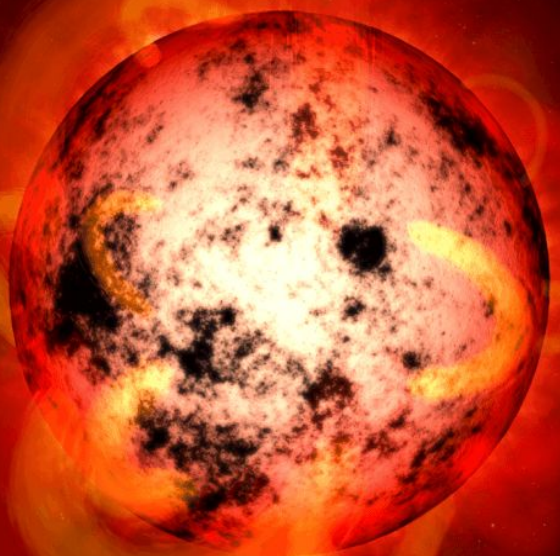
Stellar magnetic evolution:

Flaring activity in K2 open clusters

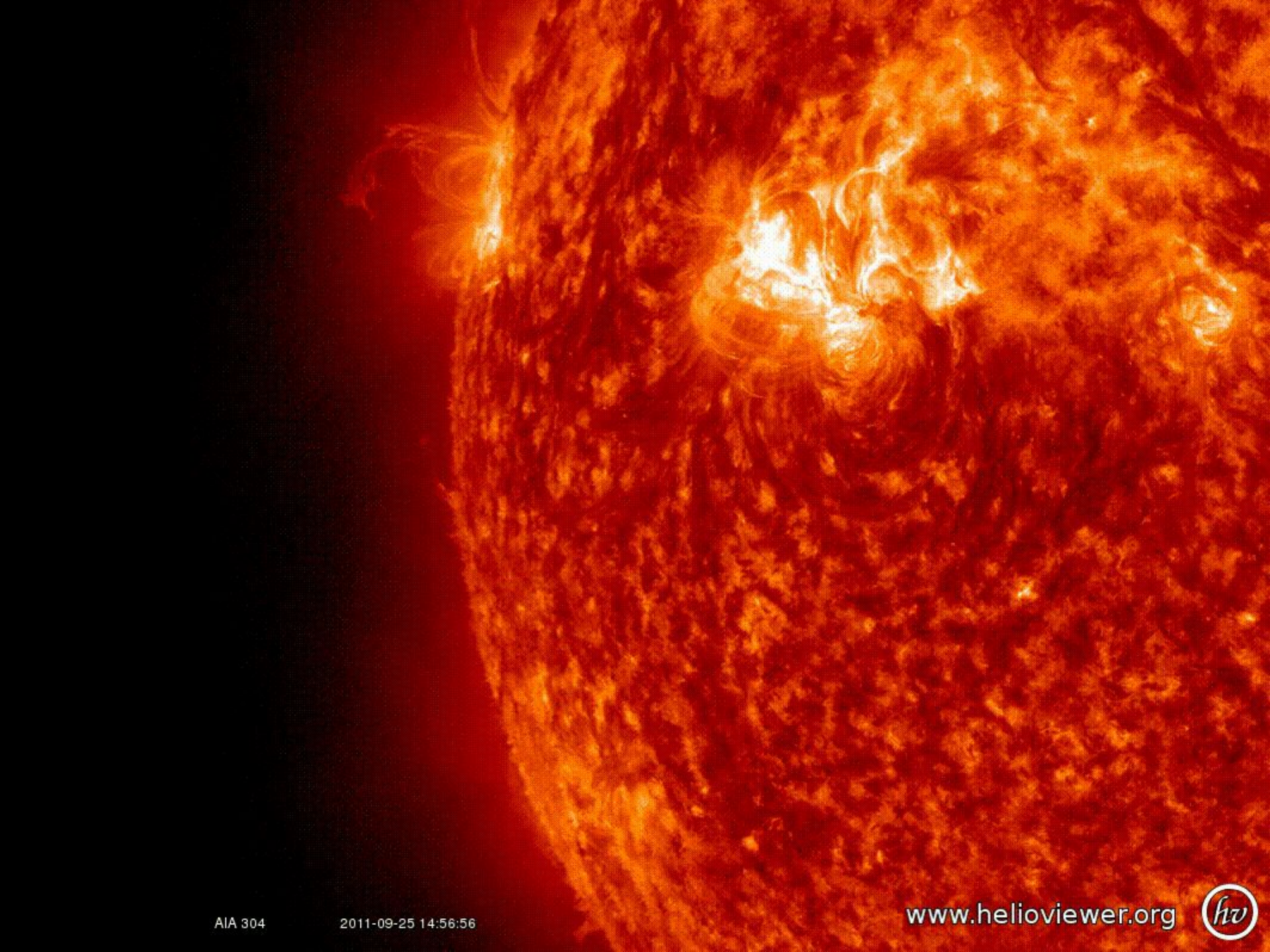


Ekaterina Ilin, PhD student

Advisors: Prof. Dr. Katja Poppenhäger, Prof. Dr. Martin M. Roth, Dr. Sarah J. Schmidt

May 21, 2019

image credit: NASA, ESA, and G. Bacon (STScI)


AIA 304
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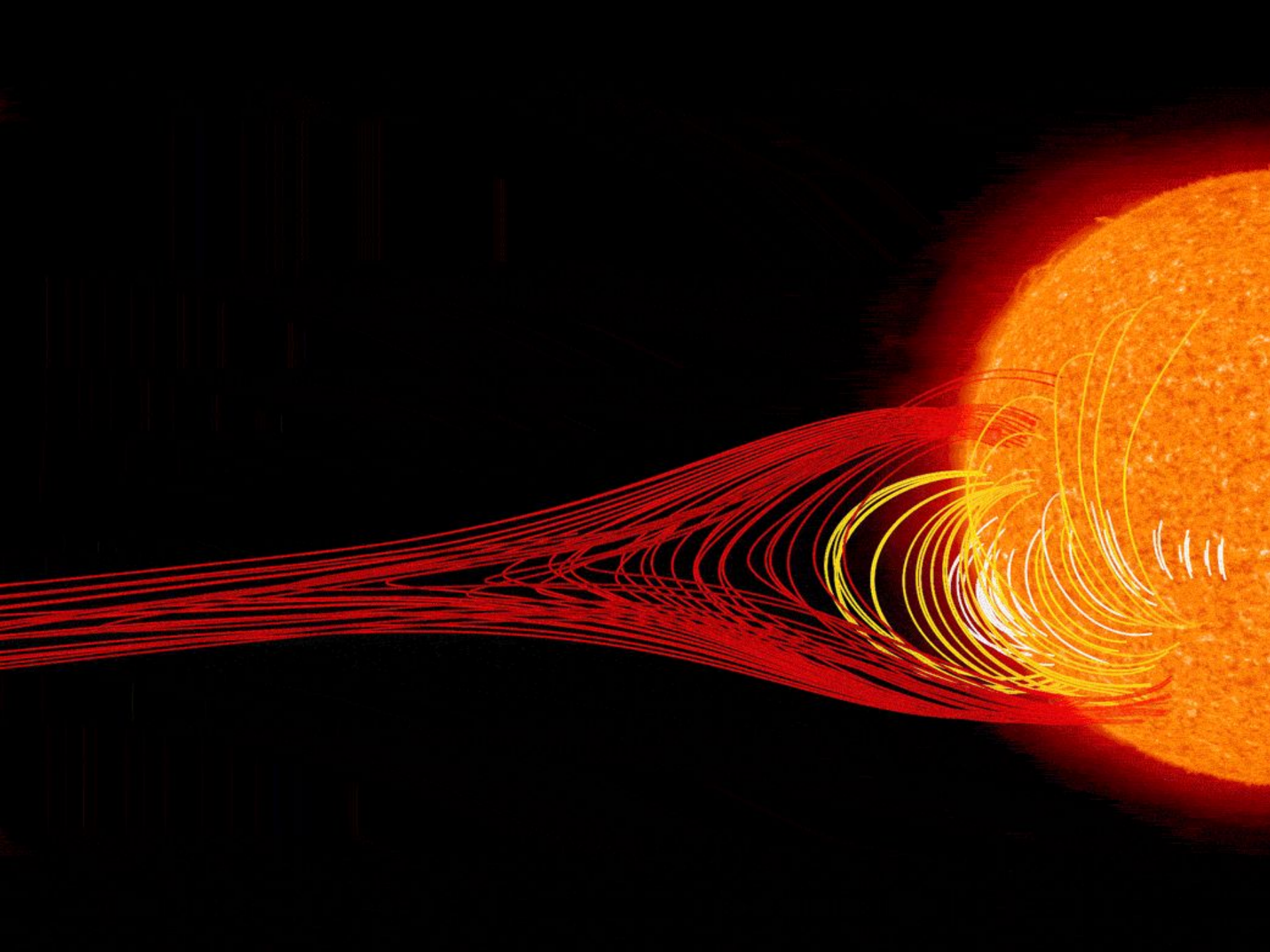
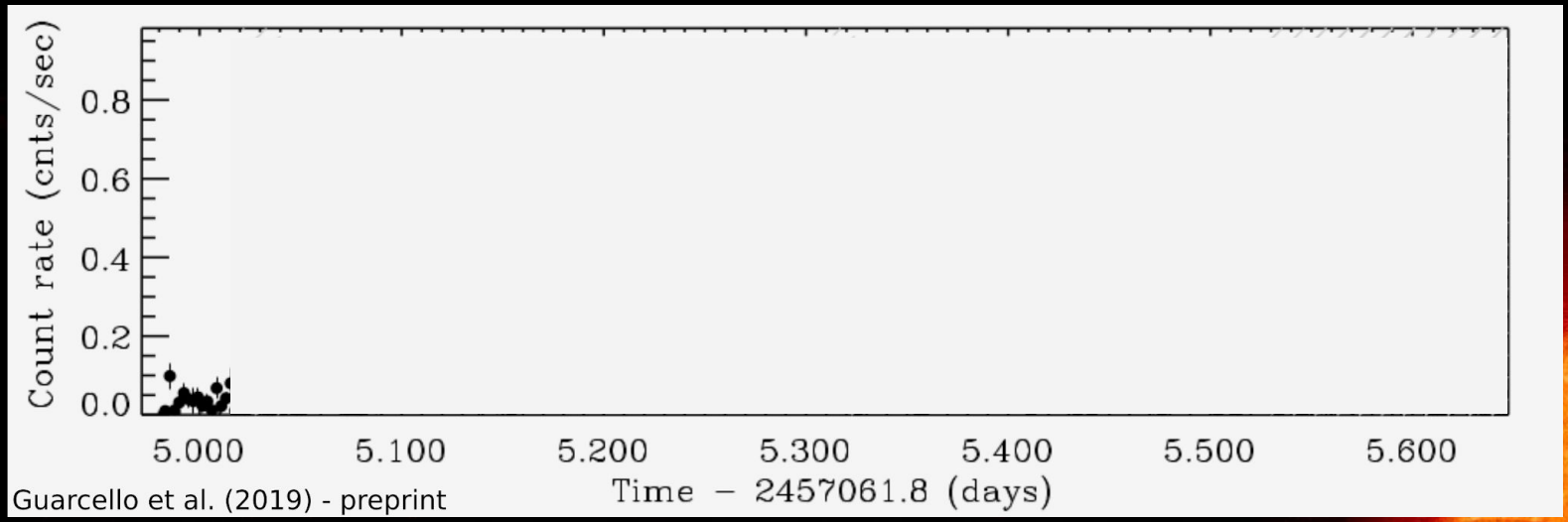
www.helioviewer.org





