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Rotation-activity relations and flares of M dwarfs with K2 long- and short-cadence data

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1 Abstract

Studies of the rotation-activity relation of late-type stars are essential to enhance our understanding of stellar dynamos and angular momentum evolution.
Photometric observations with space telescopes provide rotation periods even with low amplitudes as well as a wealth of activity diagnostics.
Our previous study of the rotation-activity relation based on photometric activity indicators from long cadence K2 data (Stelzer et al. 2016) revealed, that, at a critical rotation period of ~10d, the activity level changes abruptly. This phenomenon represents an open problem within the framework of dynamo theory.
We have now extended our work to K2 short cadence data to examine a possible influence of the data sampling on the shape of the rotation-activity relation, in particular with respect to the different sensitivity to the detection of stellar flares.

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. Our K2 observing project (PI: Scholz) comprised all Lépine & Gaidos (2011) M dwarfs in the K2 field of view. During 20 K2 campaigns (C0–C19), 485 light curves of 430 targets were obtained. For a subsample of these 430 M dwarfs short-cadence light curves are available.
Our final sample comprises 56 bright and nearby M dwarfs observed by K2 during campaigns C0-C18 in long and short cadence mode.

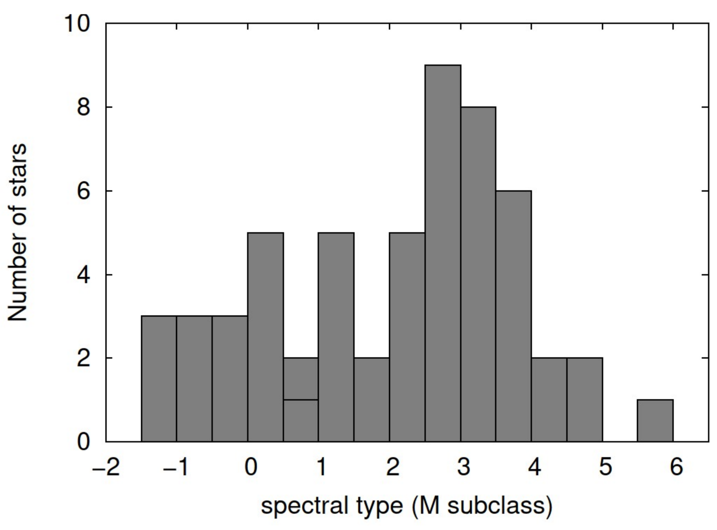


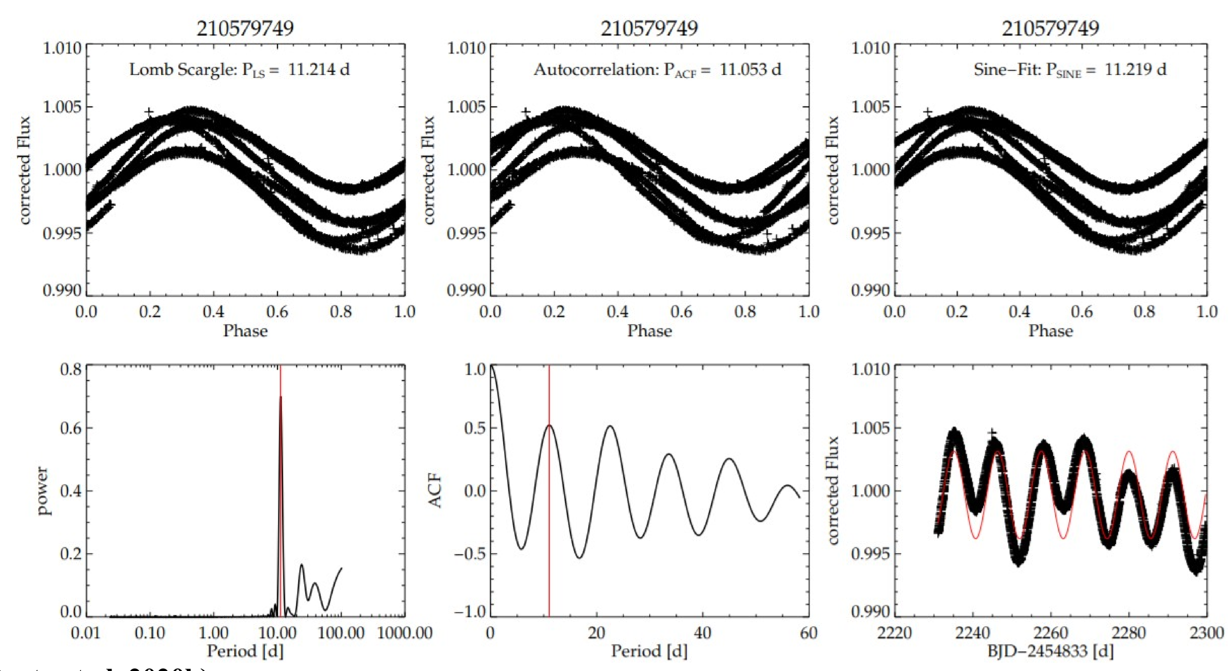
Fig.1: Distribution of the spectral types for our K2 M dwarf sample. Negative values denote spectral types earlier than M.

