EBERHARD KARLS UNIVERSITÄT TÜBINGEN
Faculty of Science
Institute for Astronomy and Astrophysics

Stellar flares with PLATO

PLATO "Flares Work Package" (WP 123 700)

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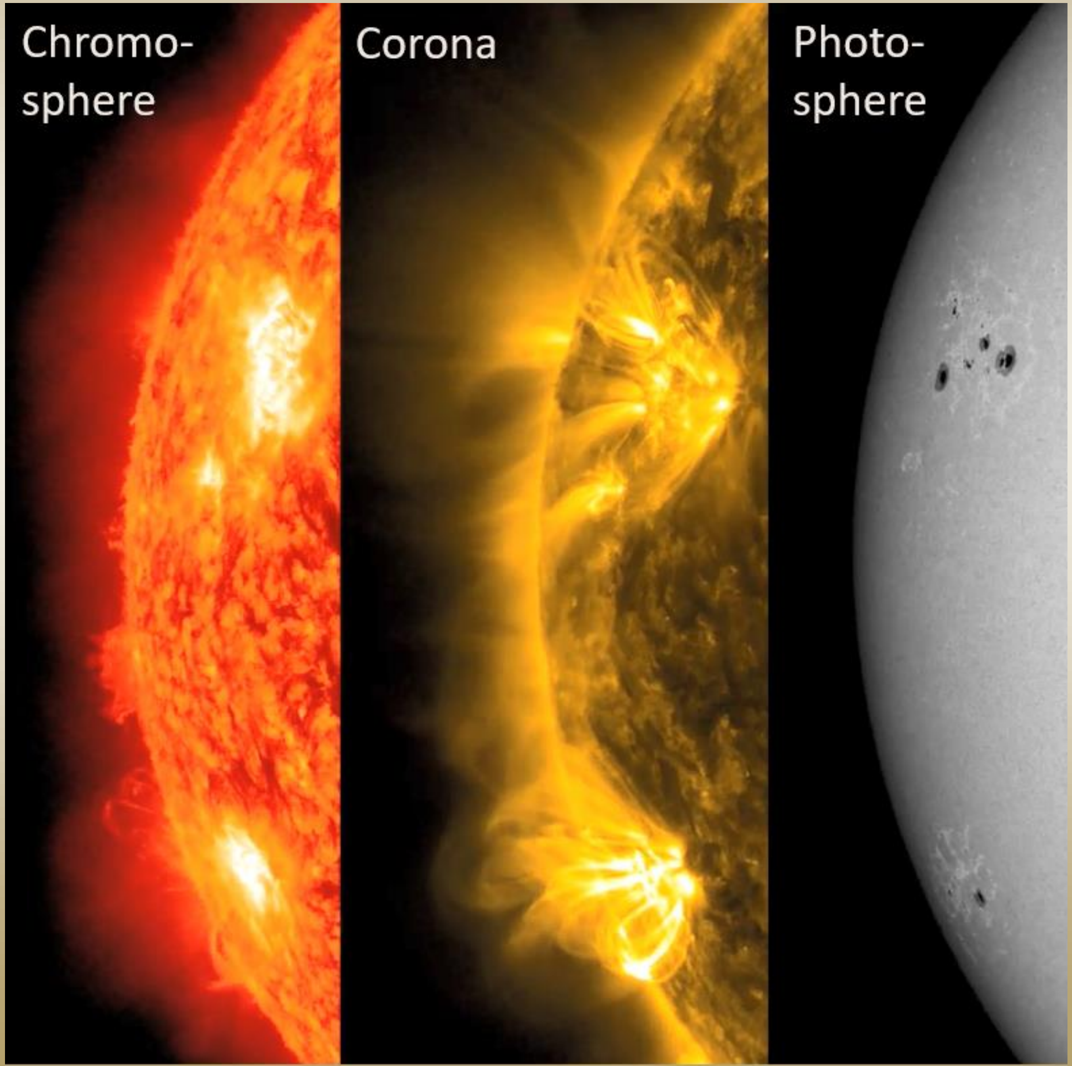
Stellar Activity

- Stellar activity is directly linked to the existence of strong magnetic fields
  → generated and maintained by dynamo processes

- Magnetic activity affects all atmospheric layers of late-type stars



- Phenomena are:

– photospheric star spots

– chromospheric line emission (e.g. Ca II , Hα)

