Stellar flares observed in long cadence data from the Kepler mission

Tom Van Doorsselaere

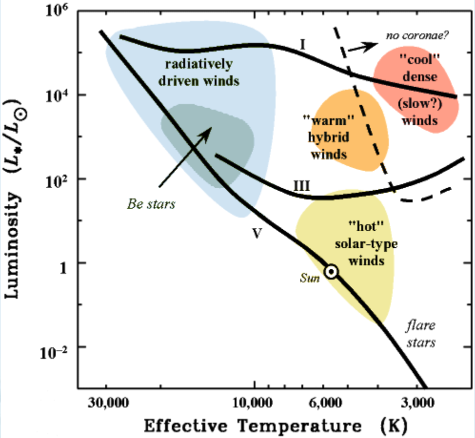
Centre for mathematical Plasma Astrophysics, Mathematics Department, KU Leuven

tom.vandoorsselaere@kuleuven.be

1 November 2018

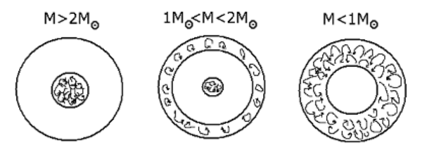
In collaboration with: Hoda Shariati, Jonas Debosscher

Magnetism in HR



Stellar evolution theory:

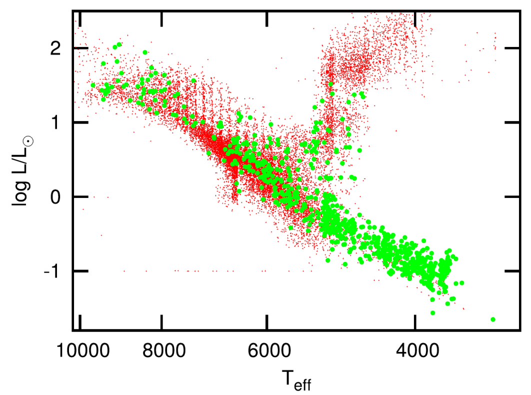
- M dwarf: strong B
- G stars: moderate B
- F stars: low B
- A stars: no B
- Giants: magnetic braking, large size, low B



Figures taken from
`https://www.cfa.harvard.edu/~scranmer/cranmer_st_cool.html`
and `http://www.maths.qmul.ac.uk/~svv/MTH725U/Lecture8.htm`

Flares in HR diagram

Balona (2015): Detection of flares in Kepler "by eye"

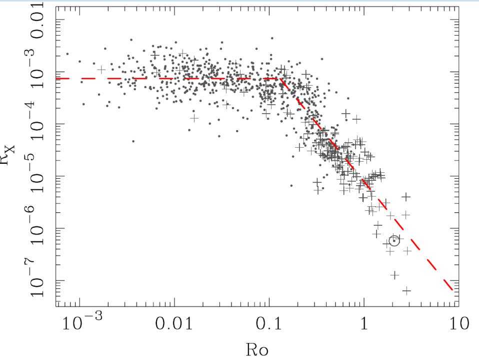


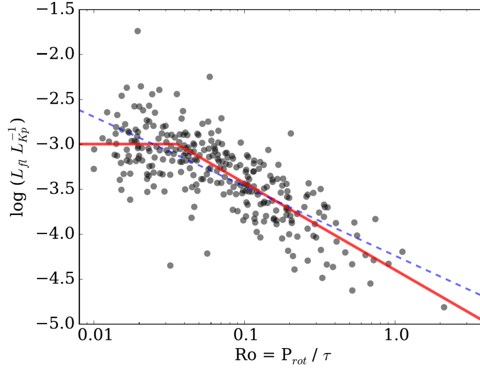
Unexpected stars have flares: giants and A-stars. Theory?

Other incomplete samples: Walkowicz et al. (2011), Maehara et al. (2012, 2015), Candelaresi et al. (2014), Pitkin et al. (2014), Davenport (2016)

Influence of rotation

X-ray luminosity and flare amplitude depend on rotation rate.

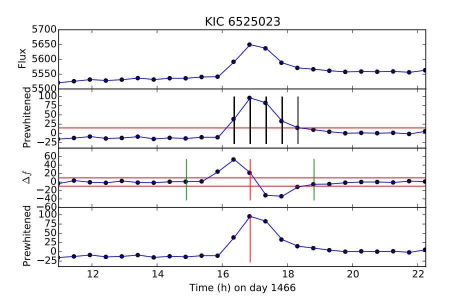




Taken from Wright et al. (2011), Davenport (2016)

How do flare occurrence depend on rotation?