We extracted the raw light curves from the target pixel files with the KeplerGO/lightkurve Code. We developed a procedure that allows us to use the detrending by Vanderburg & Johnson (2014) and apply it to the original long and short cadence light curves.

3 Starspot modulation

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



(Raetz at al. 2020b)

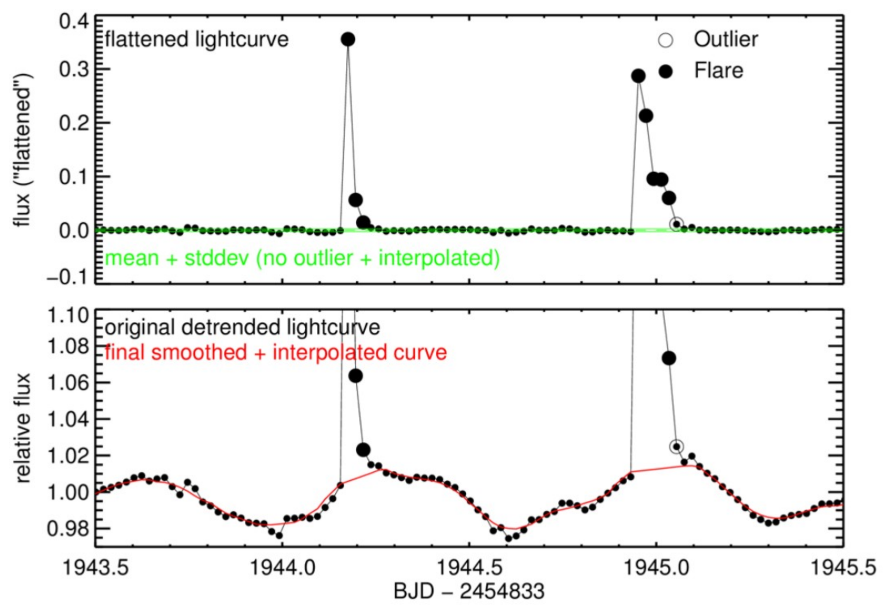
All light curves were phase-folded with the periods of the three methods. By eye-inspection we selected the best-fitting period, which we then used in the further analysis. In the case of equally good periods from different methods, we adopted the average rotation period.
In total, we found rotation periods for 46 stars, which is ~82% of all targets in our M-dwarf sample.

4 Flare Detection

We searched for flares in the K2 light curves. Our flare analysis procedure is based on the routine used in Stelzer et al. (2016):

Iterative process of
- boxcar smoothing
- removing 2σ outliers

→ final smoothed LC (interpolated to all points of the original input LC)
- → points that lie 3σ above the final smoothed LC were flagged
- → groups of **at least two** (long cadence) / **five** (short cadence) **consecutive flagged points** were assigned as potential flares



Flare validation:

