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Exploring Flaring Activity as an Age Indicator Using Open Cluster Data

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Flaring activity - a stellar clock for cool stars?

Flares on cool dwarfs are more frequent, energetic and high-contrast compared to main-sequence stars of earlier spectral type. Likewise, flares are a manifestation of magnetic activity that has long been known to decline as the star ages. Combining these two facts suggests that a mass dependent flaring-age relation may be established to trace individual stellar ages.

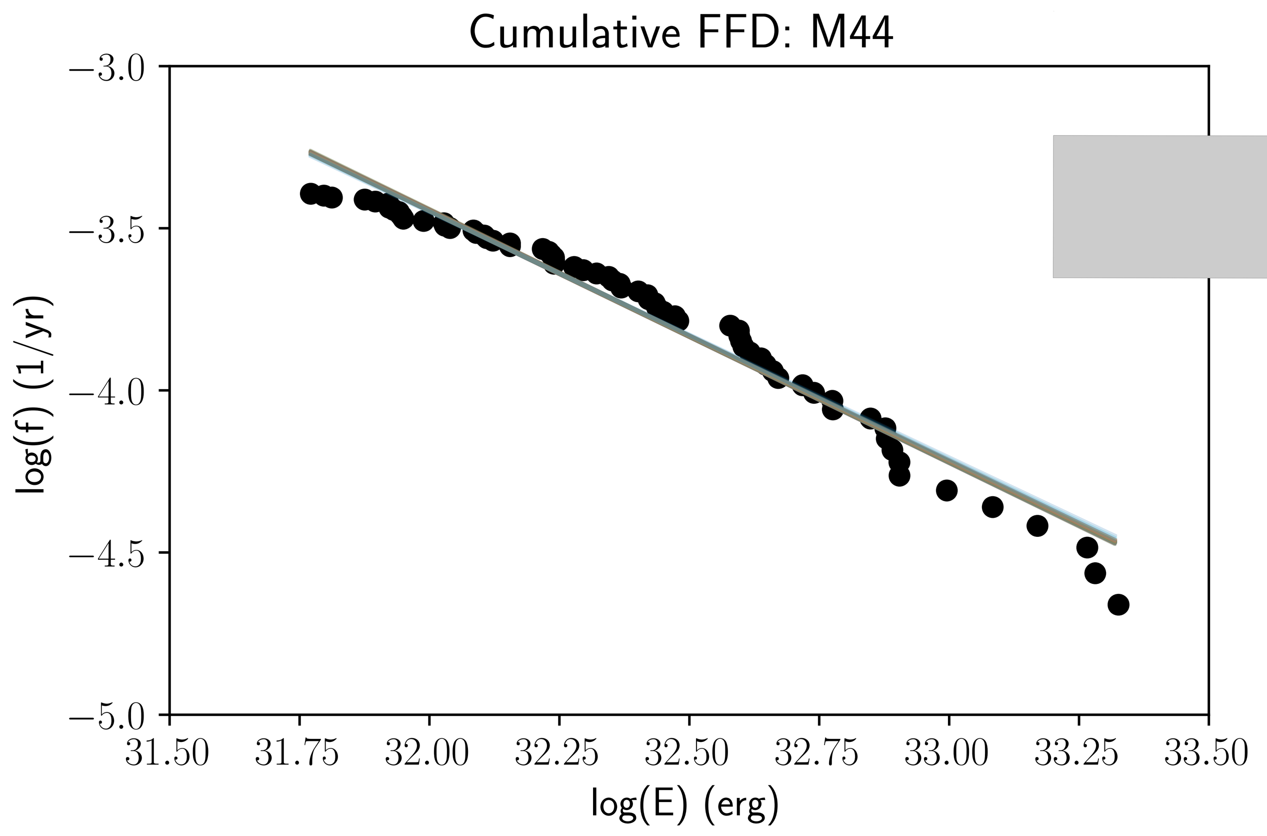
K2 open cluster photometry

cluster	M45 (Pleiades)	M44 (Praesepe)	M67
age	125 Myr (1)	630 Myr (2)	4.3 Gyr (3)
[Fe/H]	-0.01 (4)	0.16 (4)	0.03 (4)
distance	135 pc (1)	160 pc (2)	908 pc (3)
#targets (membership)	721 (5)	740 (6,7)	178 (8)
#flares	558	201	1

(1) Bell et al. 2012, MNRAS 424, 3178-91 (2) Boudreault et al. 2012, MNRAS 426, 3419-34 (3) Dias et al. 2012, A&A 539, A125 (4) Netopil et al. 2016, A&A 585, A150 (5) Rebull et al. 2016, AJ 152, 113 (6) Kraus & Hillenbrand 2007, AJ 134, 2340-52 (7) Douglas et al. 2014, ApJ 795, 161 (8) Gonzalez 2016, MNRAS 459, 1060-68

Flare frequency distributions

In a large energy range, the distributions of solar and stellar flares are well described by a power law with exponent α:



