Studying Kepler Superflare Stars

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Abstract. Nearly 300 “superflare stars” (SFS) of approximately solar spectral type have been found in the data observed by the Kepler satellite (Shibayama et al. 2013). These SFS show white-light flares with estimated energies between 10^{34} and 10^{36} erg in the Kepler band, making them at least two orders of magnitude more energetic than the largest flares observed on the Sun. We study a sample of SFS using optical high-resolution spectroscopy, an in-depth light curve analysis and XMM-Newton X-ray observations. We find no spectroscopic “peculiarities” in these stars, most of our sample stars appear as singles in our spectra. Most, but not all, show significant chromospheric emission. We find decay times of more than one hour for the majority of detected flare events. This duration massively exceeds the lifetime of solar white-light flares which are visible only up to a few minutes. We detect X-ray emission for all SFS in our XMM-Newton sample, corresponding to luminosities between several 10^{29} erg/s and a few 10^{30} erg/s in soft X-rays, i.e. considerably more luminous than the Sun. However, our $15 - 20$ ksec exposures cover no significant X-ray flare.

1. Superflares

Shibayama et al. (2013) detected more than 1500 “superflares” on nearly 300 solar-type stars. Sixty of these stars have effective temperatures between 5600 and 6000 K and rotate with periods of at least 10 days. This raises the question whether our Sun might also produce such large flare events which could have disastrous influence on terrestrial infrastructure (cf. e.g. Baker et al. 2013).

1.1 Optical CAFE Spectra

We analyzed spectra of eleven superflare stars (SFS) observed with the CAFE spectrograph mounted on the 2.2m telescope of the Calar Alto observatory. The spectra cover 4000Å to 10400Å with a resolution of 65000, they exhibit S/N ratios between 20 and 70. The results are presented in Wichmann et al. (2014).

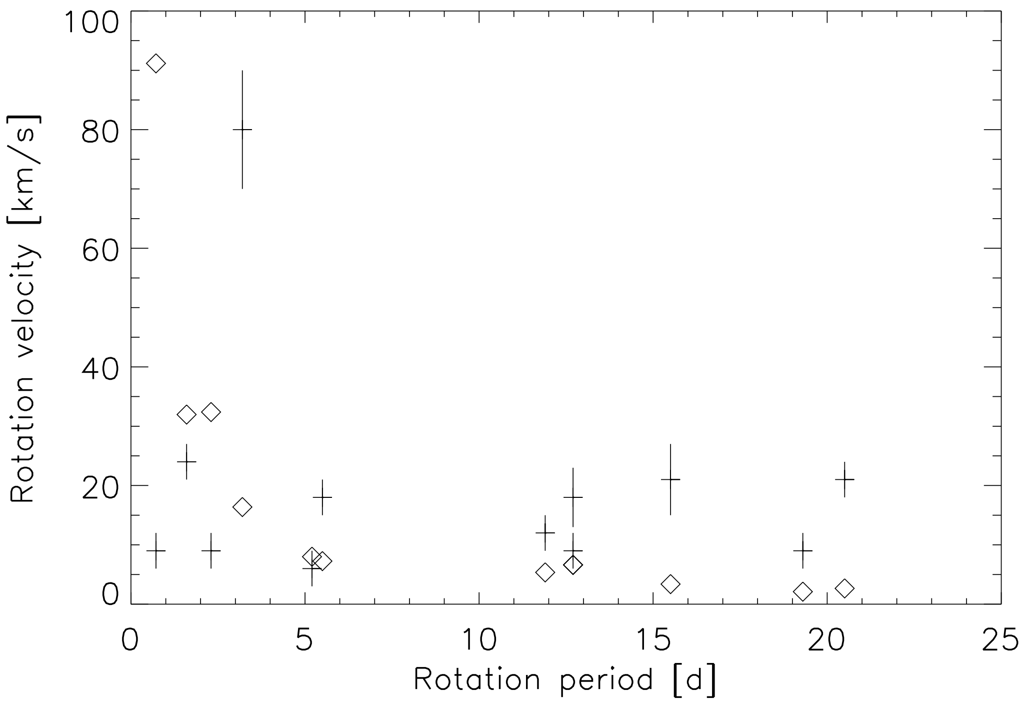

Figure .1: Spectroscopically determined *vsini* (error bars) and estimated equatorial rotation velocities v_{eq} (diamonds) of our CAFE sample stars as a function of rotation period. The v_{eq} have been calculated using the radius estimates of the Kepler input catalog and the rotation period determined from the light curves. Several stars show $v \sin i$ values significantly exceeding the estimated v_{eq} – the reason for this is currently unclear. We find the largest deviation for KIC 9653110 with a $v \sin i$ of 80 ± 10 km/s. The two $v \sin i$ measurements in the same column belong to the spectroscopic binary KIC 7264976, the corresponding rotation period presumably only characterizes one of its components. The star with the shortest rotation period (KIC 3626094) would need to be seen nearly pole-on which would be at variance with its lightcurve modulation being caused by rotation.

