Flares from Kepler: an Empirical Flare Template from the M dwarf GJ 1243

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GJ 1243, M4
GJ 1243, M4

$P_{\text{rot}} = 0.59$ days, ~300 days 1-min data

Let’s ignore the starspot today

Davenport et al. (2014)
GJ 1243, M4

$P_{\text{rot}} = 0.59$ days, $\sim 300$ days 1-min data

starspot removed with median
Flares By EYE (FBEYE)

- Pick flare start/stop times
- Assign classifications
- Help train “autofinder”

github.com/jradavenport/FBeye

Davenport et al. (2014)
Interesting to compare users

Davenport et al. (2014)
Large Flare Sample!

- **6107 unique flares**, spanning 300 days of data most for any star, besides the Sun!

- 15% flares are “complex”
  higher % for large energy flares

- wide energy range: $\log E = 28-33$ erg
  large solar flares around $1E32$ erg

Hawley et al. (2014)
Davenport et al. (2014)
No correlation between flares & starspot

1 month short cadence

Hawley et al. (2014)
Flare Template: Study Morphology

885 “clean” flares

Relative Flux

median flare

Time (FWHM)

Davenport et al. (2014)
Rise Phase

2 Decay Phases

Fit with 4th order polynomial

exponentials

Energy budget:
rise=20%,
decay1=41%,
decay2=39%

Davenport et al. (2014)
Complex Flare Fitting

Davenport et al. (2014)

works well for "classical" events
Complex Flare Fitting

Use to objectively determine “complex” vs “classical” events & decompose events!

Maybe one of the flares in Pugh+2015?

Davenport et al. (2014)
Some flares *not* well fit by template

- Caused by different physical morphology (e.g. arcade)?
- Active region rolling off limb?

Davenport et al. (2014)
# of Flare Components

![Bar chart showing the number of events for different numbers of flare components.

- 1 component: 1000 events
- 2 components: 100 events
- 3 components: 10 events
- 4 components: 1 event

The chart illustrates the distribution of flare components across different event counts.]
Flare Peak Order

Energy_2

\frac{\text{Energy}_2}{\text{Energy}_1}

\text{Time}_2 - \text{Time}_1

39\% \quad 61\%
Flare Energy Distribution

Complex events dominate at high → focus for QPP search
For GJ 1243, I’m not sure we can tell the difference… **too many flares!**

As Christoffer Karoff said in introduction

But: are there extreme/edge cases where each model is very clear?
Some new(ish) work

THE KEPLER CATALOG OF STELLAR FLARES

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ABSTRACT

A homogeneous search for stellar flares has been performed using every available Kepler light curve. An iterative light curve de-trending approach was used to filter out both astrophysical and systematic variability to detect flares. The flare recovery completeness has also been computed throughout each light curve using artificial flare injection tests, and the tools for this work have been made publicly available. The final sample contains 851,168 candidate flare events recovered above the 68% completeness threshold, which were detected from 4041 stars, or 1.9% of the stars in the Kepler database. The average flare energy detected is $\sim 10^{35}$ erg. The net fraction of flare stars increases with $g-i$ color, or decreasing stellar mass. For stars in this sample with previously measured rotation periods, the total relative flare luminosity is compared to the Rossby number. A tentative detection of flare activity saturation for low-mass stars with rapid rotation below a Rossby number of $\sim 0.03$ is found. A power law decay in flare activity with Rossby number is found with a slope of -1, shallower than typical measurements for X-ray activity decay with Rossby number.

1. INTRODUCTION

Flares occur on nearly all main sequence stars with outer convective envelopes as a generic result of magnetic reconnection (Patterson 1980). These events occur as a means for constraining the age of field stars (e.g. Parsamyan 1976, 1995).

The duration of a star’s life that it produces frequent large spots and flares may dramatically affect planetary,
Flare Activity vs. Rossby Number

\[ Ro = \frac{P_{rot}}{\tau} \]
Flare Activity vs. Rossby Number

$\beta = -1$

$R_{\text{sat}} = 0.03$

Used least-sq approach, as close to Wright (2011) as possible

@jradavenport
Evolution with Spectral Type?

by-eye “fits”

Work in Progress: Flare(t,M)
Flare Frequency Distribution - Power law

Automated & Human agree well

Varying 68% limit

GJ 1243

Long Cadence
Short Cadence

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Flare Frequency Distribution - Power law

Break in power law!

many examples of this

“Pearl”
Break in power law!
many examples of this

Are these still good solar analogs?
Good for QPP searches?

“Pearl”
Activity Cycles

A. Özgüç, et al. (2003), SoPh

See also S-index, Ca II H&K, TSI, etc…
Activity Cycles from Flares

Flare rate varies by an **order of magnitude** between active/quiet Sun!

Veronig et al. (2002)

This is a goal of mine in 2017(ish)

@jradavenport
“Complex” flare model

Can statistics save us?
(large samples, careful fitting)

Flare + QPP model
Summary

- Homogeneous sample of flare rates & energy distributions
- Breaks in power law
- Evolution with rotation/Rossby number
- Saturation regime (?)
- Flares useful metric for magnetic activity level
- activity cycles?

- empirical template!
- useful for deconstructing
- QPP’s, odd morphologies?