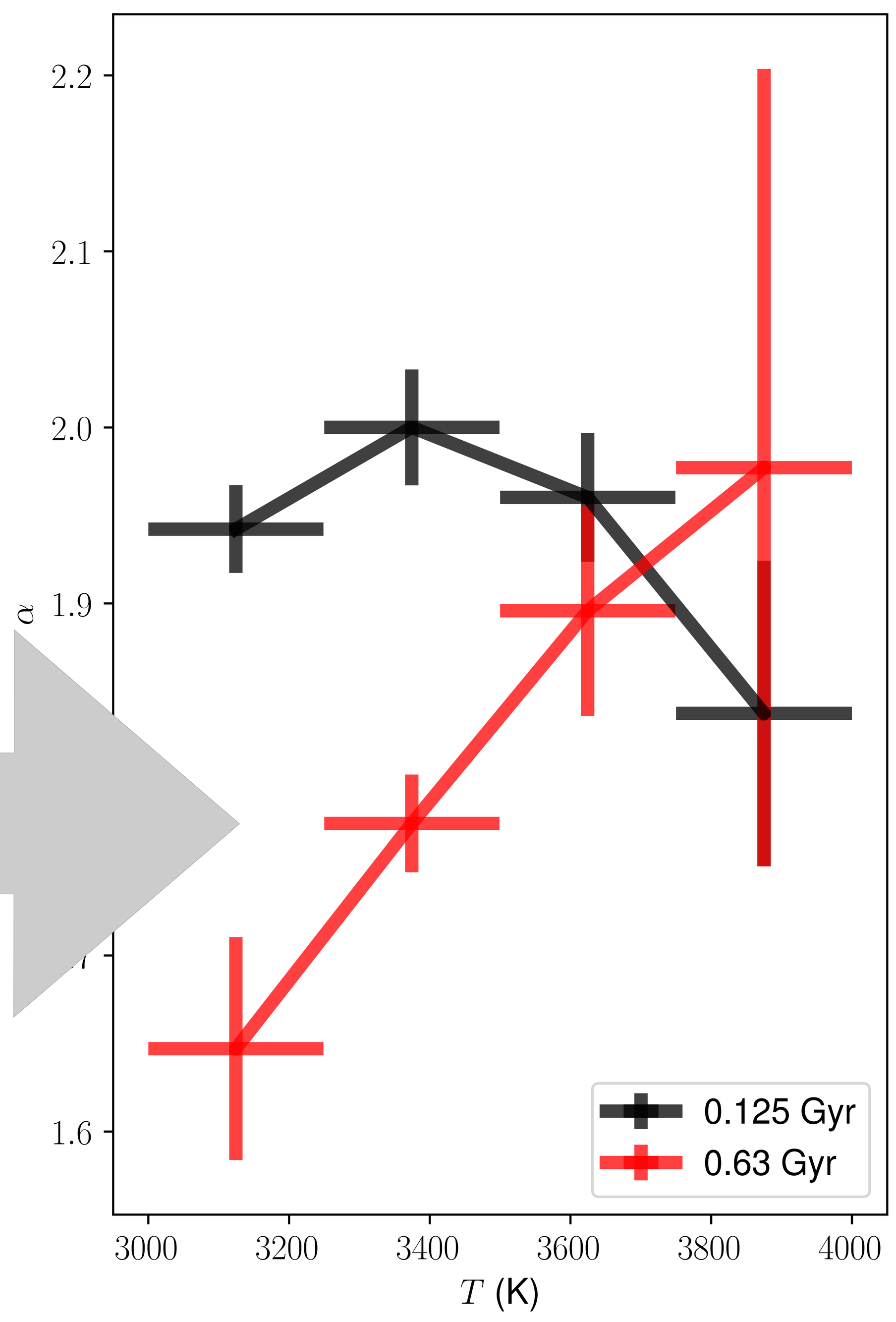
Cumulative distribution f(E) of flare energies on stars with effective temperatures 3250-3500K (M2.5-M3) at 630 Myr, based on 139 different K2 targets, on which 71 flares were detected, yielding α~1.78 .

Automated flare finding: *Appaloosa*

Space missions like Kepler and TESS enable continuous long-term monitoring of white-light flares which is required to measure flaring activity, especially on low-activity targets. Appaloosa is a flare detection and analysis pipeline, designed for Kepler light curves by J. R. A. Davenport (2016). For this study we have enhanced its performance by an artificial flare injection and recovery subroutine that allows us to characterize individual light curves and determine energy detection thresholds and account for the systematic underestimation of energies observed in long cadence data. As we analyse photometry from the follow up mission K2 instead of original Kepler data, we use de-trended and variability cleared light curves from Aigrain et al. (2016).

Appaloosa is open source!

Flare frequency distribution: power law slope α



Slopes of flare frequeny distributions for Pleiades and Praesepe. We found only one flare candidate in M67 hence this cluster is not included here.

M2.5-5.5 dwarfs shed relatively more energy in large flares in Praesepe than in the Pleiades.

While late-K to earliest-M dwarfs show similar distributions, cooler stars appear to produce more high energy flares relative to weak ones at 630 Myr compared to 125 Myr.