– strong coronal UV, X-ray, and radio emissions

– *multi-wavelength flares*

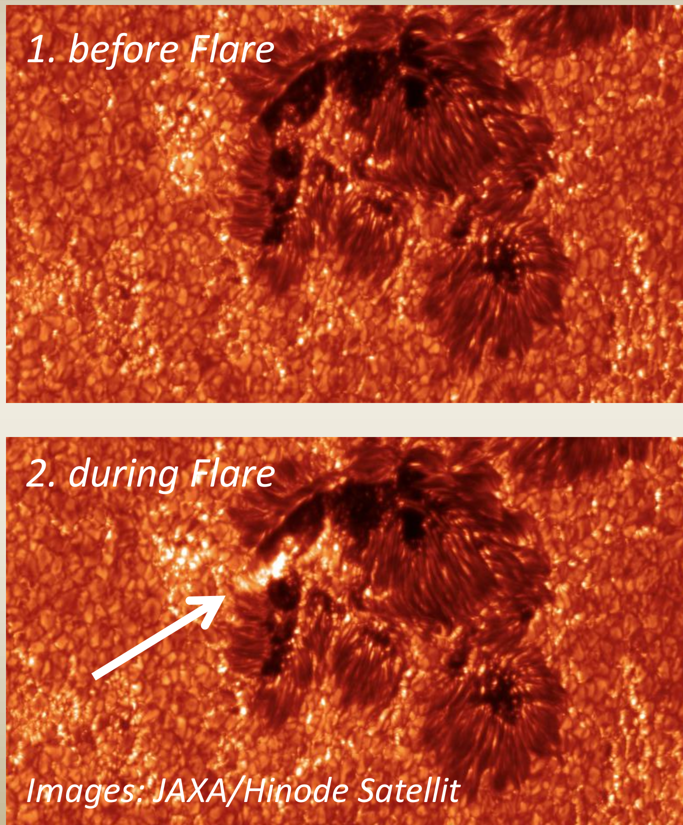
Two days in the life of the Sun (Aug 15-17, 2011)

Solar Dynamics Observatory Image Gallery: https://sdo.gsfc.nasa.gov/gallery/main

White light (optical) flares

Sun in visible light (photosphere):

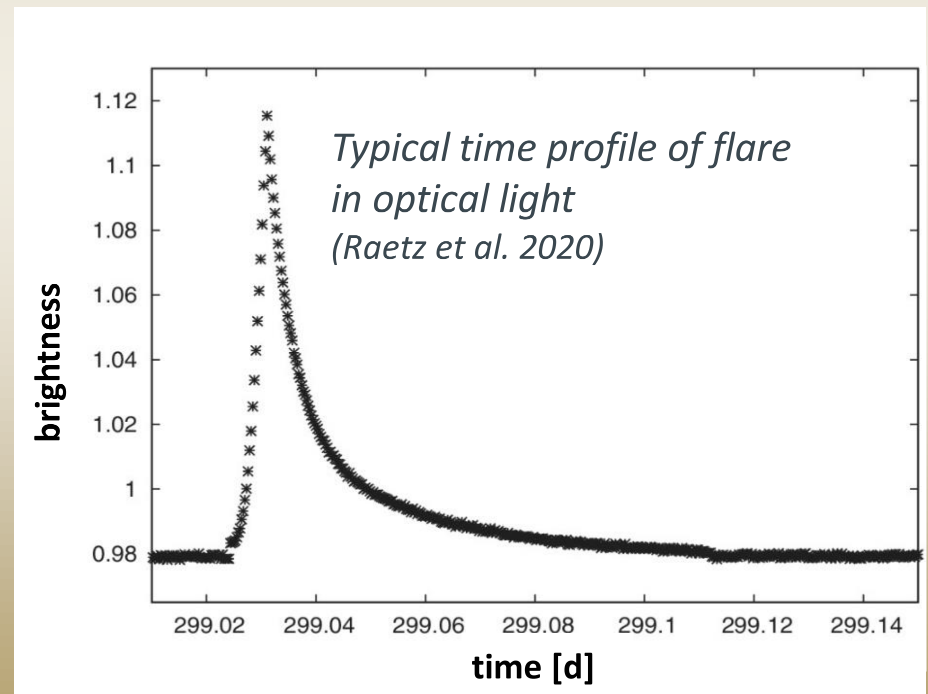
Localized brightening = “flare”



Other stars:

The stellar surface can not be resolved spatially.

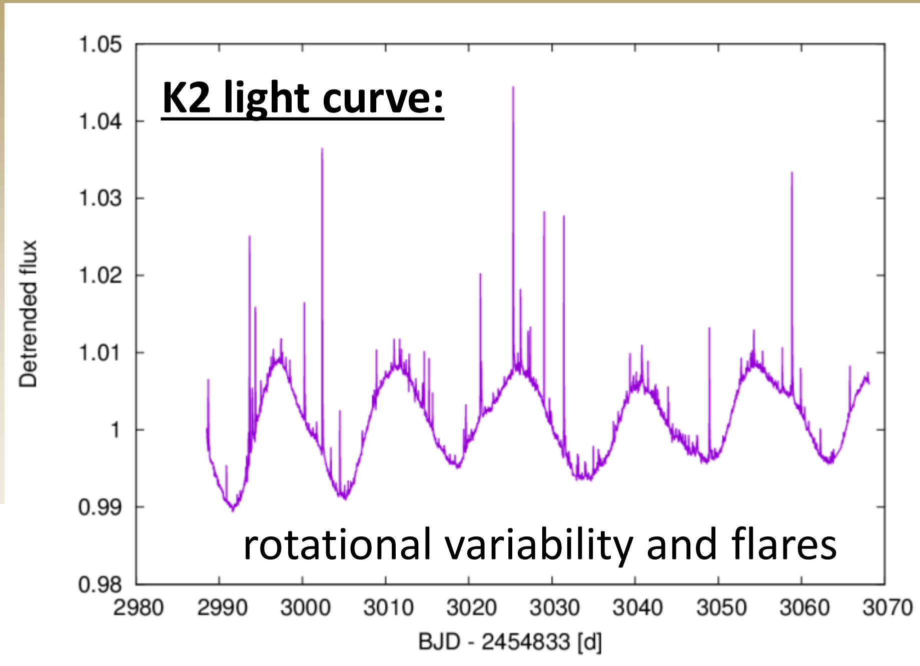
→ Measurement of abrupt brightness change associated with flare

