computed the flux in the minimum (S_{min}) and maximum (S_{max}= S_0) for Kepler and TESS
- The amplitude is then calculated with (X = Kepler/TESS): $A_X = -2.5 \log \frac{F_{min,X}}{F_{max,X}}$

4 Measurement of rotation period and variability amplitude

Stellar rotation rates are derived from the periodic brightness variations that are caused by cool spots on a stellar surface. We used three standard time series analysis techniques to search for the rotation period:

1. generalized Lomb Scargle (GLS) periodogram
2. autocorrelation function (ACF)
3. sine fit



a) All light curves were phase-folded with the periods of the three methods. By eye-inspection we selected the best-fitting period, which we then used in the further analysis. In the case of equally good periods from different methods, we adopted the average rotation period.

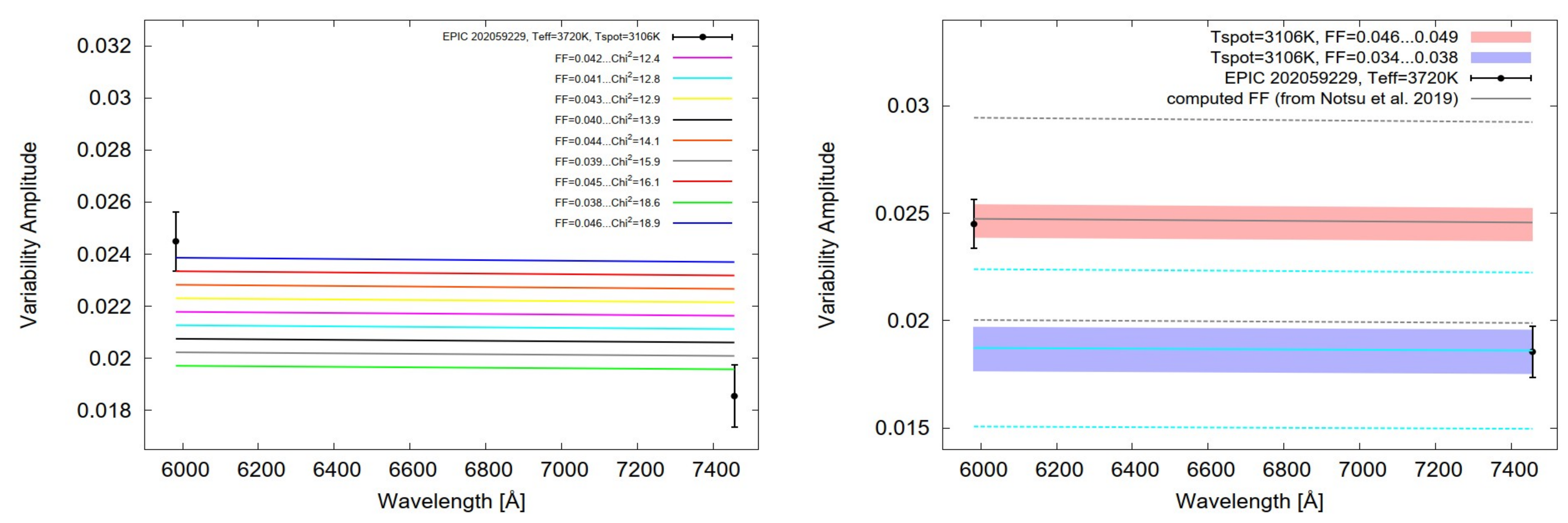
b) The full amplitude ↕ was measured for every rotation from the highest maximum to the deepest minimum
→ final amplitude: average of all amplitudes

(Raetz at al. 2020)