Guarcello et al. (2019) - preprint

FUV (Loyd et al. 2018)

optical (Davenport 2016, Yang and Liu 2019)

IR (Davenport 2012, 2019, Gillon et al. 2017) - TRAPPIST-1

radio (Güdel and Benz 1993, Berger 2002, Route 2017)

gif credit: NASA's Goddard Space Flight Center/ARMS/Joy Ng
Sun image: NASA STEREO

atmospheric ozone can be lost

Loyd et al. (2018)
Howard et al. (2018)
Tilley et al. (2019)

exoplanet

flaring, age, and mass are related

Hilton et al. (2011) - galactic height
Chang et al. (2015) - M37 vs. field stars
Clarke et al. (2018) - interbinary comparison
Howard et al. (2019) - SpT and galactic height

flare

M

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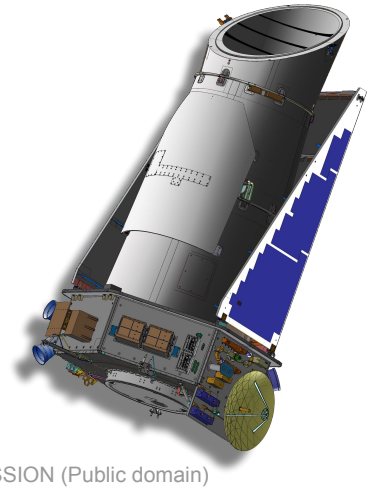
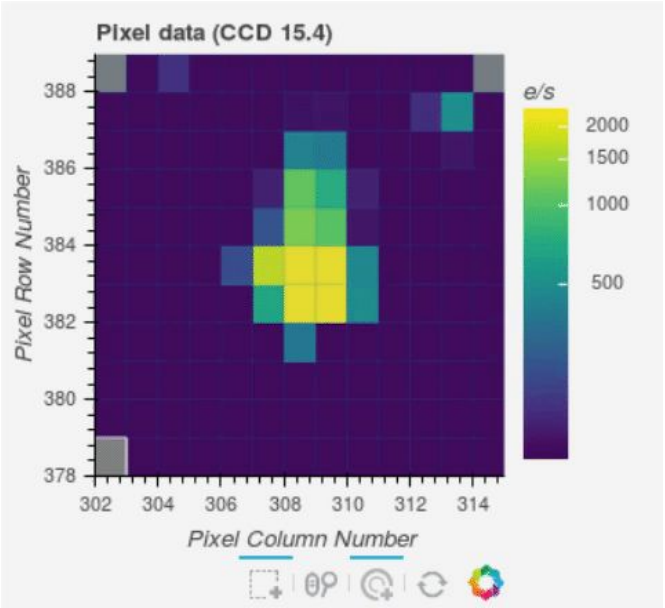
The Kepler satellite collected...



by NASA KEPLER MISSION (Public domain)

...high precision time resolved photometry...



created using `lightkurve`

...from which we extracted light curves to...

Open Source Software:

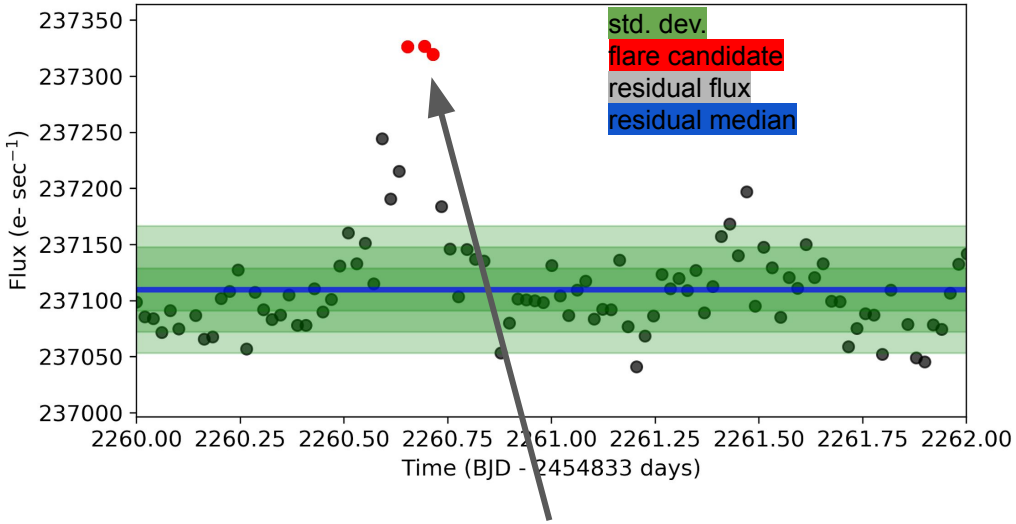
`K2SC` (Aigrain et al. 2016)

`george` (Ambikasaran et al. 2014)

`lightkurve`

(Lightkurve Collaboration 2018)

ALTAI PONY



… detect superflares.

On thousands of stars in open clusters.

