

Superflares on solar-like stars

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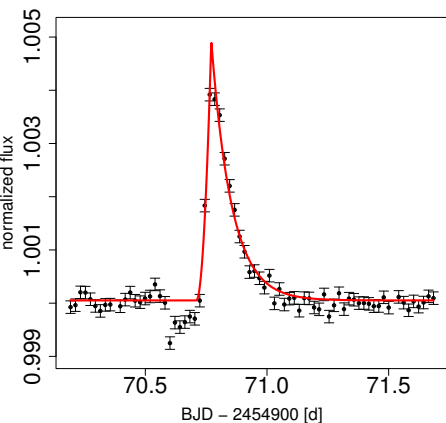
Freiburg, September 4, 2015



kepler.nasa.gov/



Definition of Superflares



- Solar flares
 - typical values of 10^{29} erg¹
 - largest flare reported Carrington-event 10^{32} erg (1859)
- Superflares: flares with energies $10 - 10^6$ times that of largest known solar events

$$1 \text{ erg} = 10^{-7} \text{ J}$$

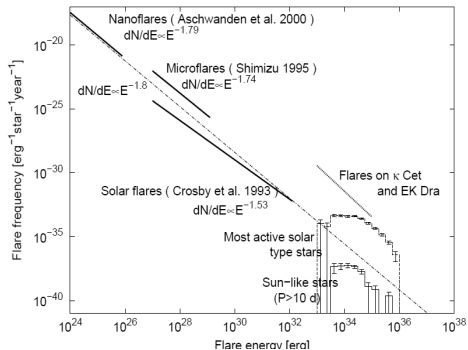
Currently known frequency properties

- four dozen superflares on ordinary solar-type stars with spectral class F8-G8 involving $10^{33} - 10^{38}$ ergs (Schaefer 1989; Schaefer 1991; Schaefer, King & Deliyannis 2000)
- Maehara et al. (2012): 365 high energetic flares on 148 solar-type stars ($T_{eff} = 5200 - 6000$ K, $\log(g) > 4.0$) using Kepler, **14 superflares on 10 presumable Sun-like stars** ($T_{eff} = 5600 - 6000$ K, $\log(g) > 4.0$; $P_{rot} > 10$ d)
- Shibayama et al. (2013): 1547 superflares on 279 solar-type stars, **44 superflares on 19 presumable Sun-like stars**

In this work we are especially interested in the Sun-like stars with $T_{eff} = 5600 - 6000$ K and $\log(g) > 4.0$, $\Delta T = 3.6$ yr

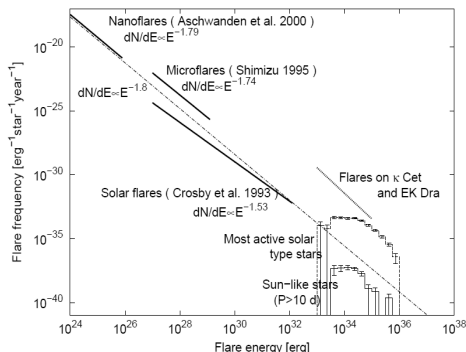
Currently known frequency properties

(Shibayama et al. 2013)



Currently known frequency properties

(Shibayama et al. 2013)



Are those stars really solar twins?

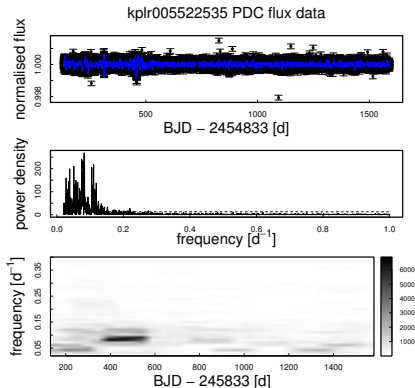
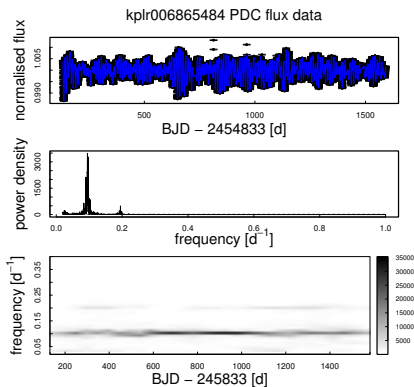
Are those stars really solar twins?

