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Solar and Stellar Flares and their Effects on Planets
Proceedings IAU Symposium No. 320, 2015
A.G. Kosovichev, S.L. Hawley & P. Heinzel, eds.

doi:10.1017/S1743921316002179

Flares in A–type stars?

May G. Pedersen[1], Victoria Antoci[1] and Heidi Korhonen[3]

[1]Stellar Astrophysics Centre (SAC), Aarhus University,
Nordre Ringgade 1, DK-8000 Aarhus C, Denmark,
email: maygp@phys.au.dk & antoci@phys.au.dk

[2]Finnish Centre for Astronomy with ESO (FINCA), University of Turku, Väisäläntie 20,
FI-21500 Piikkiö, Finland
email: heidi.h.korhonen@utu.fi

Abstract. Stellar flares are known to originate from magnetic reconnection in the atmospheres of late–type stars or through radiatively driven wind instabilities in early–type stars. Situated right between these two groups, the A–type stars are not expected to support either of the two mechanisms. However, recent studies report flare features in the *Kepler* light curves of 32 A–type stars, contradicting theory. We investigate the stars reported in literature, setting strong constraints on the detection criteria. Although significantly fewer, we conclude that flare-like features are present. To determine the origin we obtained high-resolution spectra from the Nordic Optical Telescope (NOT) for the ten brightest, flaring A-type stars for 3-4 epochs. Here we present the preliminary results of these spectroscopic observations, with respect to spectral classification and binarity.

Keywords. stars: activity, stars: flare, binaries: spectroscopic

1. Introduction

In late-type stars flares are the result of the release of energy when magnetic field lines in the stellar atmospheres reconnect to a lower energy configuration (Benz & Güdel 2010). For magnetic fields to get sufficiently strong to emerge at the surface and form flares a dynamo is required, which is operated by a convective envelope. The envelope gets thinner towards earlier–type stars and is only on the order of 1-3% of the total stellar radius (e.g. Kallinger & Matthews 2010) for A–type stars. Therefore they are not expected to support flaring through magnetic reconnection.

Early B–type stars show flare-like time variations in X-ray. These differ from late–type stars as they are believed to occur through shocks and instabilities in the radiatively driven winds of these stars (e.g. Lucy 1982). Radiation pressure becomes negligible around B5-B8, meaning that the winds should likewise disappear (Cassinelli *et al.* 1994). Therefore, neither magnetic reconnection or wind instabilities are expected to support flaring in A–type stars.

Recently, Balona (2012;2013) detected flare-like features in the *Kepler* light curves of 32 A–type stars. We re-investigated the light curves of 26 of these stars and detect significantly fewer events. Two possible explanations are 1) the stars are not A–type stars or 2) the flares originate from a binary companion. In order to test these explanations, we analyse high-resolution spectra for the ten brightest, flaring A–type stars. The spectra were obtained from the Nordic Optical Telescope for 3-4 epochs.

2. Analyses

The detection criteria are defined as: 1) the flare in *long cadence* (LC; 30 minutes integration time) *Kepler* (Koch *et al.* 2010) data must consist of at least *three* consecutive

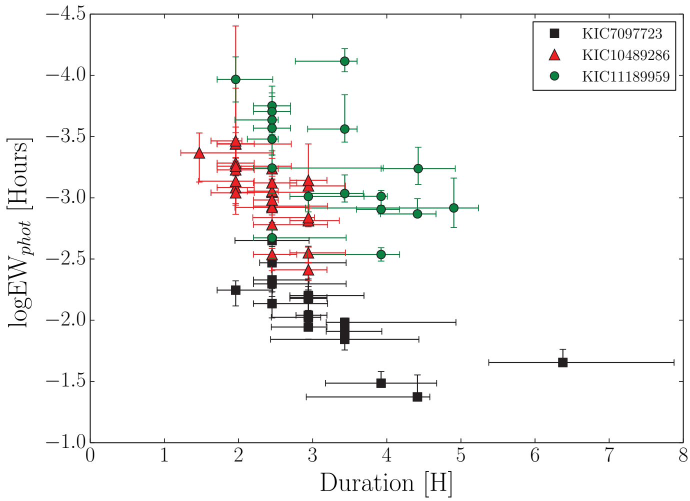

Figure 1. The photometric equivalent width plotted as a function of duration for three of the most flaring A–type stars. See text and table 1 for more details.

data points showing exponential decay, 2) flares in the *short cadence* (SC; 1 minute integration time) *Kepler* data have to be *fully resolved* when compared to the corresponding LC flare and 3) the duration of the flares must be less than 10 hours. Similar criteria were used by Walkowicz *et al.* (2011) to detect flares in the Q1† *Kepler* LC light curves of M– and K– dwarfs.