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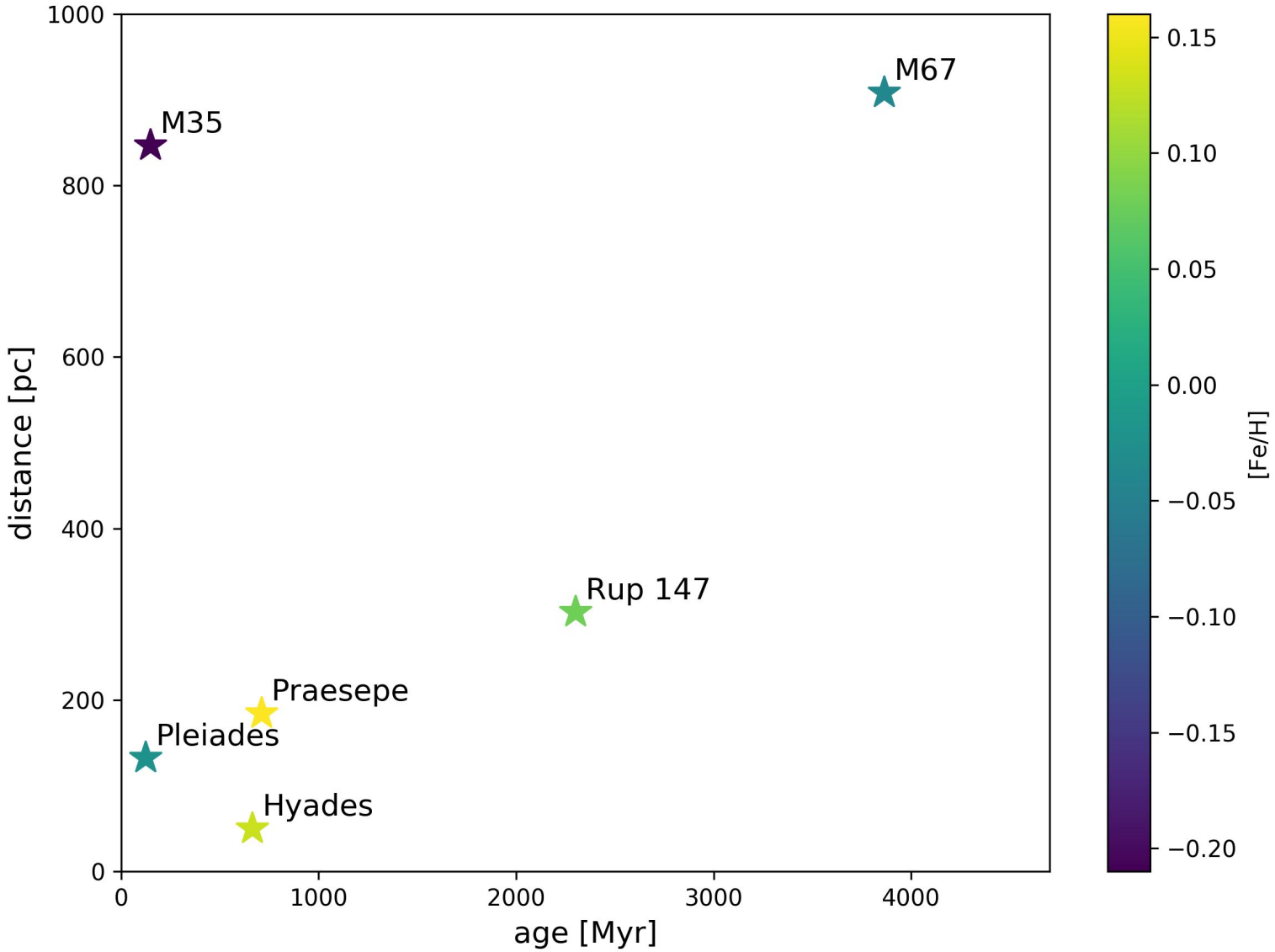
Open Clusters in K2



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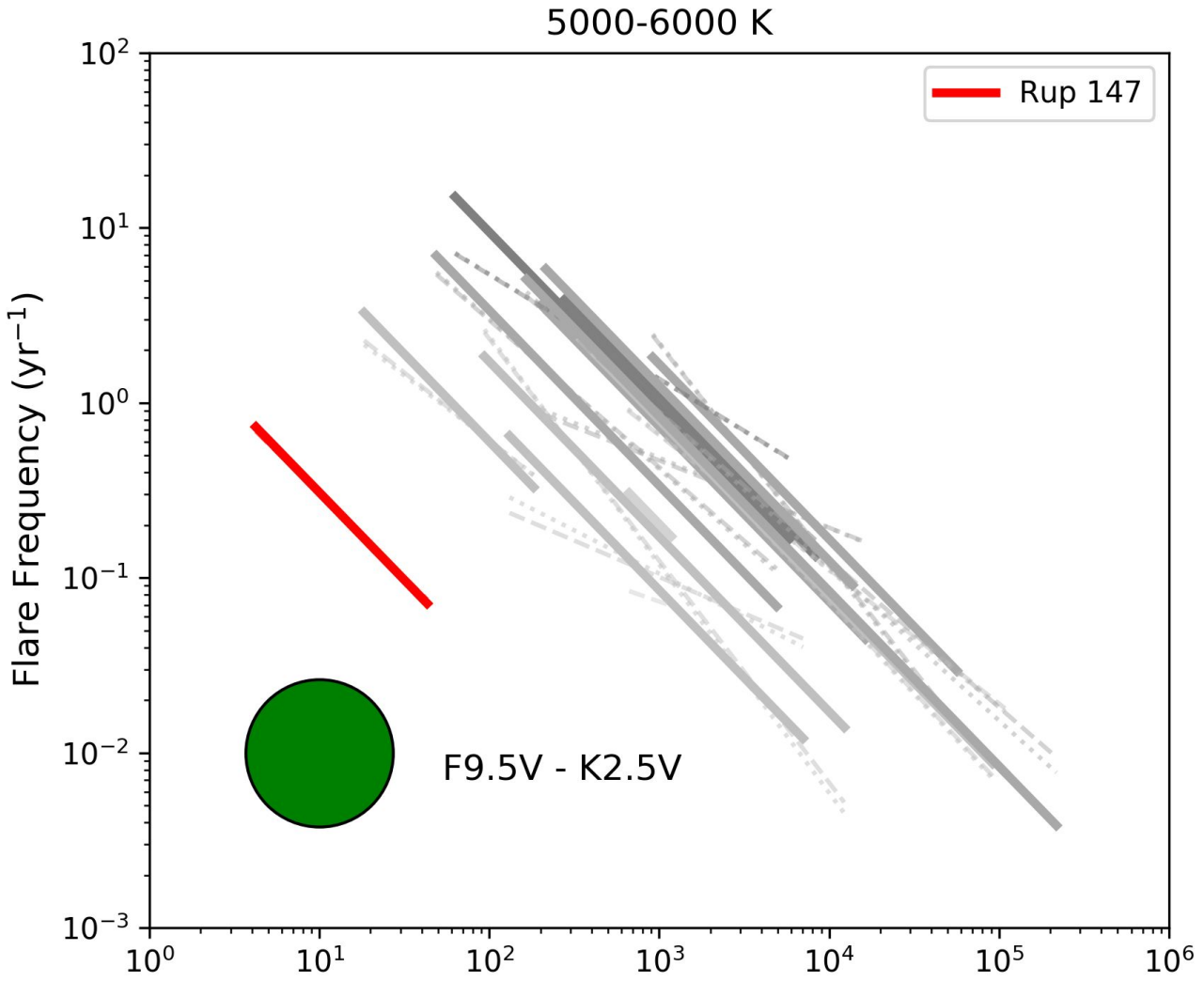
Cumulative flare frequency distributions (FFD): binned by effective temperature

$$f(ED_{\mathrm{flare}} > ED) = \beta_2 \left(\frac{ED}{1\,\mathrm{s}} \right)^{-1}$$



= how long does the star have to shine to release as much energy as the flare? (one hemisphere)

Ilin et al. (2018), Ilin et al. (2019, in prep.)