What changes the flare production mechanism?

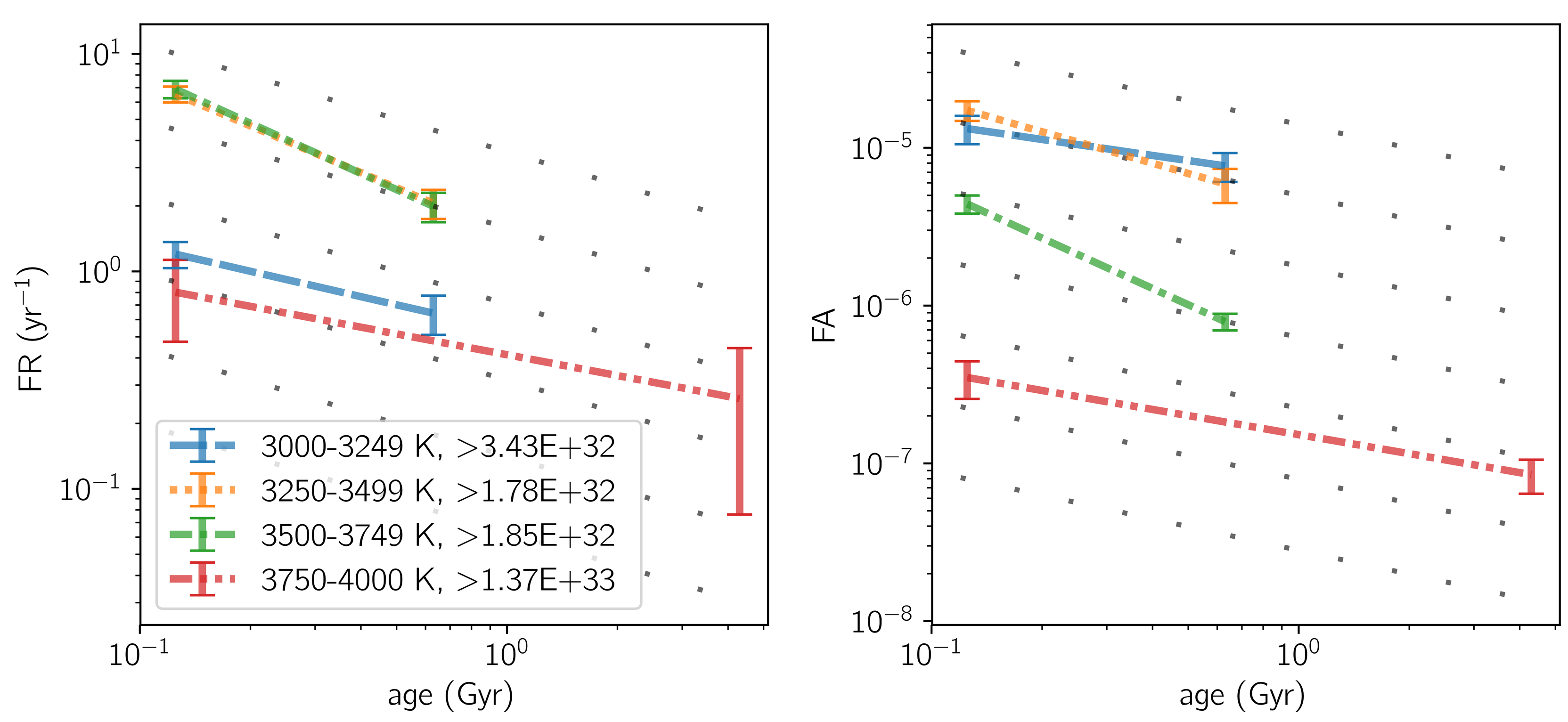
a. An entirely different dynamo below the full convection boundary around M3.5

b. Mass-dependent surface and large scale magnetic structures age differently, observable in flaring activity evolution.

c. Magnetic structures are in fact similar in the given mass range but flares evolve differently in increasingly neutral atmospheres.

d. The coolest Pleiades dwarfs have not yet begun to spin down, i.e. they have not yet reached the Main Sequence and rotate close to maximum speed.

Flaring activity declines Skumanich (1972) - style (?)



Left: Flare rate (FR). Right: total energy released in flares relative to stellar bolometric luminosity (FA). The dotted gray lines indicate a power law with slope -1/2, i.e. the Skumanich law. Line shapes and colors represent different bins in effective temperature and bin-wise energy detection thresholds.

Outlook

We have shown that K2's long cadence photometry contains valuable information about the evolution of flaring activity as a function of stellar mass and the mission's observational treasury has not yet been fully tapped. K2 has so far observed around a dozen open clusters from Pre-Main Sequence to solar age that can be investigated to disclose the nature of the flaring-age relation and its sensitivity not only to stellar mass but also to metallicity and multiplicity..

References

Aigrain et al. 2016, MNRAS 459, 2408-2419
J. R. A. Davenport 2016, ApJ 829, 23
Skumanich 1972, ApJ 171, 565

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