- 19 superflare stars among 14000 investigated sun-like stars, 11 superflare stars with only one detected superflare
- large pixel scale of Kepler ($4''/\text{px}$) and small pixel mask ($\approx 20 \text{ px}/\text{star}$) – close binary interaction or wide late type companions cannot be excluded
- crowded Kepler FoV – contaminated light from background objects possible
- estimated superflare rate for the sun (once every 800 yr for $> 10^{34}$ erg) not consistent with observations and historical records (e.g. last 14000 years of ^{14}C data, polar ice cores)

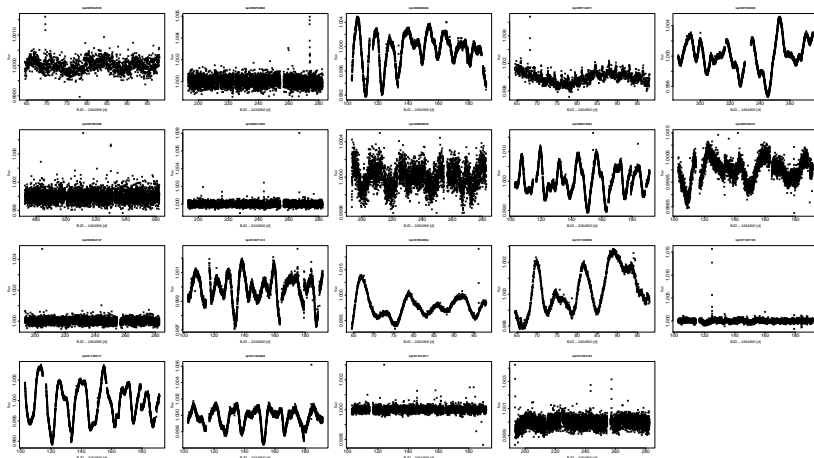
A rough look to the 19 presumed Sun-like superflare stars

KIC	Kmag	kepmag	Teff	logg	Av	R*
5522535	12,146	13,788	5732	4,258	0,358	1,29
6750902	13,083	14,670	5654	4,396	0,346	1,09
6865484	12,144	13,780	5688	4,363	0,341	1,13
7133671	13,730	15,472	5657	4,358	0,581	1,14
7354508	11,925	13,416	5714	4,363	0,291	1,13
7597685	14,230	15,866	5834	4,561	0,475	0,89
8212826	12,461	13,965	5811	4,224	0,343	1,36
8880526	11,381	12,752	5936	4,318	0,262	1,21
9574994	13,603	15,110	5925	4,422	0,404	1,06
9766237	12,385	13,913	5674	4,557	0,279	0,89
9944137	12,269	13,759	5725	4,619	0,254	0,83
10471412	11,897	13,449	5771	4,084	0,375	1,62
10524994	13,669	15,341	5747	4,491	0,402	0,97
11390058	11,131	12,628	5785	4,281	0,230	1,26
11401109	13,003	14,525	5732	4,545	0,338	0,91
11455711	12,429	13,955	5664	4,666	0,258	0,78
11494048	12,089	13,444	5929	4,363	0,283	1,15
11612371	11,935	13,401	5826	4,384	0,294	1,11
11961324	12,569	14,166	5750	4,375	0,343	1,12

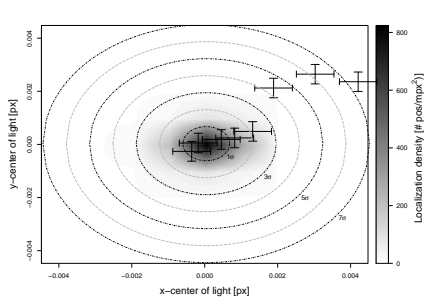
Are the rotational periods reproducible?



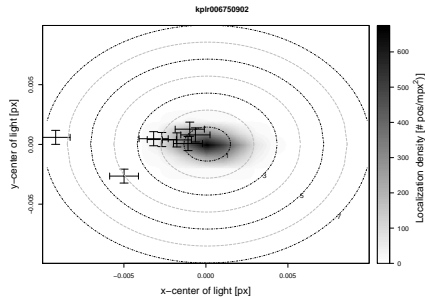
Are the rotational periods reproducible?



Are the Sun-like stars the origin of the superflares



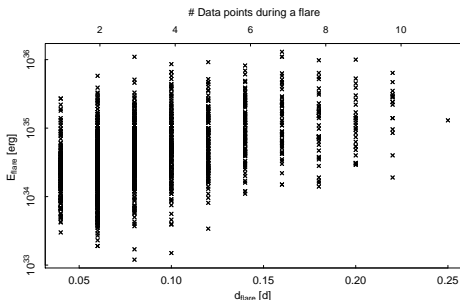
KIC007133671



KIC006750902

During the flares, photons come from another position, either a background object, companion, probably not a solar twin

Which parameter constraints do the flares have?