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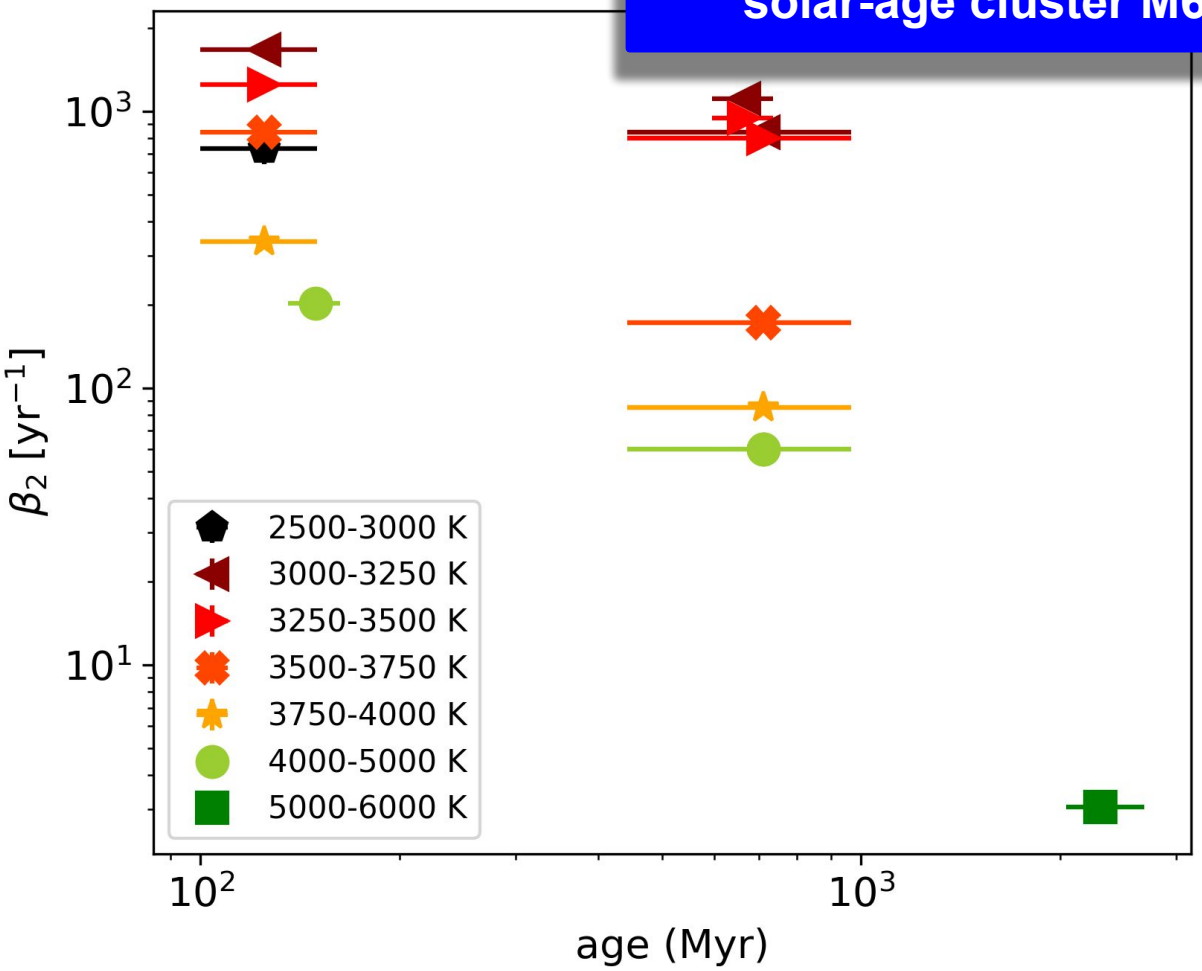
$$f(ED_{\rm flare} > ED) = \beta_2 \left(\frac{ED}{1\,\rm s}\right)^{-1}$$

M67? Poster!

"The frequency of super-Carrington flares in the solar-age cluster M67"

high flaring rates

low flaring rates



Ilin et al. (in prep.)

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To take home:

- **Flaring activity declines with age.**
- **This decline is slower for lower mass stars.**
- ***We have now quantified the flaring-age-mass relation***

  using long baseline high cadence light curves.
- We need to factor flares into exoplanetary evolution models.

Better *flaring* stars - better planets.

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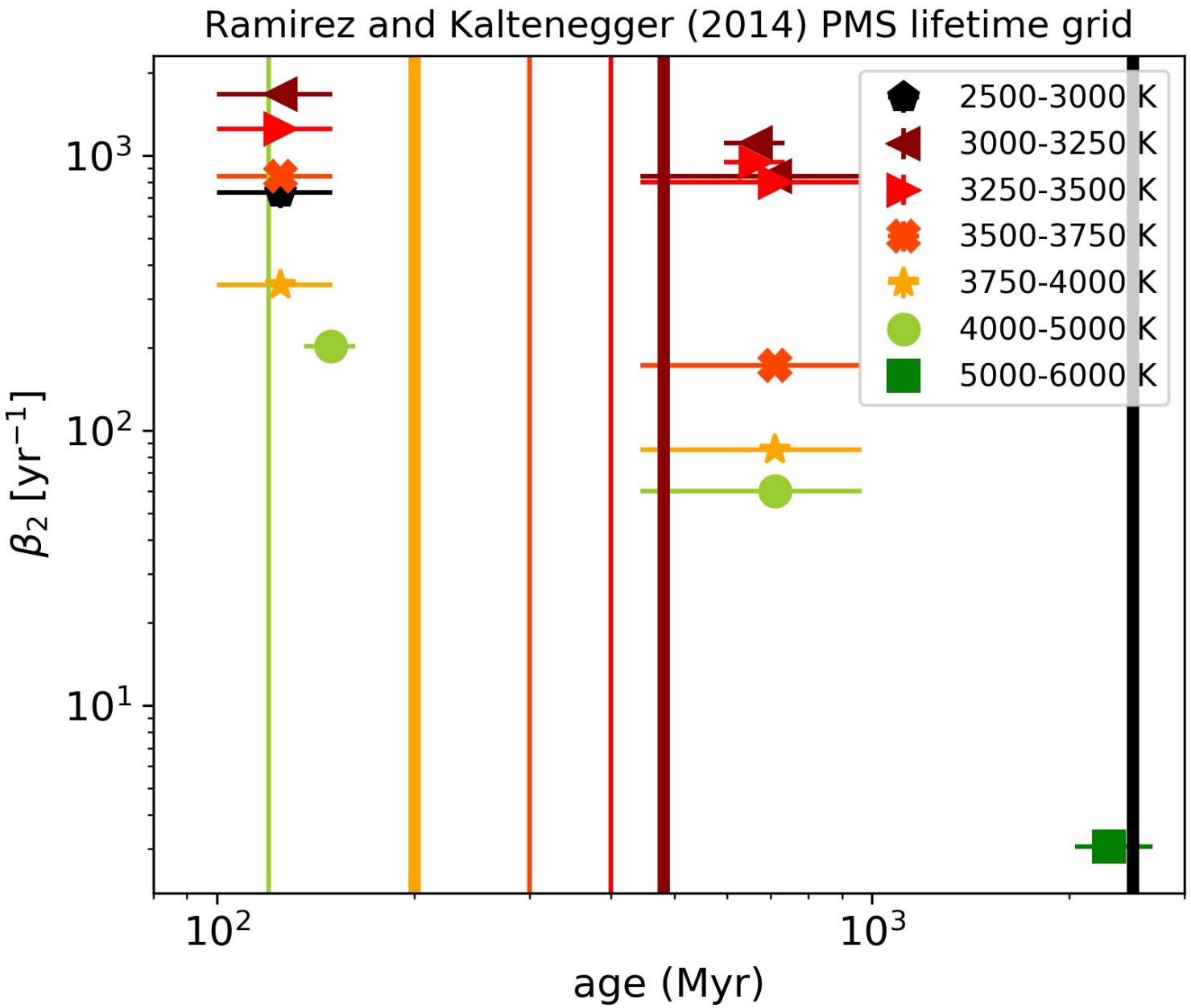