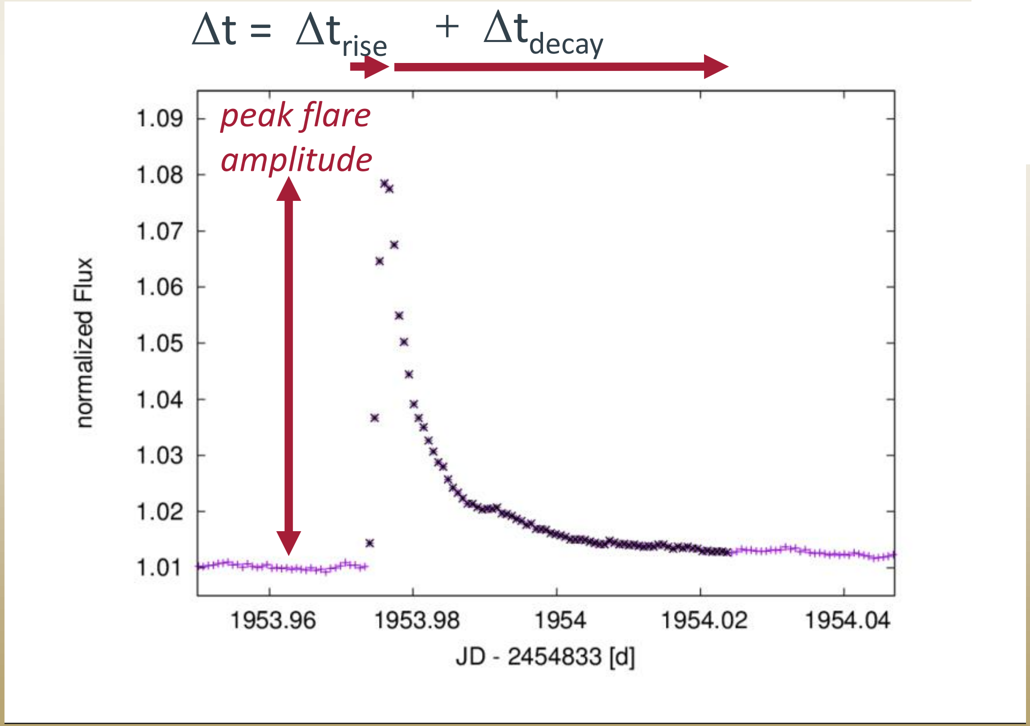


Physical parameters of activity in photometric light curves:

Flare parameters:

- flare amplitude
- flare duration (rise and decay time)
- flare energy
- flare frequency





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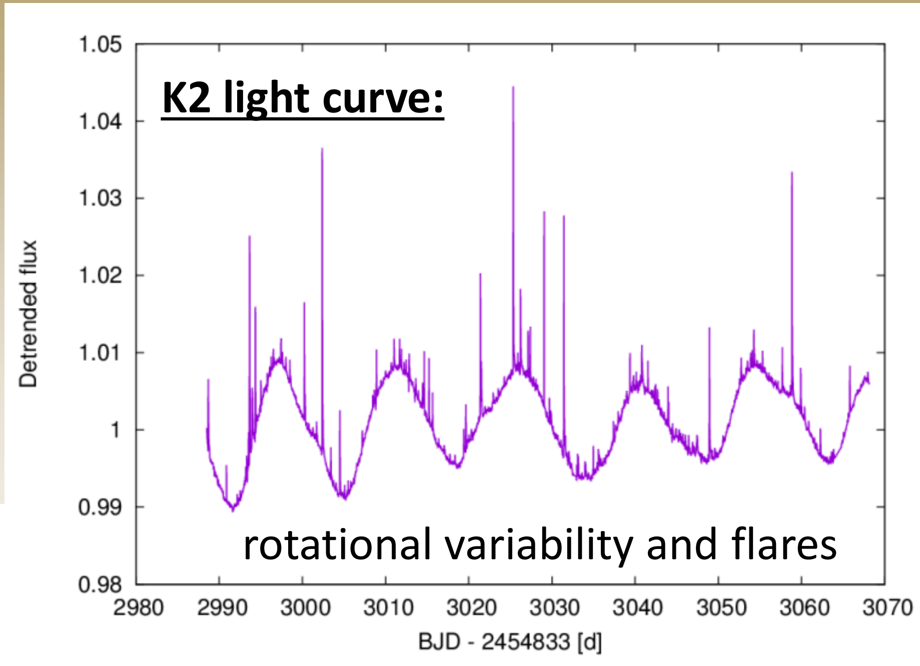