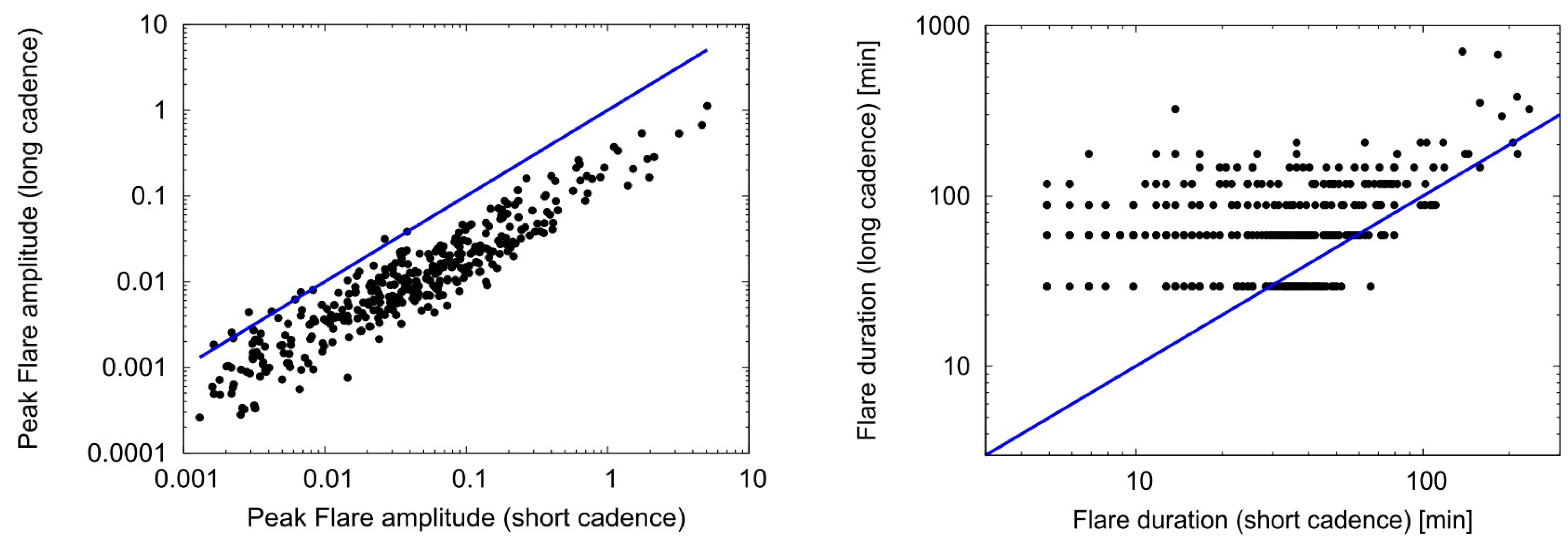
The following criteria have to be fulfilled:

(1) the flare does not happen right before or after a data gap
(2) the maximum flux value is significant with at least 3σ
(3) the flux ratio between the flare maximum and the last flare point is ≥2,
(4) the decay phase is longer than the rise phase
(5) the flare maximum is not allowed to be the last point of the potential flare
(6) [only for short cadence flares]
a flare template (Davenport et al. 2014) fits the data better than a linear fit through all flare points
(7) of the potential long-cadence flares, only those with a short-cadence counterpart were considered a flare.