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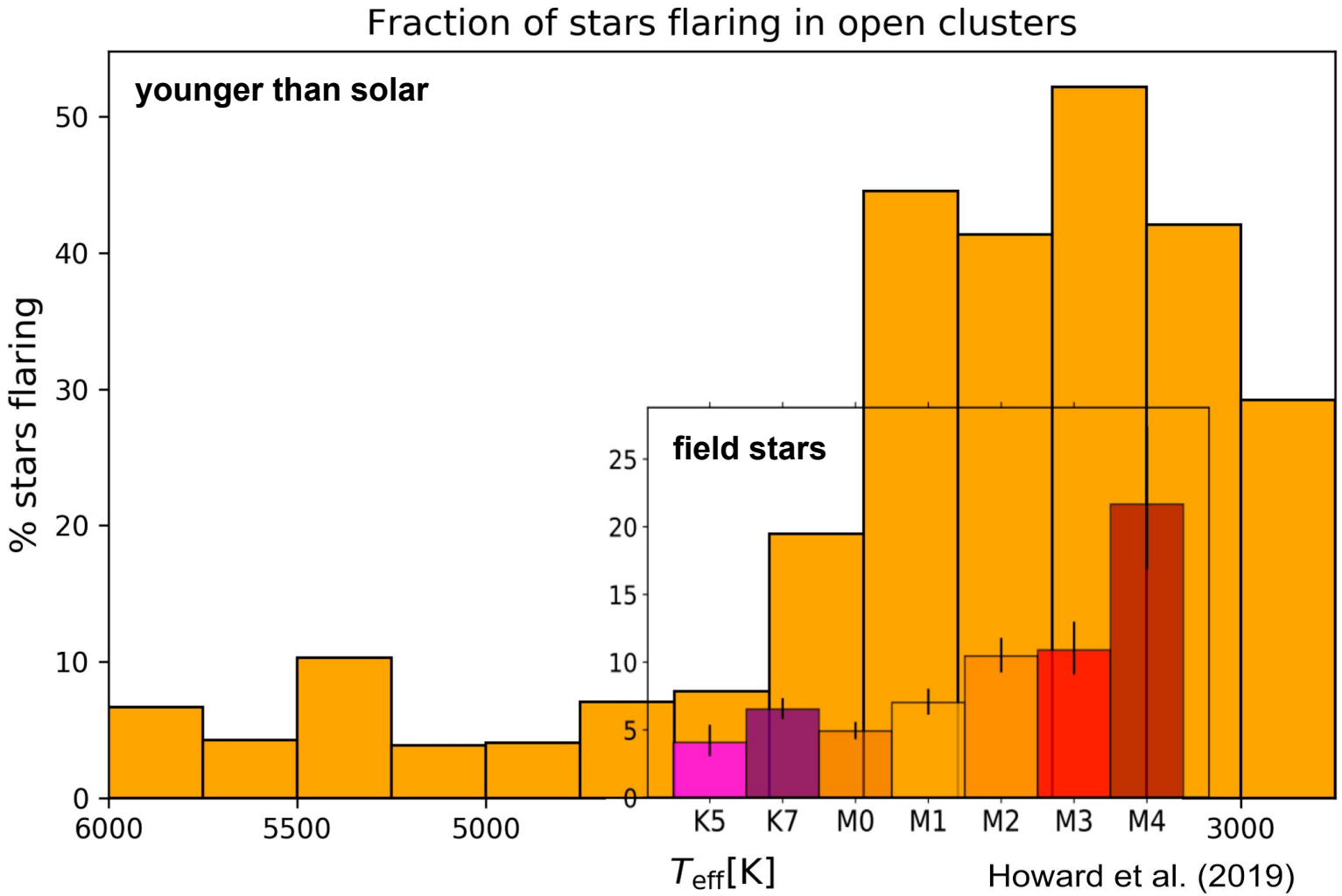

Ilin et al. (in prep.)

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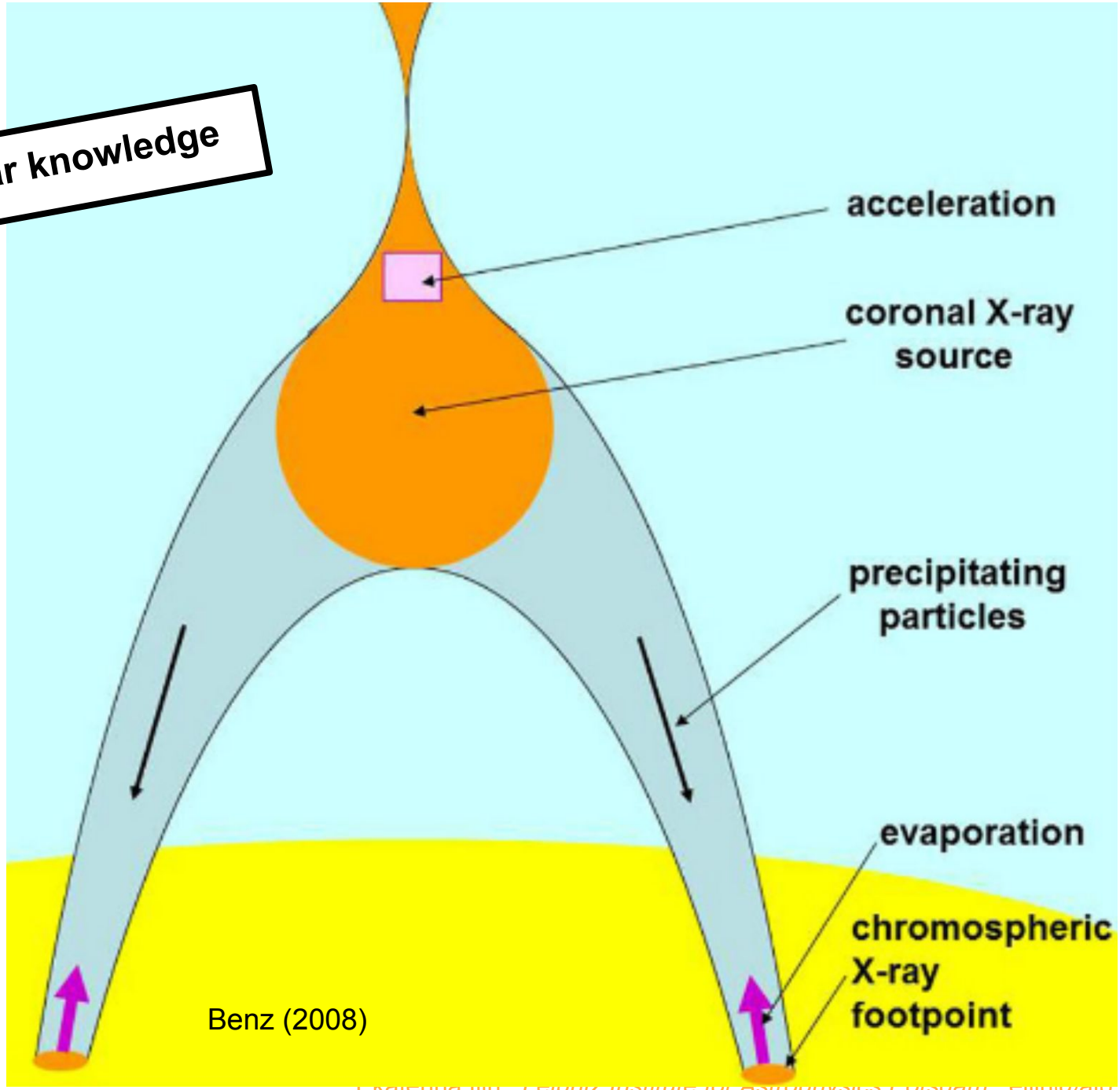
solar knowledge



Benz (2008)

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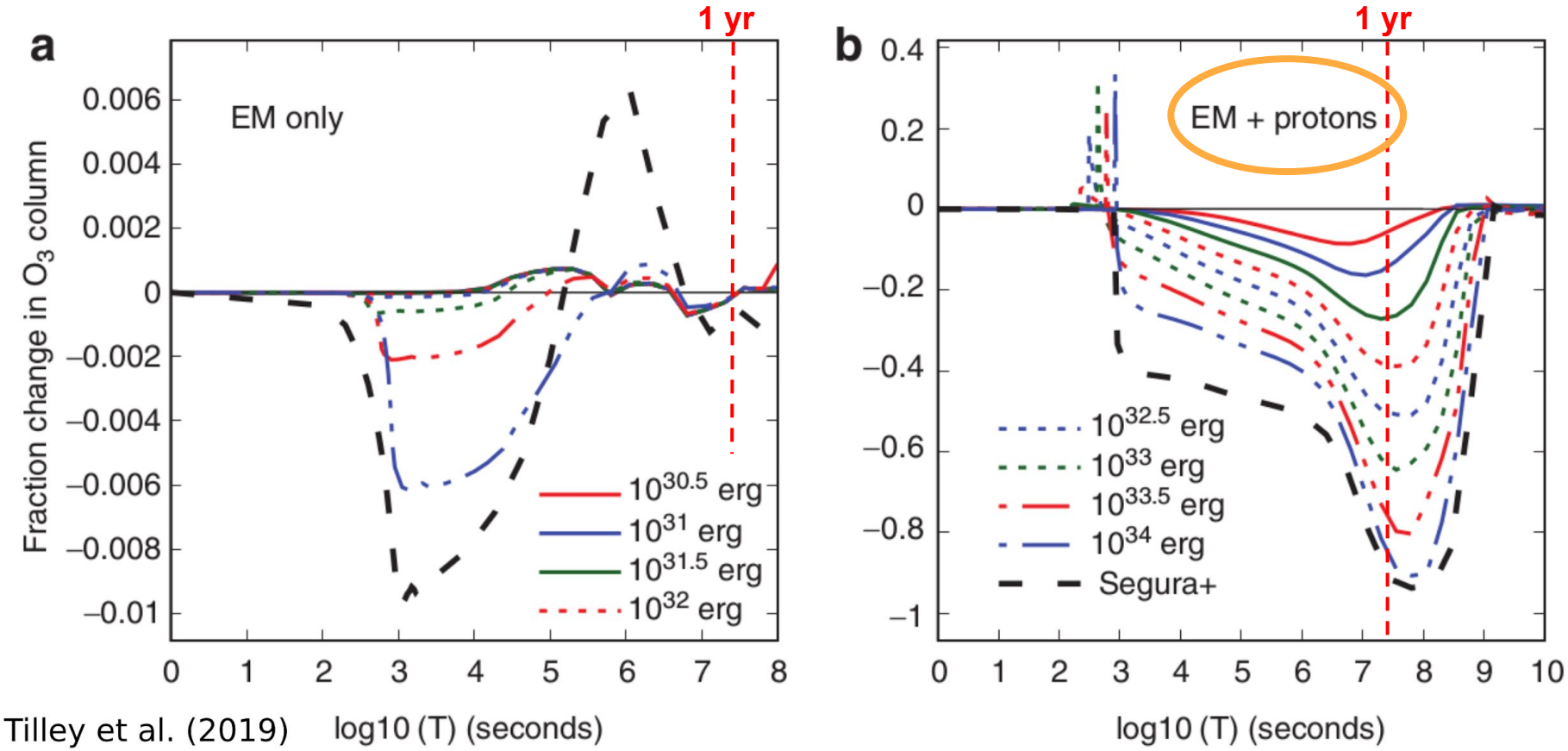
Flares can erode the ozone layer of an Earth-like atmosphere in an M dwarf star-planet system.