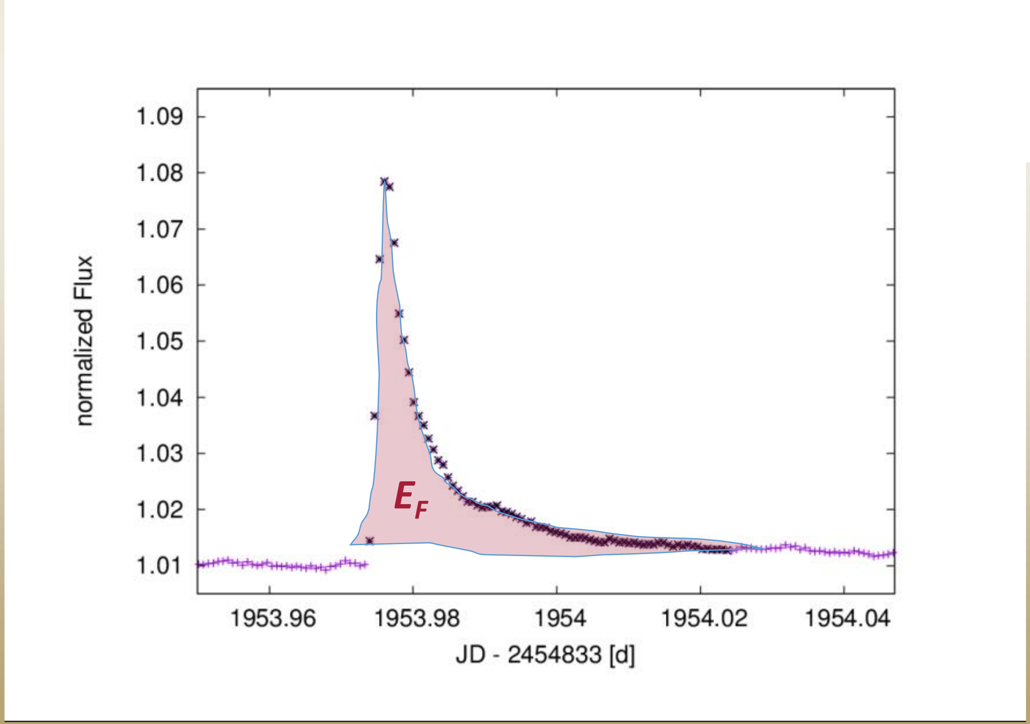

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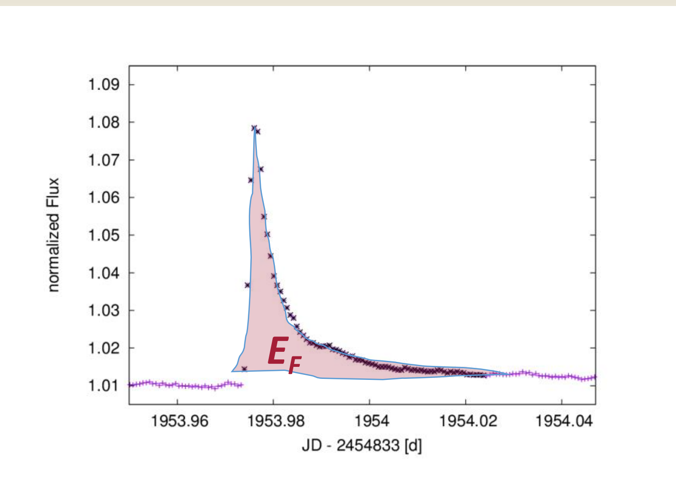
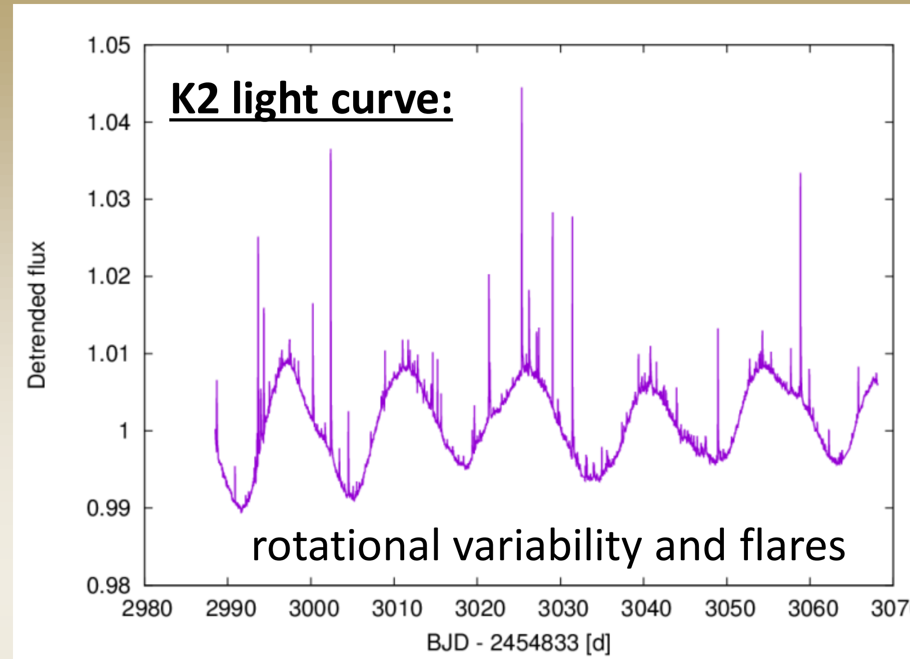