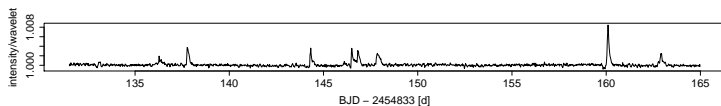
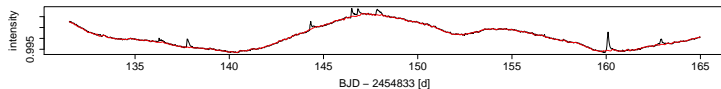
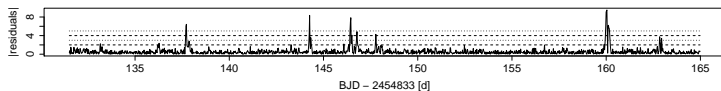
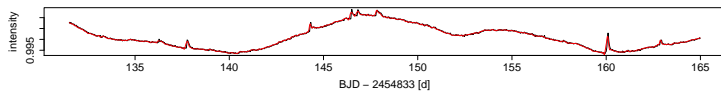
10 of the 19 presumed sun-like Superflare stars are dubious for further consideration as sun-like superflare stars

- no or fast rotation
- photons during the flares come from another source
- only one or two data points in flare

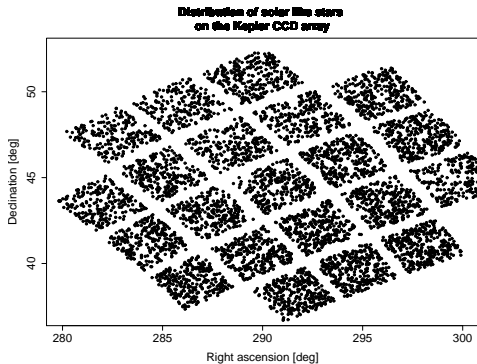
Necessity to reinvestigate sun-like *Kepler* stars

- introduce a new detection method to find more real flares
- check significance of a period detection
- use *Kepler* astrometry to find potential background stars, that are responsible for the flares
- using photometry and KIC data to estimate bolometric flare luminosities and energies
- reject stars with known nearby stars
- set more reliable parameter constraints for the superflares
- roughly estimate the ages of the stars with gyrochronology for a more reliable comparison to the sun

Wavelet-Detection and trend correction



Kepler astrometry



- 42 CCD Module Output pairs
- for each star for each time stamp - calculate photocenter
- compare with time stamps of the flares
- finding background objects responsible for the flares

Gyrochronology

- using rotational periods and colors to determine a characteristic age
- empirical finding for field stars

$$\log(t_{gyro}) = \frac{1}{n} \{ \log(P) - \log(a) - b \cdot \log(B - V - 0.4) \} \quad (1)$$

$$a = 0.7725 \pm 0.011 \quad (2)$$

$$b = 0.601 \pm 0.024 \quad (3)$$

$$n = 0.5189 \pm 0.007 \quad (4)$$

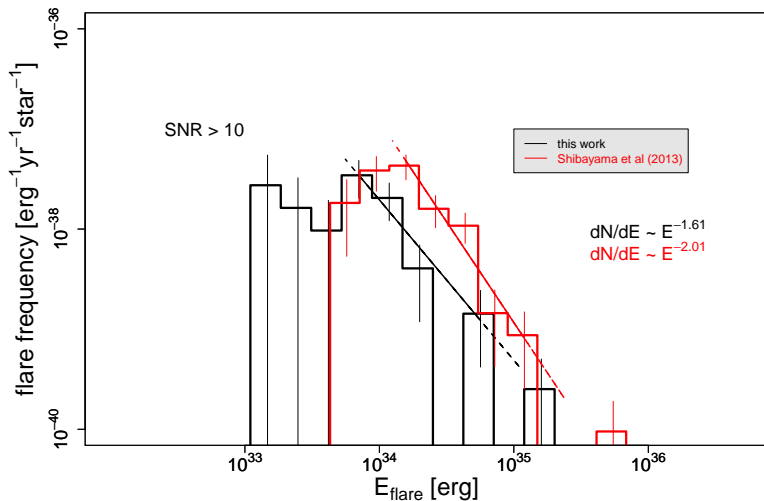
(Barnes 2007)

- investigation of 48000 Sun-like *Kepler* stars for the whole period of *Kepler* observations (in total ≈ 4 yr)
- several hundreds to thousand new superflare detections
- several hundreds of new superflare star candidates

Comparison to the sun:

- 7300 stars have a significant period detection
- 400 stars have ages > 2 Gyr
- 21 superflares $> 10^{33}$ erg with $SNR > 10$