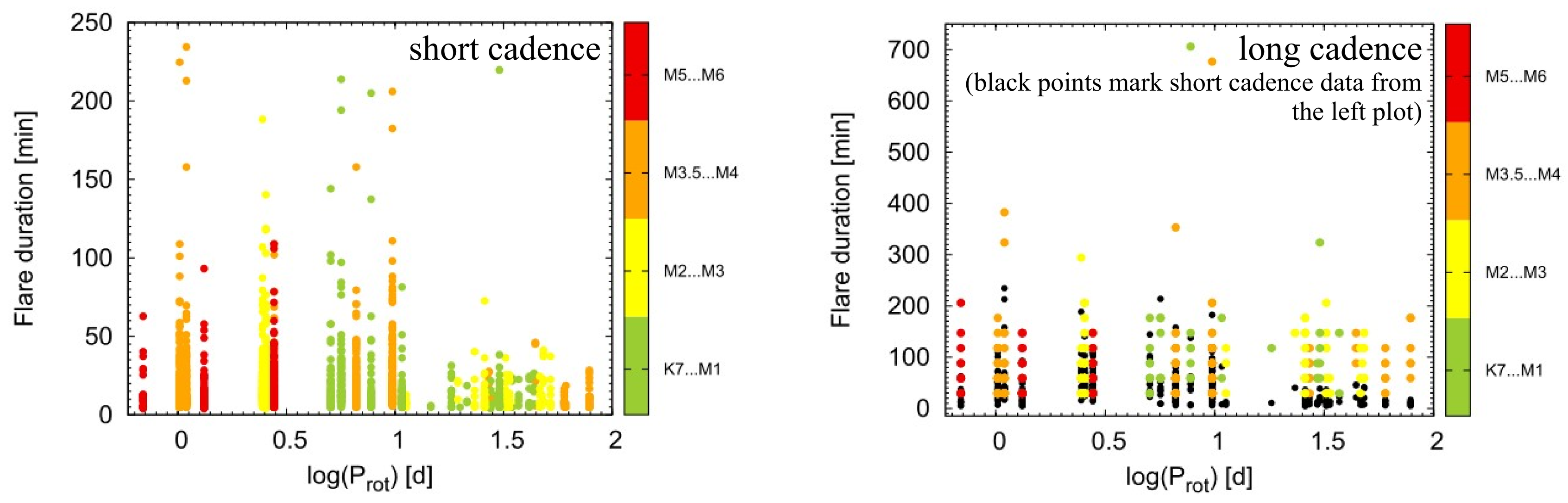
5 Results

(Raetz et al. 2020a)