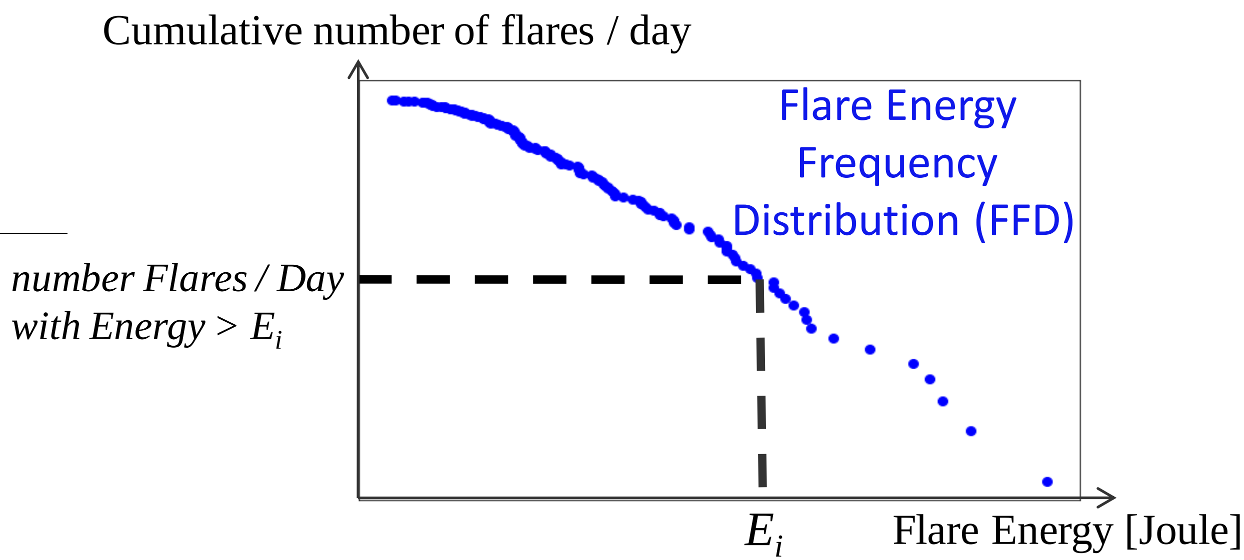
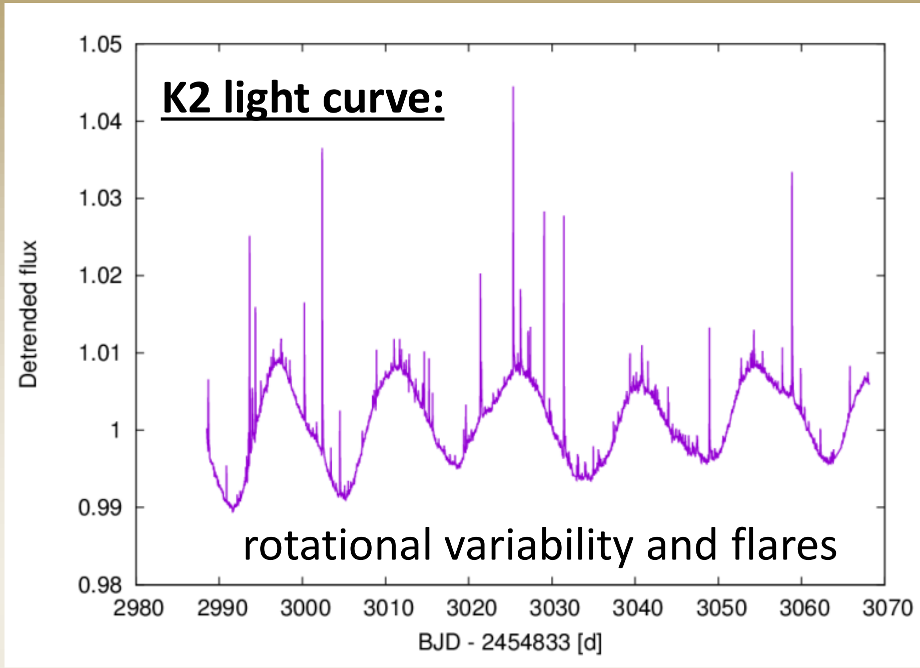