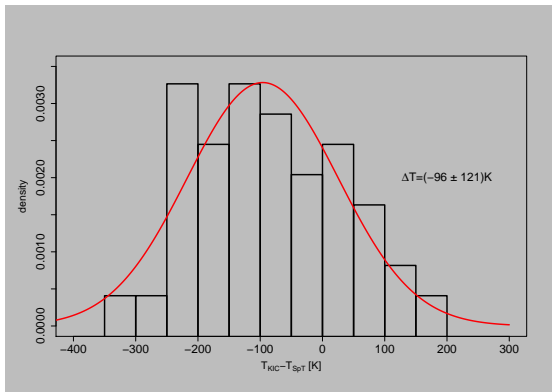
Flare energy distribution - preliminary results



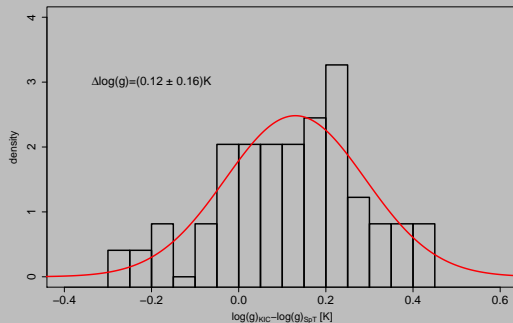
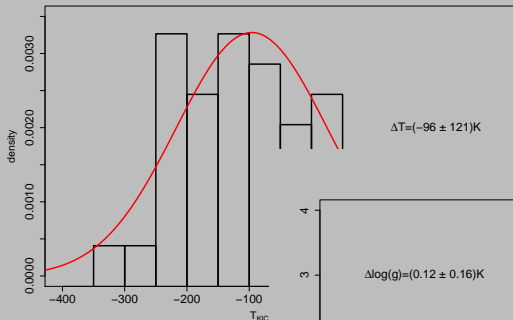
- estimated superflare frequency on the sun for 10^{34} erg is 1 event per 3000 yr, for 10^{35} erg 1 event in 20000 yr (consistent with observational records and natural archives)
- one explanation for such large brightenings is that the stars have stronger magnetic field and are therefore not a solar twin
- superflares on the sun can be harmful to the biosphere and very relevant for space weather – importance to better understand the superflare rate on the sun
- fully automatic data analysis has finished recently
- playing with the data, critical look, finding further constraints, visible inspection, observe the stars with other techniques

Thank you

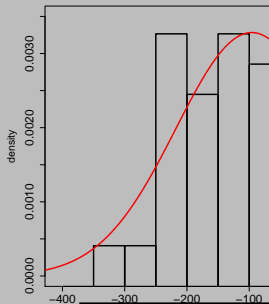
Are the KIC data be correct (on average) ?



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Uncertainties from the KIC

$$\Delta T = 200 \text{ K}$$

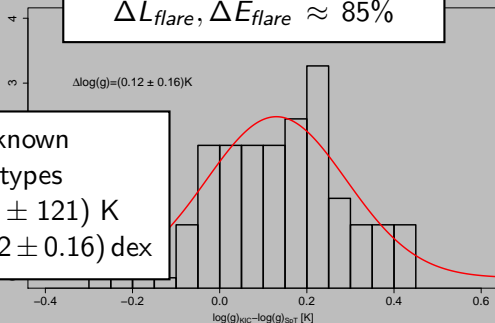
$$\Delta \log(g) = 0.4 \text{ dex}$$

$$\Delta L_{flare}, \Delta E_{flare} \approx 85\%$$

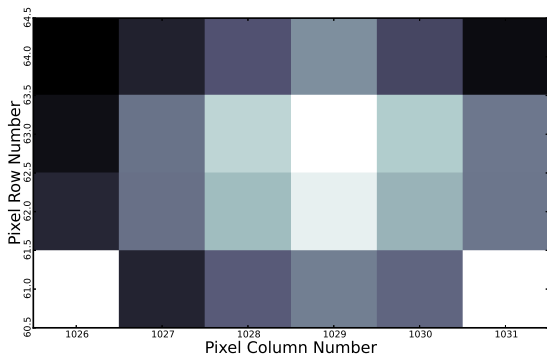
from 49 known
spectral types

$$\Delta T = (-96 \pm 121) \text{ K}$$

$$\Delta \log(g) = (0.12 \pm 0.16) \text{ dex}$$



Kepler astrometry

**CLEAR****LOAD****DUMP****PRINT**

```
KepID: 10524994  
RA (J2000): 287.32725  
Dec (J2000): 47.74898  
KepMag: 15.341  
SkyGroup: 23  
Season: 3  
Channel: 39  
Module: 12  
Output: 3  
Column: 1026  
Row: 61
```

Image scale: 3.98 arcseconds per pixel

Pixel size: 27×27 microns