1. Comparison of flares in long cadence and short cadence data

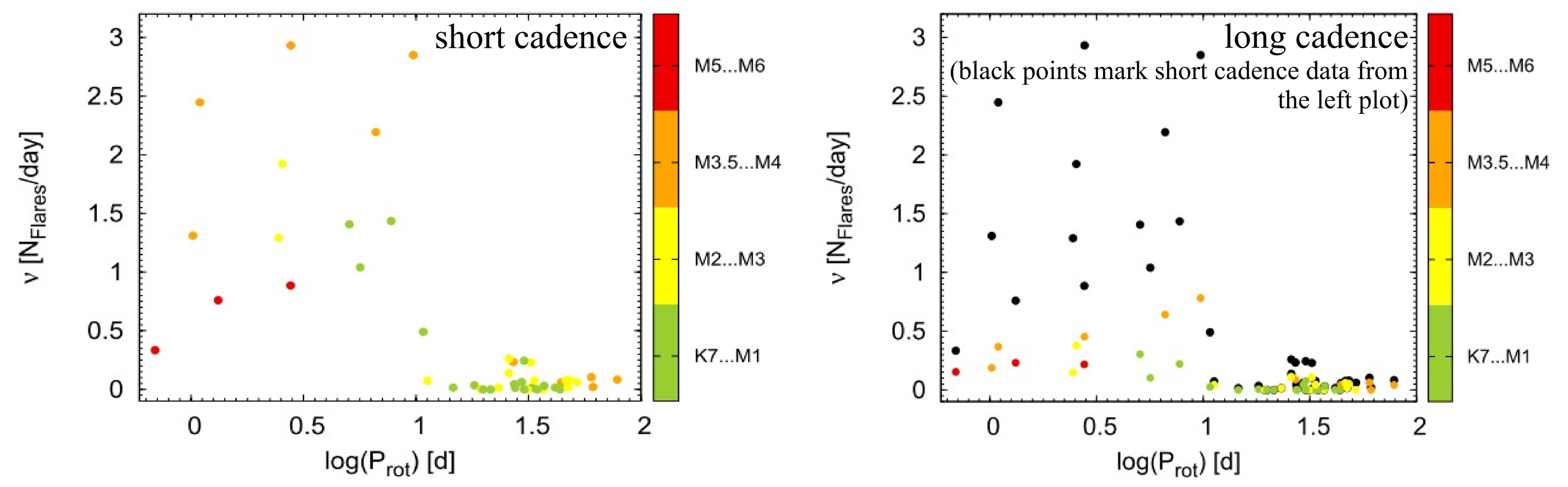


2. Flare durations:



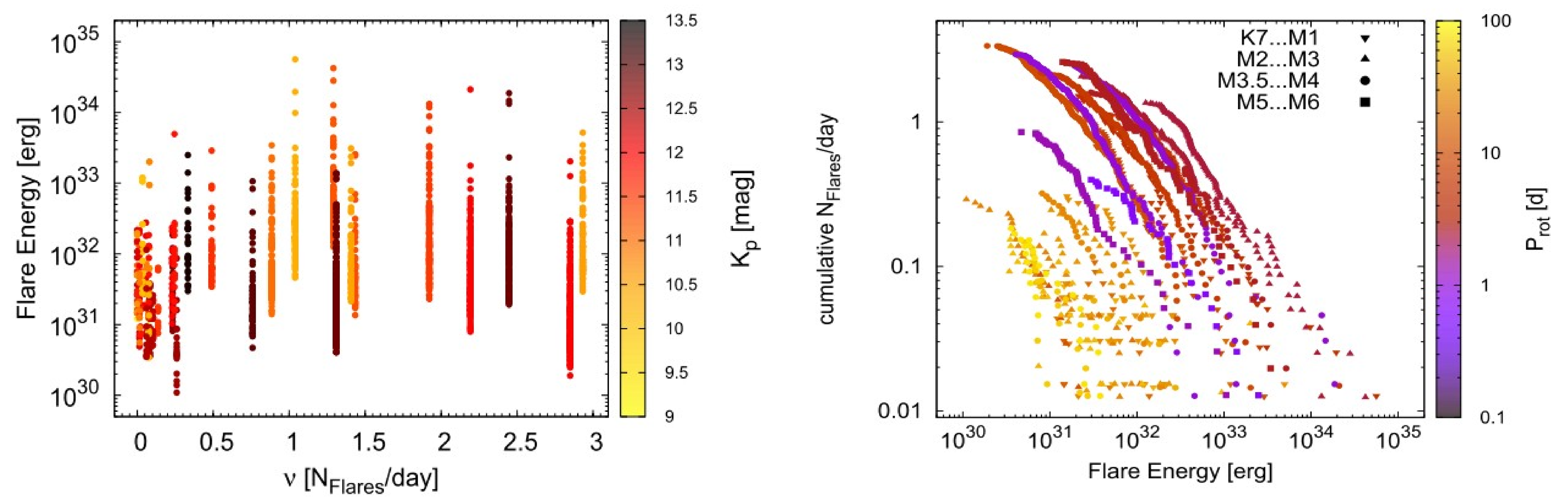
- durations are more overestimated for shorter flares
  → consequence of the strong artificial quantization due to the ~30 min cadence
- bimodality is only barely visible in long-cadence data

3. Flare frequencies



- fast rotator regime (P_{rot} < 10d): flare rate is ~5 times higher for short-cadence data
- slow rotator regime (P_{rot} > 10d): flare rate is ~3 times higher for short-cadence data
- whole sample:
  → $(N_{flares}/day)_{SC}$ = 4.6 x $(N_{flares}/day)_{LC}$
- the highest flare rates are not found among the fastest rotators
  (also seen by Mondrik et al., 2019 in the MEarth data set)

4. Flare energies



- stars with the highest flare rates do not show the most energetic flares
- average power law slope for the fit of the flare energy frequency distributions for all targets:

α = 1.84 ± 0.14

(Consistent with previous M dwarf studies and the value found for the Sun.)

- the superflare frequency (E ≥ 5 × 10^{34} erg) for the fast-rotating M stars is twice higher than for solar like stars in the same period range (Maehara et al., 2012)

6 Summary

Our study that comprises 56 bright and nearby M dwarfs observed by K2 during campaigns C0-C18 in long and short cadence mode showed how a higher data cadence improves the detection and analysis of stellar flares.
The analysis of the short cadence light curves resulted in a 4.6 times higher flare rate than the long cadence data.
We confirm in the short cadence data the abrupt change of the activity level in the rotation-activity relation at a critical period of ~10d. This change is most drastic in the flare duration and the flare frequency. Our flare studies revealed that the highest flare rates are not found among the fastest rotators and that the stars with the highest flare rates do not show the most energetic flares. Finally, we found a ~2 times larger superflare frequency for the fast rotating M stars than for solar-like stars in the same period range.