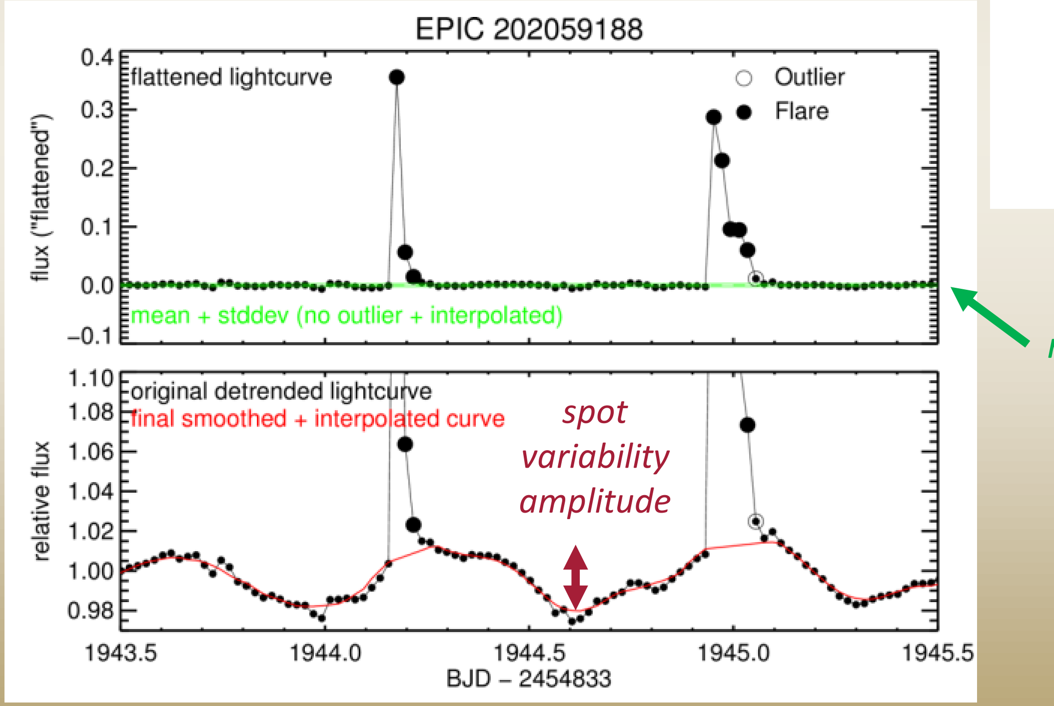
Fig. adapted from M.Bogner (Bachelor thesis)

Physical parameters of activity in photometric light curves:

Additional activity parameters:

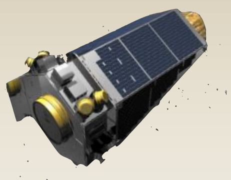
- amplitude of the rotational modulation
- scatter after removal of rotation and flare variability