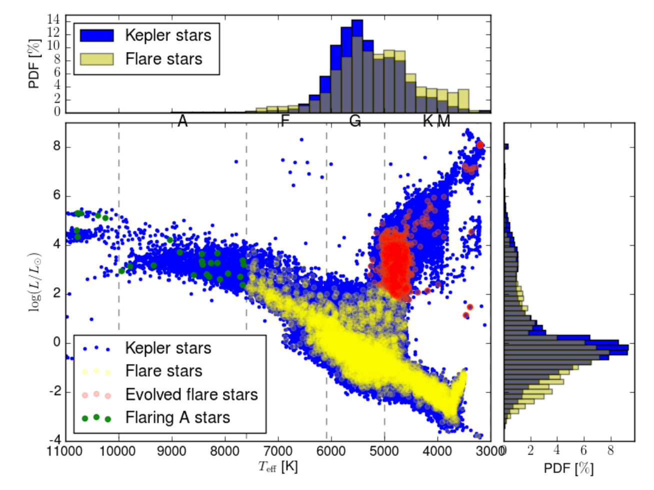
Detection method



1. Fit instrumental effects with 3rd order polynomial
2. Prewhiten: remove 100 frequencies + remove binary stars
3. Compute slope of intensity f by $\Delta f = (f_{i+1} - f_{i-1})/2$
4. Threshold in intensity: $4.5\sigma_{\Delta f} \approx 3.2\sigma_f$
5. Threshold in intensity increase: $3\sigma_{\Delta f}$
6. Require max of slope 4 points left of flare peak, min of slope right of peak

HR-diagram with flare stars

Quarter 15 long cadence: 16850 flares on 6662 stars

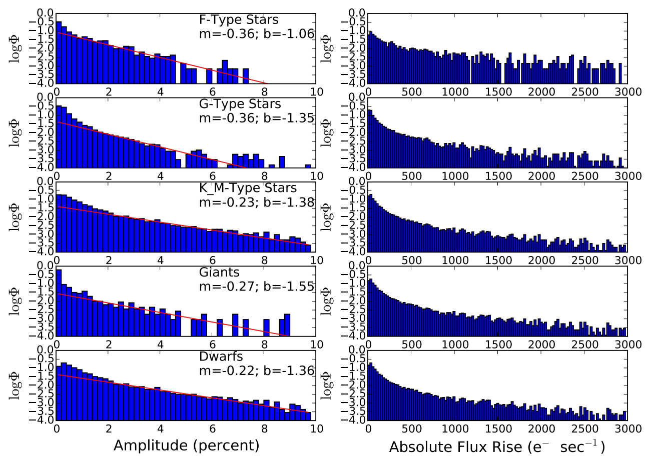


Occurrence per spectral type

Stellar type	# objects	# flare stars	Incidence
A+B	2141	28	1.54%
F	22107	708	3.20%
G	116178	3365	2.90%
K+M	48411	2556	5.28%
giants	22837	653	2.86%

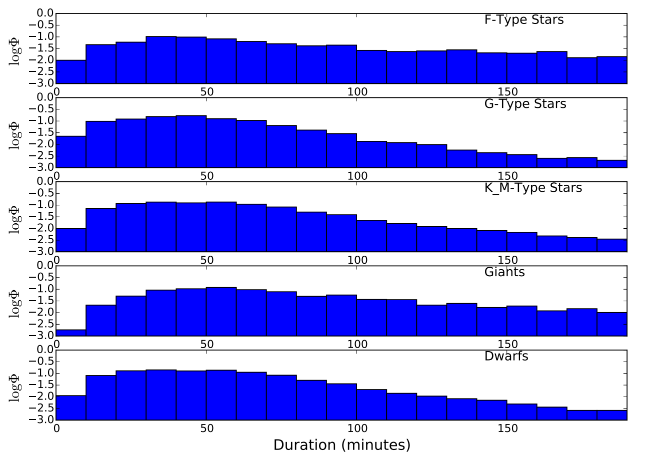
- New flaring A stars: add 24 new objects to Balona (2012), Pedersen et al. (2017)
- 653 flaring giants: Balona (2015) has only a few
  Compare also to Cranmer graph: giants + flares = corona/wind!?

Flare amplitude per spectral type



Group F+G vs. K+M. Magnetism in giants more like K+M → flare amplitude determined by location in HR?

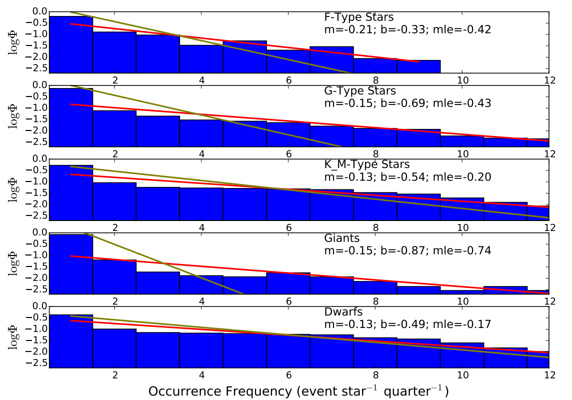
Flare duration per spectral type



Group F+giants vs. G+K+M. Magnetism in giants more like F → flare duration determined by progenitors?