Tilley et al. (2019)

Repeated flaring over some decades = ozone loss

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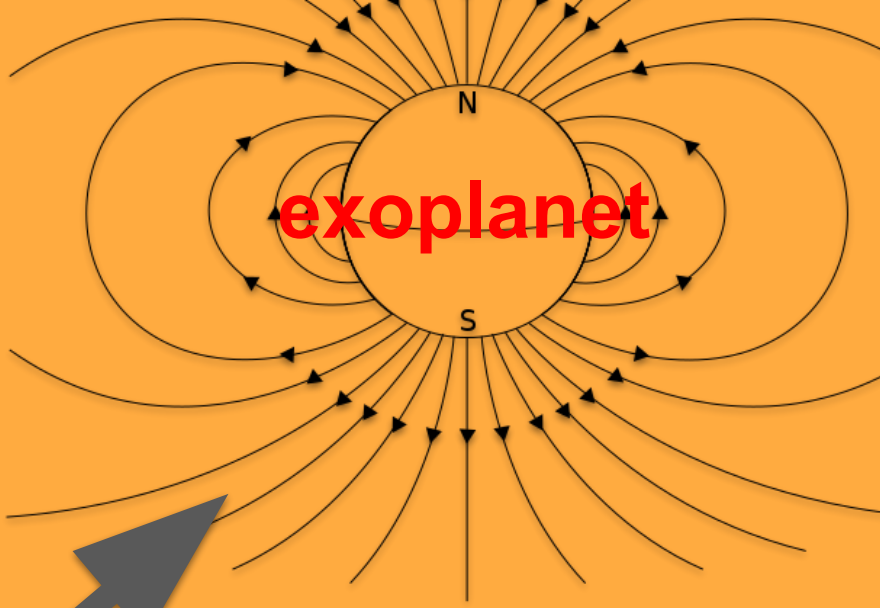
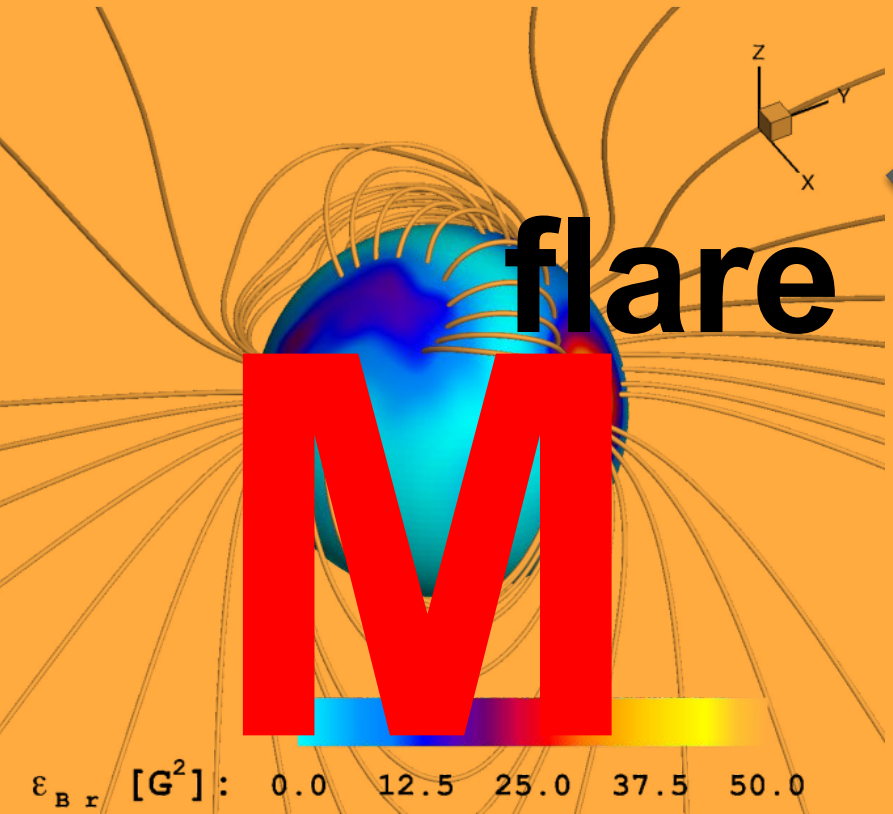
no planetary magnetic fields detected so far
Lazio et al. (2016)



complex magnetic field = CME supression
Alvarado-Gómez et al. (2018)



= CME?
Aarnio et al. (2012),
Odert et al. (2017),

= 10 000 K photospheric footprint emission?
Kowalski et al. (2013),
Froning et al. (2019),
Loyd et al. (2018)

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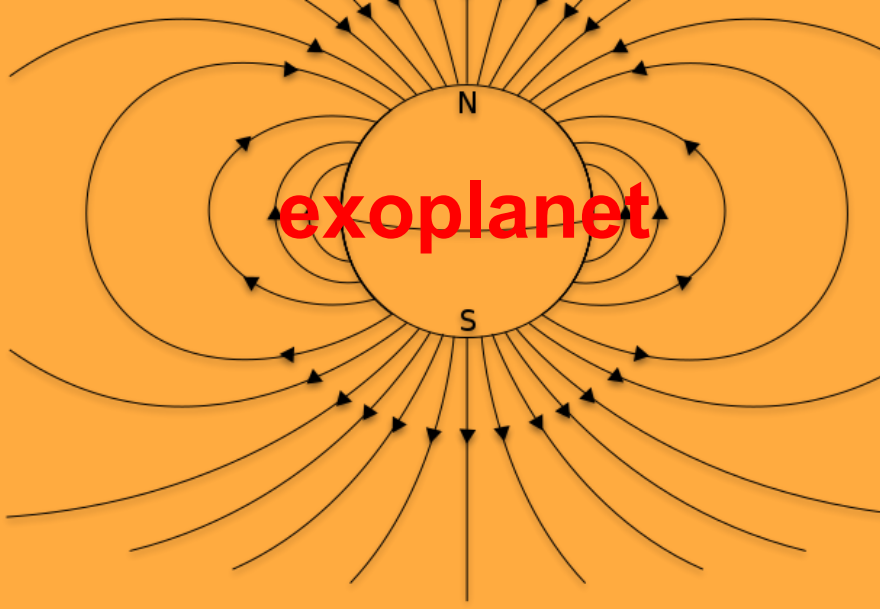

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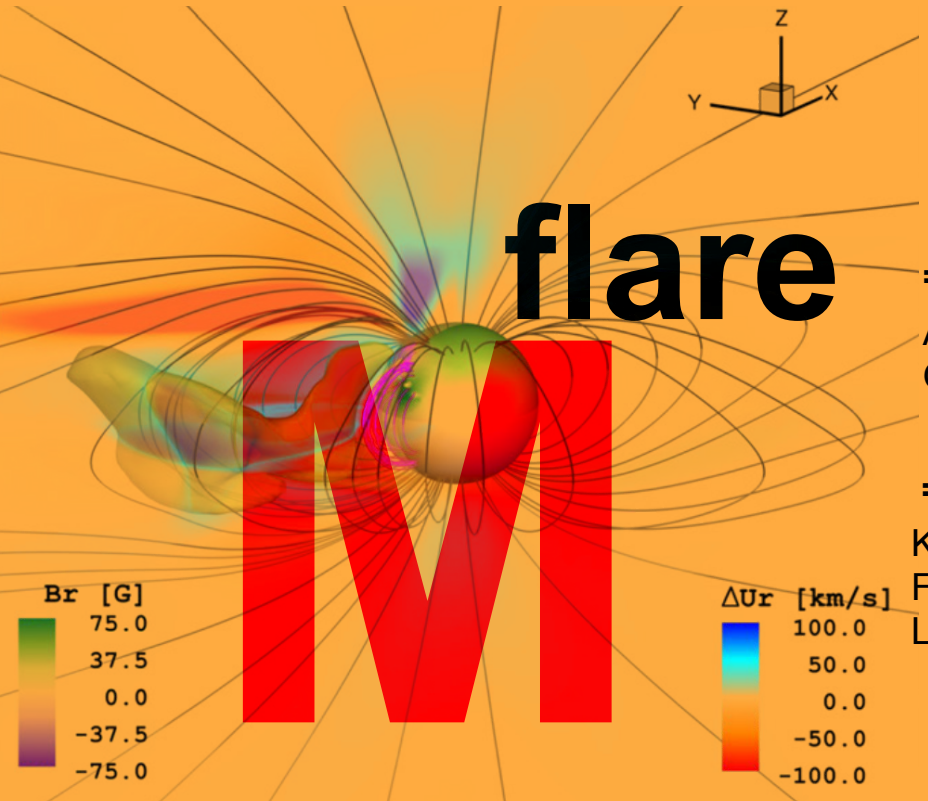

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Loyd et al. (2018)

When we look at exoplanetary evolution, flares are an understudied external factor.