Following Walkowicz *et al.* (2011) we estimate the flare energies of three of the most flaring A–type stars by calculating the photometric equivalent width EW_{phot} of the events. The EW_{phot} is the time interval over which the star emits as much energy as released in the flare (Walkowicz *et al.* 2011). Figure 1 shows the EW_{phot} as a function of the duration. The energy increases with duration, which indicates that the observed features are indeed flares.

The spectral classification of the ten brightest flaring A–type stars is based on Gray & Corbally (2009). The result of this classification is shown in table 1. During our analyses, the $v \sin i$ of the stars is likewise estimated by comparing the data to a synthetic spectrum of Vega, for which different values of $v \sin i$ were assumed. These synthetic spectra were calculated using the program SPECTRUM, developed by Richard O. Gray‡. We then estimated the radial velocities (RVs) for the different epochs by cross-correlating each spectral order for each epoch using synthetic spectra of Vega with a fitting $v \sin i$. In this analysis the orders including Balmer lines were excluded and the final RVs were found by taking the average for all the included spectral orders for each epoch. The current conclusion from this RV determination is shown in table 1.

3. Conclusions and future work

Out of the ten stars in our sample, three were found to be single stars and one is a binary. Because of their high $v \sin i$, resulting in a high scatter in the determined RVs, the remaining stars require more detailed analysis before we can reach a final conclusion. Based on the NOT spectra we confirm that seven of the stars are A-type stars.

† Q1: Quarter 1 of the *Kepler* observing campaign. Each quarter corresponds to three months of observing time.

‡ http://www.appstate.edu/∼ grayro/spectrum/spectrum.html

Table 1. List of the stars, spectral type (SpT), *Kepler* estimated visual apparent magnitude (Kp), $v \sin i$, the number of detected flares in the Q1-Q13 *Kepler* data and the result from the test of binarity (RV binary). SpTs listed with bold characters have been found in literature. The rest are rough estimates based on Gray & Corbally (2009). N_{Balona} indicates the number of flares detected by Balona (2012;2013), $N_{Candidates}$ is the number of events found in this work. N_{Spikes} gives the number of possible flares appearing like spikes in the LC data. Note that the spectra of KIC 7097723 and KIC 10489286 were not yet analysed, but the stars are plotted in Fig. 1.

KIC	SpT	Kp [mag]	$v \sin i$ [km/s]	N_{Balona}	$N_{Candidates}$	N_{Spikes}	RV Binary
5559516	B9	8.7	~ 20	5	4	1	**No**
7974841	**B9IV-V**	8.2	33 ± 5	22	1	7	**No**
8351193	**A0IV-V**/B9V	7.6	180 ± 29	14	10	13	No?
8367661	A2V	8.7	~200	23	2	9	No?
8703413	**kAm2F0**	8.7	15 ± 2	8	2	2	**Yes**
10974032	**A0IV**	8.4	280 ± 32	19	18	13	No?
11189959	A0V	8.2	~150	38	19	19	Yes?
11443271	A2V	7.5	$\geqslant200$	6	11	19	No?
11600717	A7V	7.6	~70	3	2	1	**No**
12061741	A1V	8.6	$\geqslant200$	1	3	11	No?
7097723		11.7		11	18	15	
10489286		11.8		63	25	11	

The remaining three are a late B-type stars, two found to be single stars and one requiring further analysis. No clear correlation was found between the $v \sin i$ and number of detected flares. Future work will include: i) a more detailed analysis of the six high $v \sin i$ stars in our sample, ii) RV analyses and spectral classification of ten additional stars for which we have obtained observing time at NOT, iii) flare detection and analyses for Q14-Q17 for all of the stars and iv) estimates of upper limits on mass of a possible companion. We have also been granted observing time with the SWIFT space telescope in order to obtain UV spectra for some of the stars.

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