5 Results

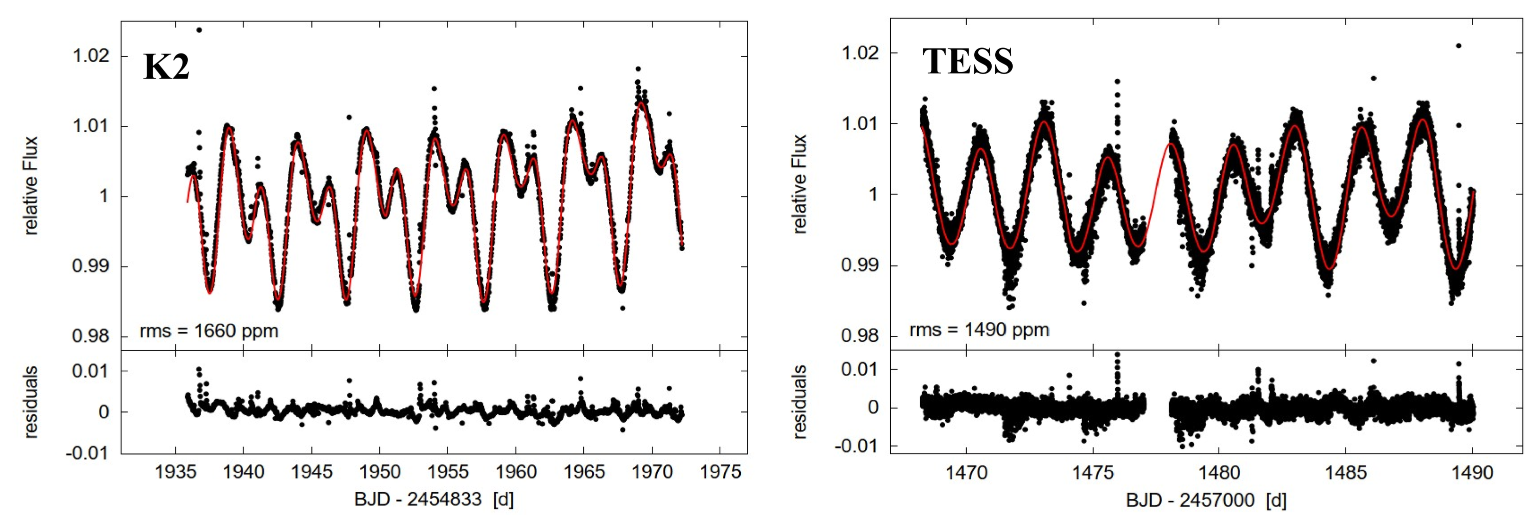
1. EPIC202059229 / TIC372611670

Photometric variability (full) amplitude over wavelength for the K2 and TESS observations



- solid lines: amplitudes that were calculated using the NextGen stellar atmosphere models
- the spot temperature was kept fixed: computed using equ. 4 in Notsu et al.(2019) which they deduced from Fig. 7 in Berdyugina (2005)
- **Left**: Best fit for K2 and TESS observations simultaneously
  –> only true if both observations were carried out simultaneously or activity level is constant
- **Right**: All models that fit either the K2 or the TESS observations are shown as the red and blue shaded areas, respectively
- gray and light blue lines: computed amplitudes that correspond to the filling factors derived using equ. 3 in Notsu et al.(2019)