Things we know (a selection):

- Flares emit energy in all electromagnetic bands.
- Flares are ubiquitous on low mass stars.
- Flares follow a power law distribution: freq (flare) ~ E (flare)$^{-2}$

Things we have some evidence for + theoretical backing:

- Flares are associated with fast proton events and CMEs.
- Flares emit most energy as a 9-10 000 K blackbody .
- Flares can erode the ozone layer of an unmagnetized Earth-like atmosphere.

Anecdotal evidence but expected theoretically:

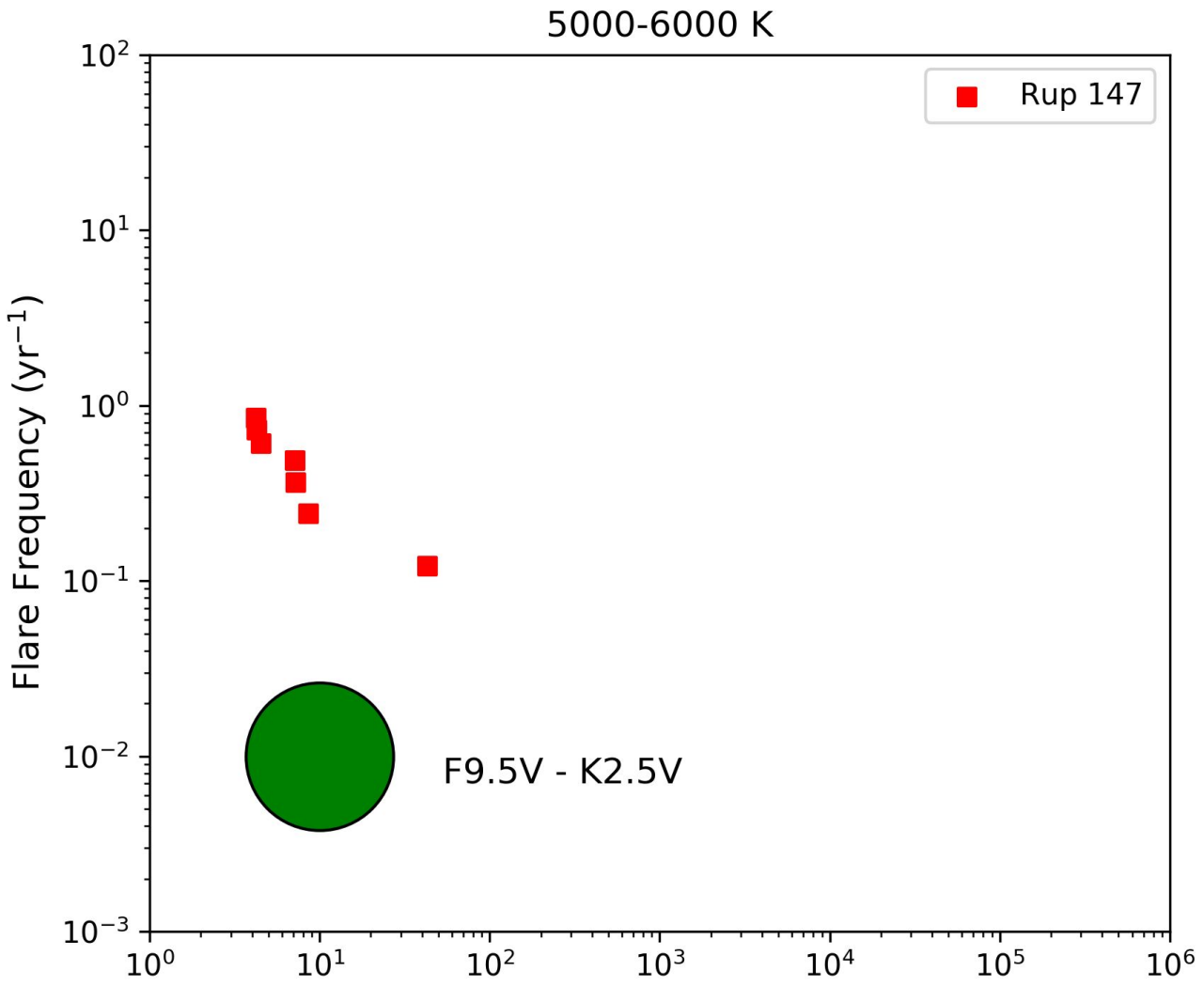
- Close-in exoplanets can influence flaring activity on their host stars (Lanza 20XX)

Dynamo theory and other magnetic observables tell us:

Flaring activity will also change with age!

Ekaterina Ilin *Leibniz Institute for Astrophysics Potsdam* eilin@aip.de @astroilin

Cumulative flare frequency distributions (FFD): binned by effective temperature



= how long does the star have to shine to release as much energy as the flare? (one hemisphere)

Ilin et al. (in prep.)

Ekaterina Ilin *Leibniz Institute for Astrophysics Potsdam* eilin@aip.de @astroilin

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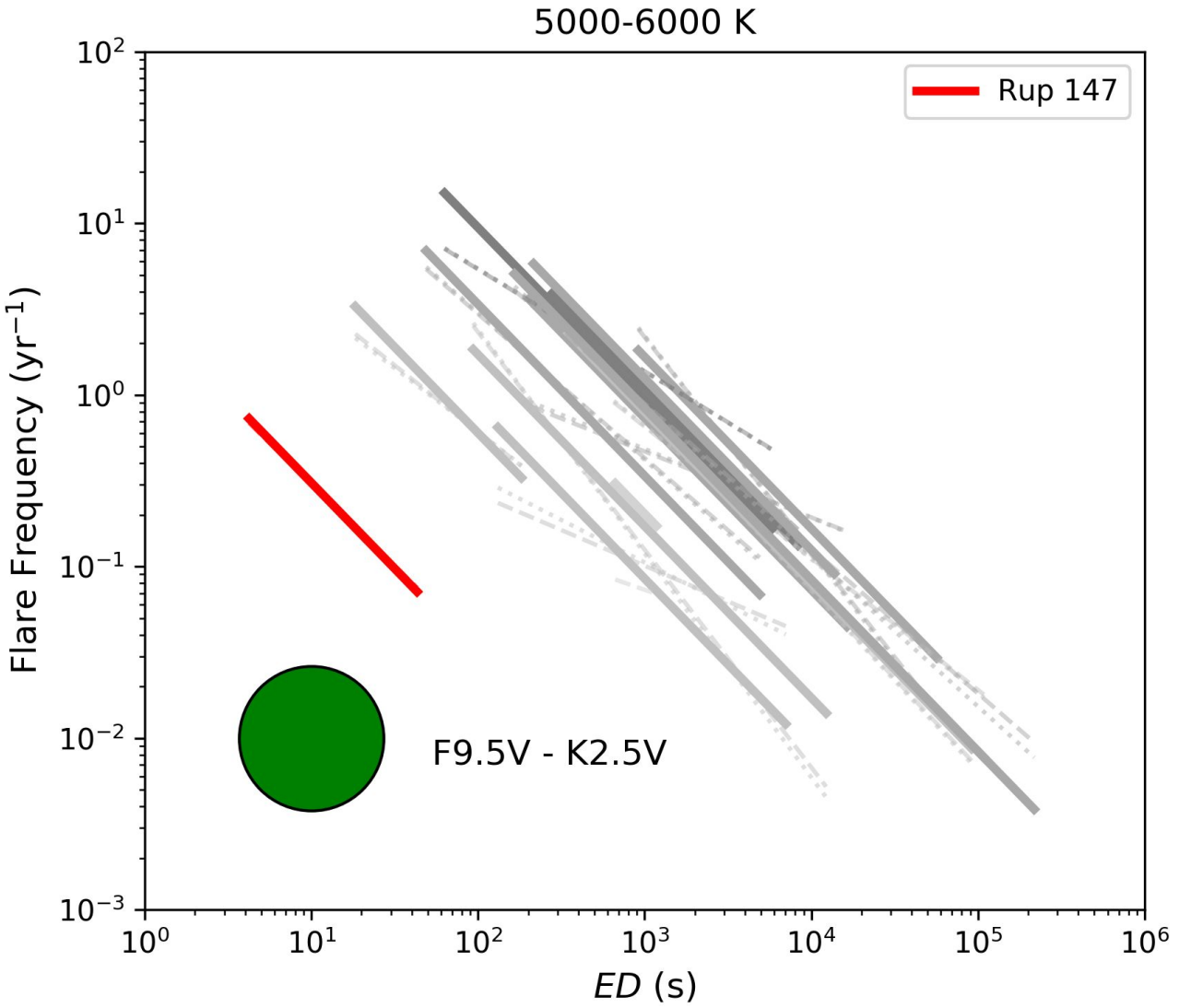