We determined stellar parameters using SME and fitting a grid of PHOENIX sythetic spectra. Our spectroscopically determined effective temperatures confirm our sample stars to be late F- to early G-type stars with the exception of KIC 1107391 which appears to be an early to mid-F-type. All determined surface gravities are consistent with the stars being on or close to the main sequence, although the low S/N ratio for some stars limits the certainty of that fact. Only one of our sample stars, KIC 7264976, shows clear indications of binarity, cf. Wichmann et al. (2014) for details. As shown in Figure .1, some stars show $v \sin i$ values significantly exceeding their equatorial rotation velocities as estimated from the radius estimates of the Kepler input catalog and their photometric rotation period. The reason for this is currently unclear.

1.2 Sensitive Flare Detection

We applied Shibayama et al.'s (2013) flare detection algorithm to a subsample of their stars, consisting of those 88 stars for which they report at least five "superflares". Increasing the sensitivity of this algorithm, we detect flare-like events with amplitudes down to 0.001, as measured relative to the quiescent stellar signal. This sensitivity can only be reached for the slow rotators for which the fast bin-to-bin variations in the light curve due to flares can be clearly discerned from rotational modulation. The detection sensitivity decreases to about 0.01 for the fast rotators in our sample. In this way, we typically detect more than 100 white-light flares for each star in the roughly 1300 days of Kepler data analyzed.

As Figure .2 illustrates, we find decay times of more than one hour (0.04 days) for most of our detected flare events. This strongly exceeds the lifetime of solar white light flares which are visible only up to a few minutes (see e.g. Hudson et al. 2006). This finding is clearly biased by the fact that most SFS were observed in the long-cadence mode of Kepler, i.e. with about 30 minute cadence. However, as a comparison with the few available short-cadence light curves shows, the decays of long-lasting flares seem to be, as expected, appropriately sampled by the long-cadence measurements. Additionally, the long-cadence sampling of the flares causes the measured amplitudes to be lower limits to their true amplitude (see e.g. Figure 11 of Shibayama et al. 2013). This must also be kept in mind when interpreting Figure .2.

1.3 X-ray Observations

With an ongoing observing programme we study the X-ray properties of several Kepler SFS. All five SFS in our XMM-Newton sample show X-ray emission corresponding to estimated X-ray luminosities of up to a few 10^{30} erg/s in the $0.3 - 9$ keV band. As illustrated by the examples shown in Figure .3, for none of them we happened to observe a significant X-ray flare.

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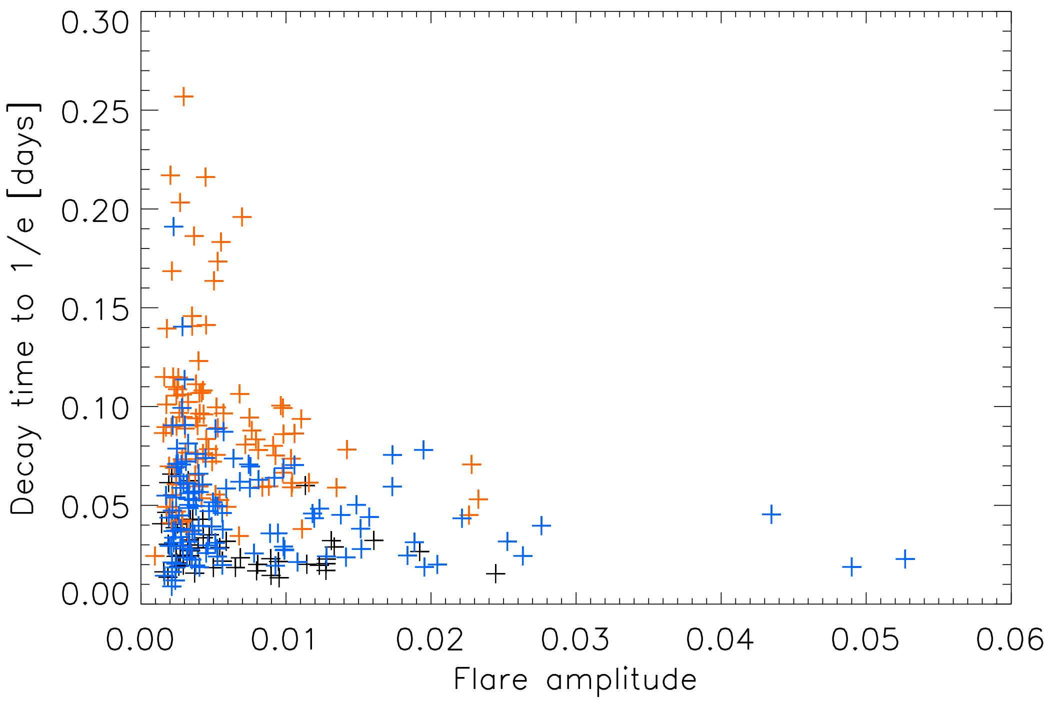