Observed K2 and TESS and simulated light curves using the SOAP2.0 spot model



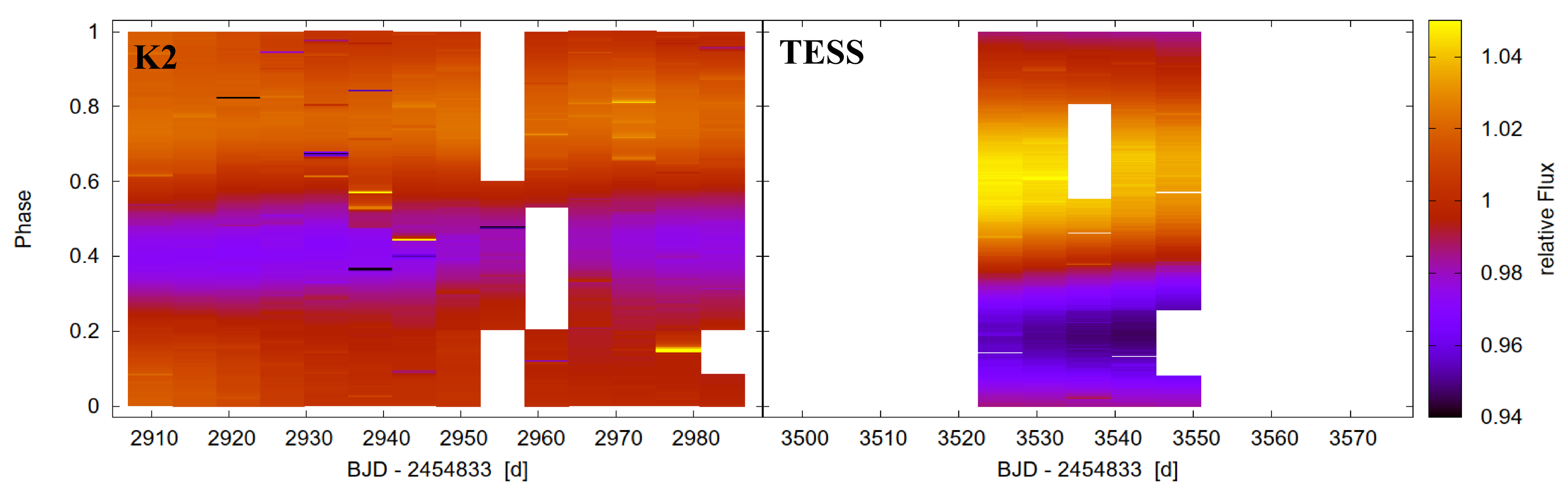
- A separate model was fitted to each individual rotation using SOAP2.0 (Dumusque et al., 2014)
  –> The model uses two dark spots of the same size
- Spot modelling is a highly degenerate problem. Hence, the stellar inclination i = 90°, T_{spot} = 3106K and the spot size were kept fixed for all models
- **K2**: R_{spot} = 0.312 R_{star} (↔ FF = 0.049)
- **TESS**: R_{spot} = 0.278 R_{star} (↔ FF = 0.039)

The amplitude and rotation period of EPIC 202059229 did not change significantly between observations that are separated by ~4.5 years

–> the activity level is ~ constant

2. EPIC245919787 / TIC434101713

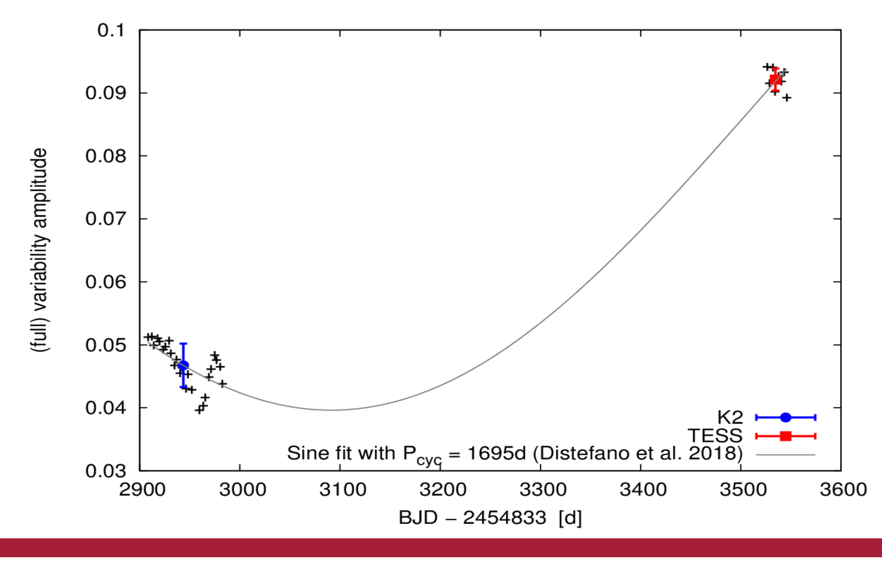
Relative flux map as function of rotation phase and time



Variability amplitude and rotation period did clearly change between observations that are separated by ~2 years

Distefano et al. (2018) found a stellar activity cycle period of **P_{cyc} = 1695d** for EPIC 245919787

➔ consistent with our detected change in variability amplitude and rotation period!



6 Summary of our combined K2 and TESS stellar activity study

In its prime mission TESS observed 45 stars that are also included in our K2 M dwarfs study published in Raetz et al. (2020). Four targets were analyzed in more detail of which two are shown here.
EPIC202059229 / TIC372611670 does neither show a significant change in its activity level nor in its rotation period between the observations.
For **EPIC245919787 / TIC434101713**, on the contrary, we detected a clear difference. Moreover, this changes are consistent with the cycle period found by Distefano et al. (2018).