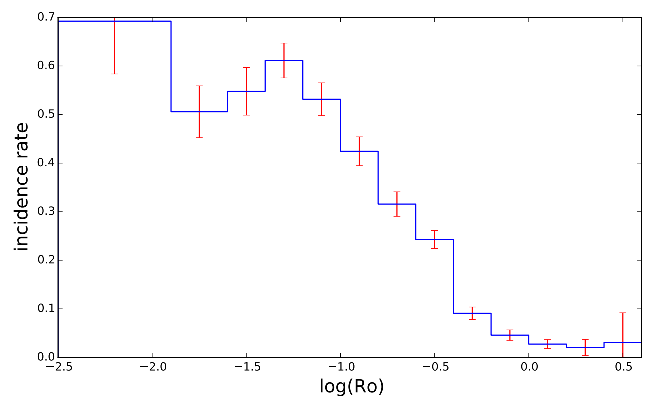
Occurrence frequency per spectral type

Fit exponential distribution with $\log(\Phi) = mx + b$ and maximum likelihood estimator (MLE).



Late type stars: higher chance of more flares (m decreases).

Occurrence rate per rotation period

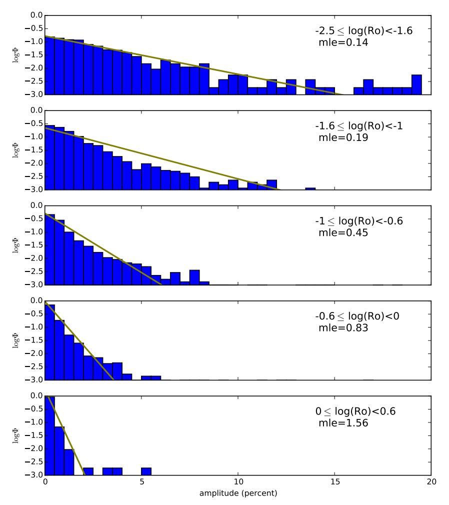


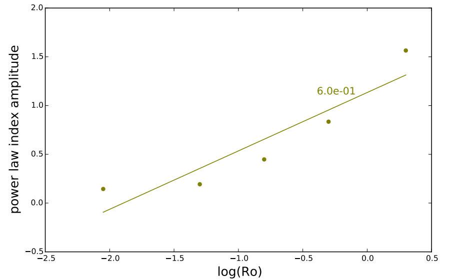
Strong correlation of flare star incidence with rotation period.

Two regimes of flaring activity?

- Slow rotators: 5% flare stars (independent of rotation rate)
- Fast rotators: similar to Wright et al. (2011), Davenport

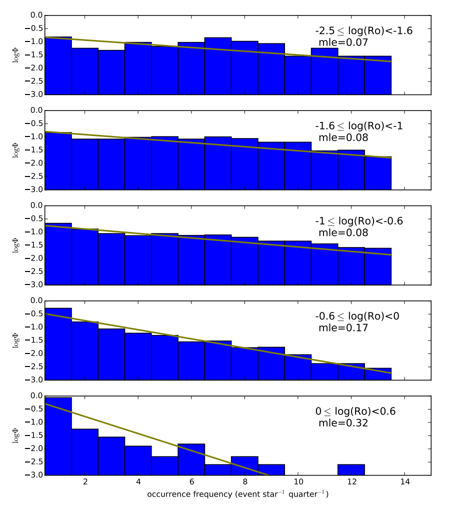
Amplitude per rotation period

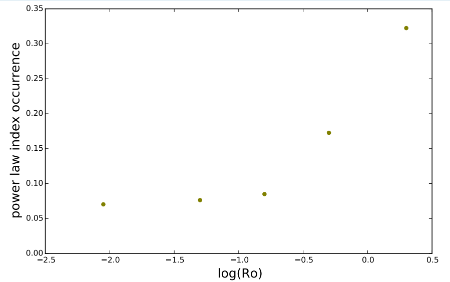




Rapid rotators:
higher chance of stronger flare

Occurrence per rotation period





Rapid rotators:
higher chance at high flare rates, but saturates

Conclusions

- Extra flaring A stars detected
- 653 flaring giants detected, sign of magnetic field/corona?
- Amplitude: F+G vs. K+M (location in HR)
- Duration: F+giants vs. G+K+M (inherit)
- Occurrence: late-type stars flare more often
- Strong correlation with rotation period of:
  - Flare star incidence (but flare stars!)
  - Number of flares per star
  - Flare amplitude