Figure .2: Exponential flare decay times as a function of flare, as measured in the 30 minute sampling of the Kepler light curves. Shown are all flares detected in KIC 4742436 (black), KIC 7264976 (blue) and KIC 11764567 (orange).

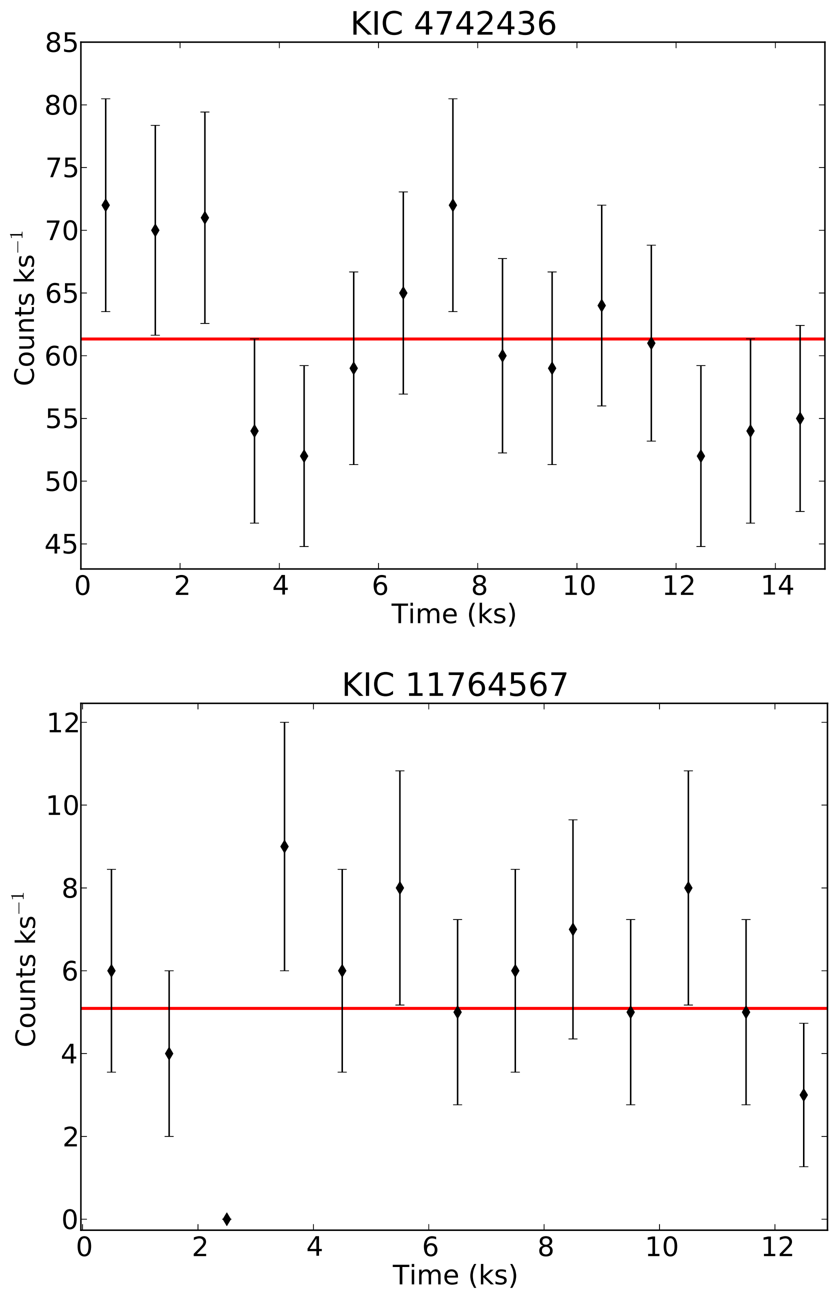

Figure .3: Preliminarily reduced X-ray light curves of two Kepler SFS observed with XMM-Newton's EPIC-pn instrument.