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e?

(one hemisphere)

Ilin et al. (in prep.)

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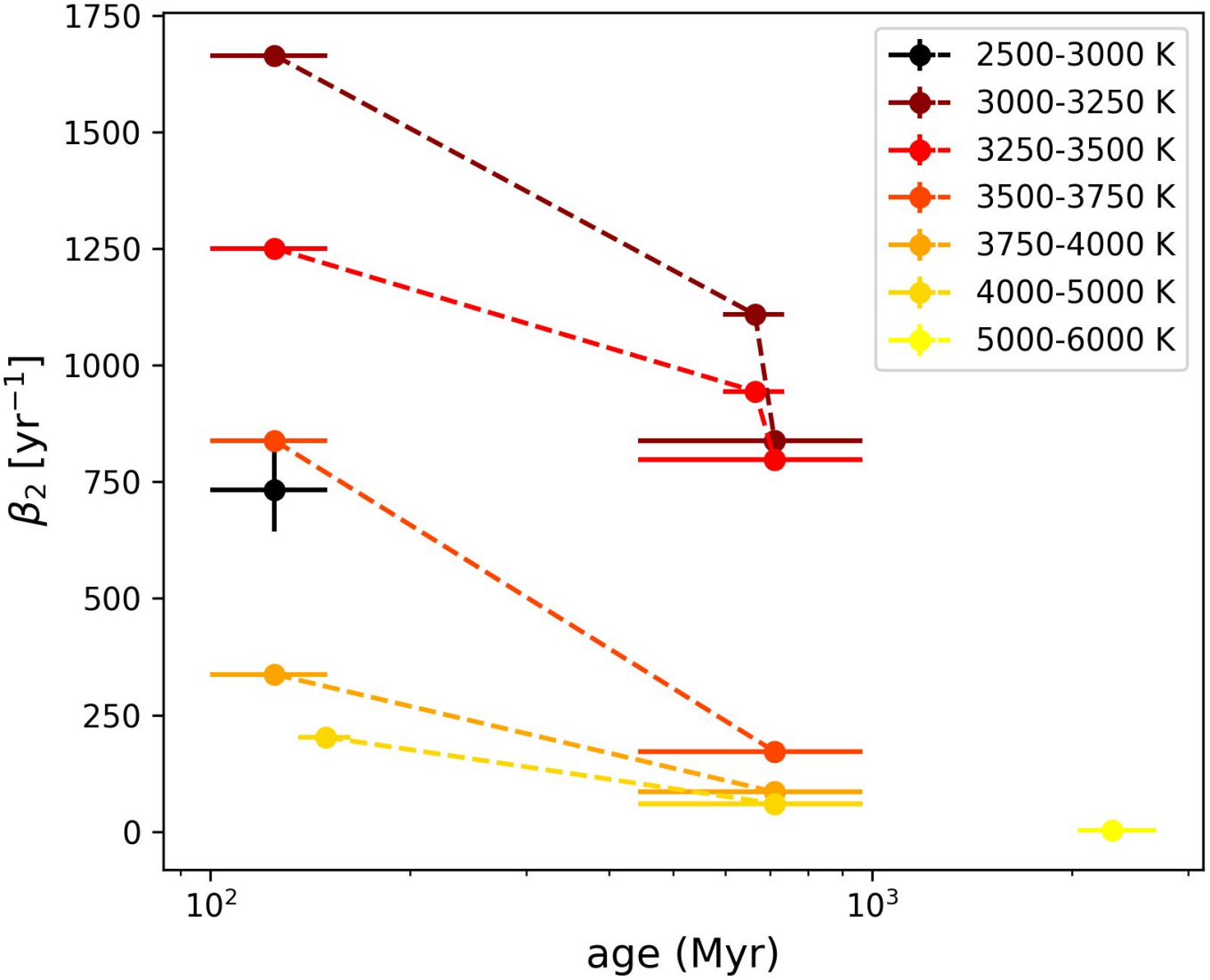
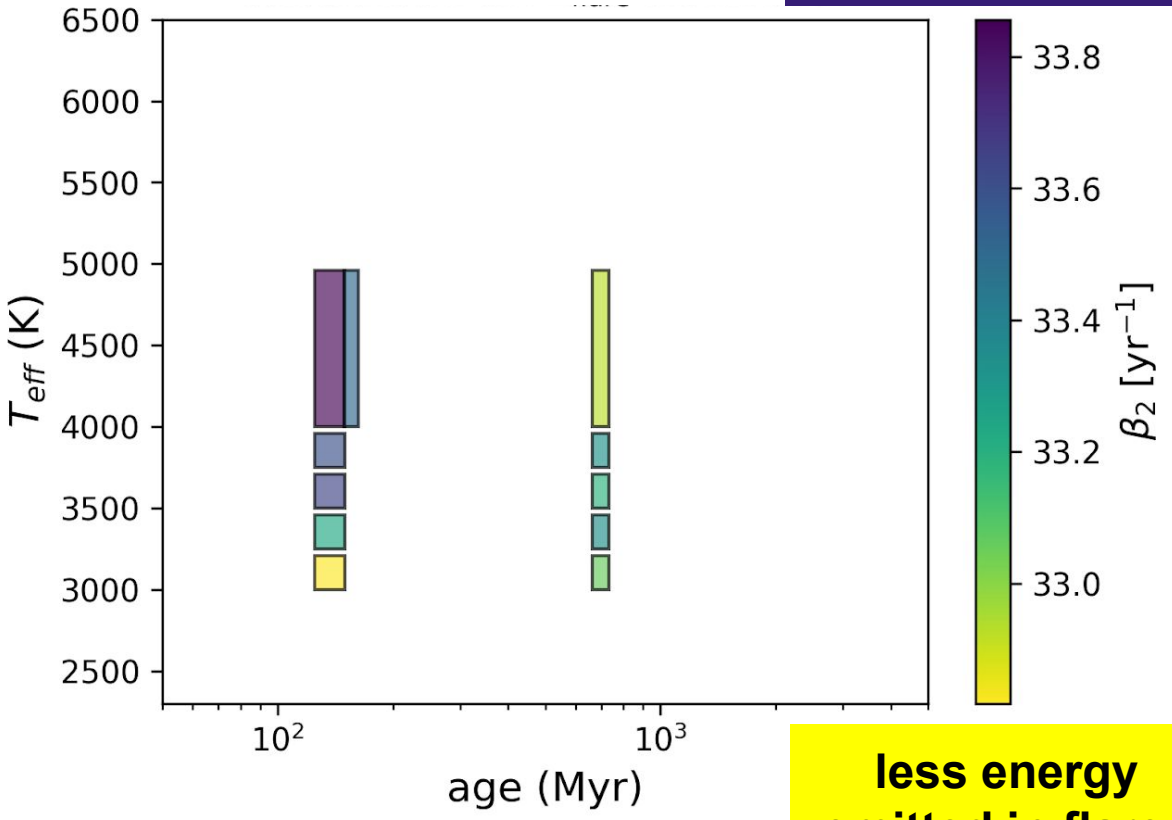

1750
1500
1250
1000
750
500
250
0
β_2 [yr^{-1}]
10^2
10^3
age (Myr)
2500-3000 K
3000-3250 K
3250-3500 K
3500-3750 K
3750-4000 K
4000-5000 K
5000-6000 K

more energy emitted in flares

hot



cool

less energy emitted in flares

young → old