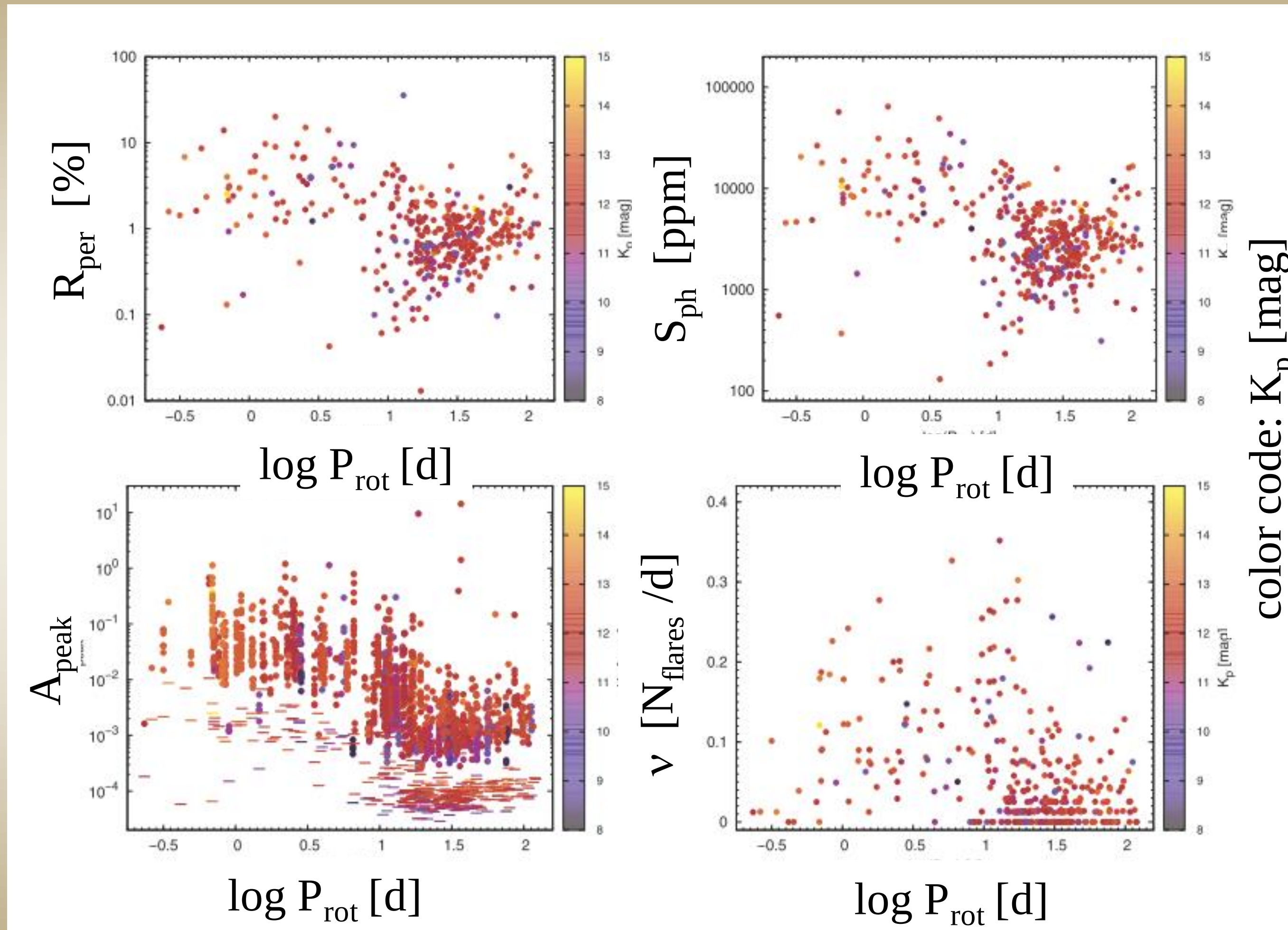




Rotation vs flares from K2 light curves of nearby M dwarfs

Stelzer et al. (2016);
Raetz et al. (2020)





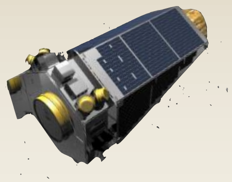
RESULT:
Photometric activity drastically changing at P_{rot} ~ 10 d

cf. saturated vs correlated regions in L_x – P_{rot} relation

Activity decays as stars spin down and dynamo becomes less efficient.

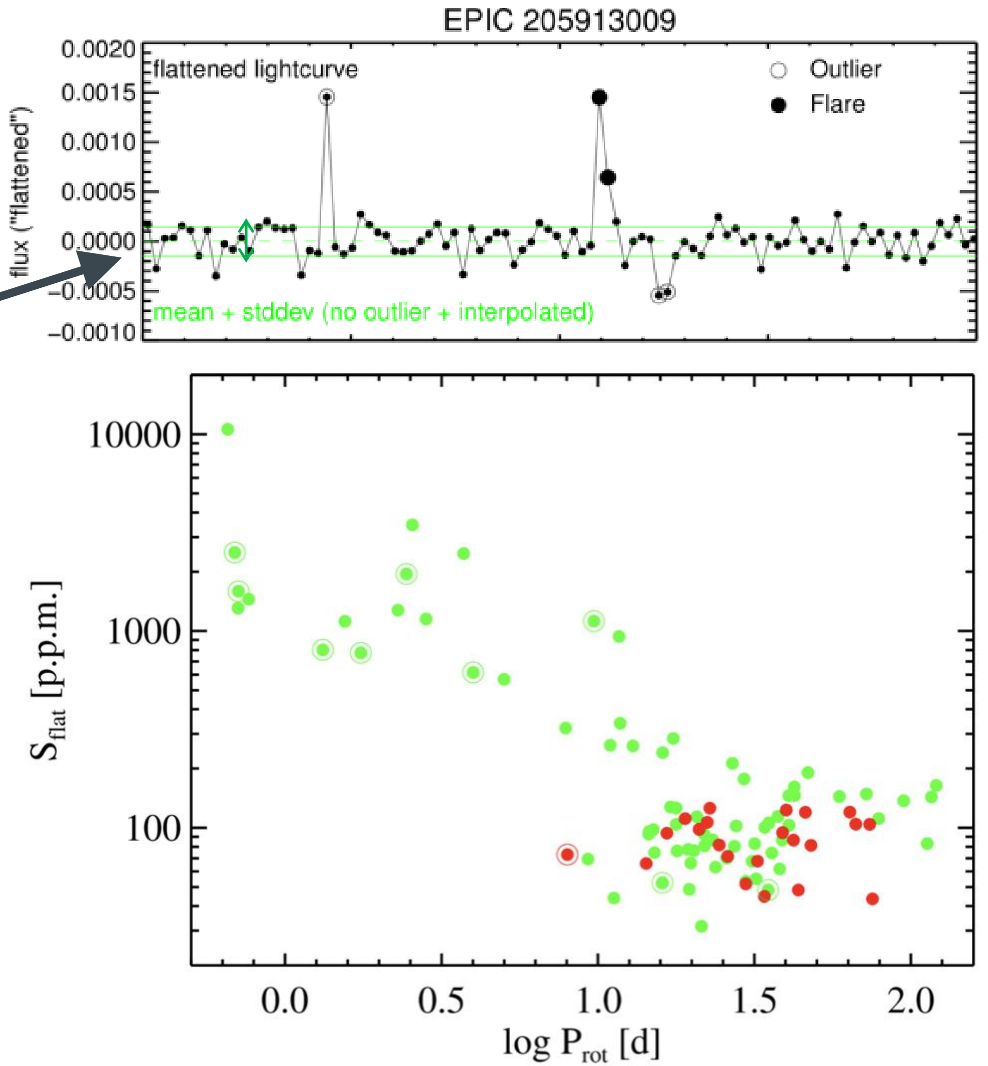
Physics hidden in the noise:

Activity diagnostic: std.deviation of lightcurve
(= "residual noise")
after removal of flares and rotational modulation: S_{flat}



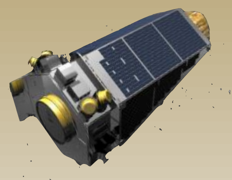
S_{flat} shows the same bimodality with P_{rot} as the other activity indicators.

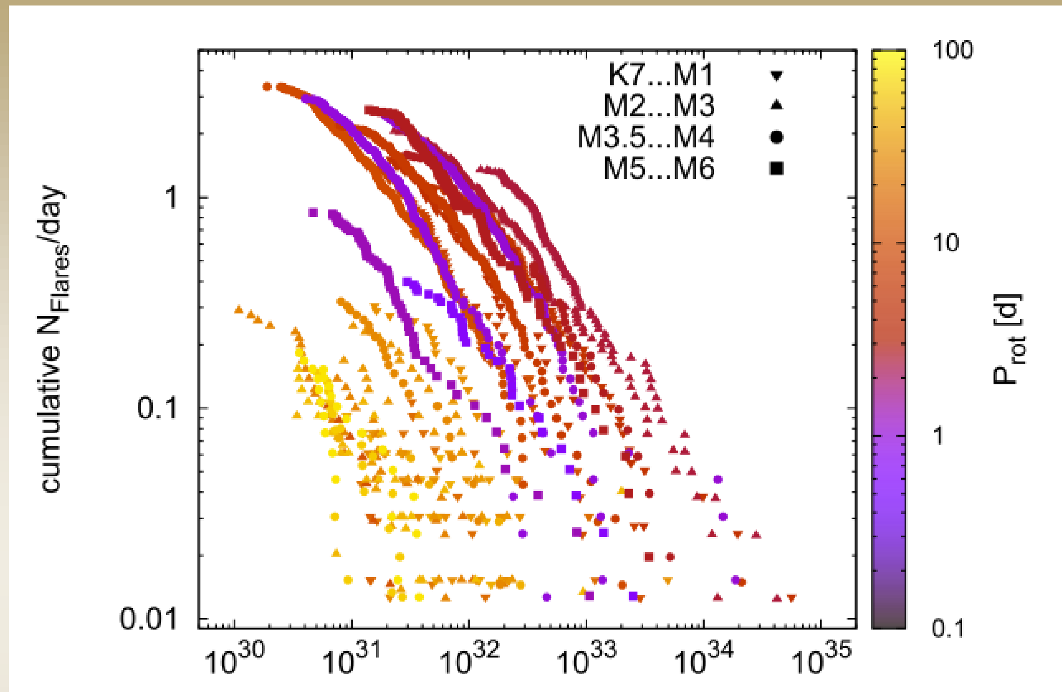
→ *There is unresolved variability in light curves of fast rotators,*
e.g. ***nano-flares, many small/rapidly changing spots***
(signatures of energy build-up)



Stelzer et al. (2016)

Flare energy frequency distributions (FFD):





(Raetz et al. 2020)

- **Power-law slope:** $\alpha = 1.84 \pm 0.14$

Consistent with previous M dwarf studies and the value found for the Sun.

$$\frac{dN}{dE} \sim E^{-\alpha}$$

If α = 2 → Sufficiently steep power-law
→ quiescent corona heated by ”nanoflares”

Flare effects on potential planets in the habitable zone

(1) highly energetic or frequent flare events can cause ozone depletion and, therefore, endanger life

- O_3 layer depletion for $E_f > 10^{34}$ erg/s @ flare occurrence frequency n_F ~ 1 / month
- consider fraction of flares hitting HZ: $n_F > 0.1 \ldots 0.4\ d^{-1}$

Tilley et al. (2019), Guenther et al. (2020)

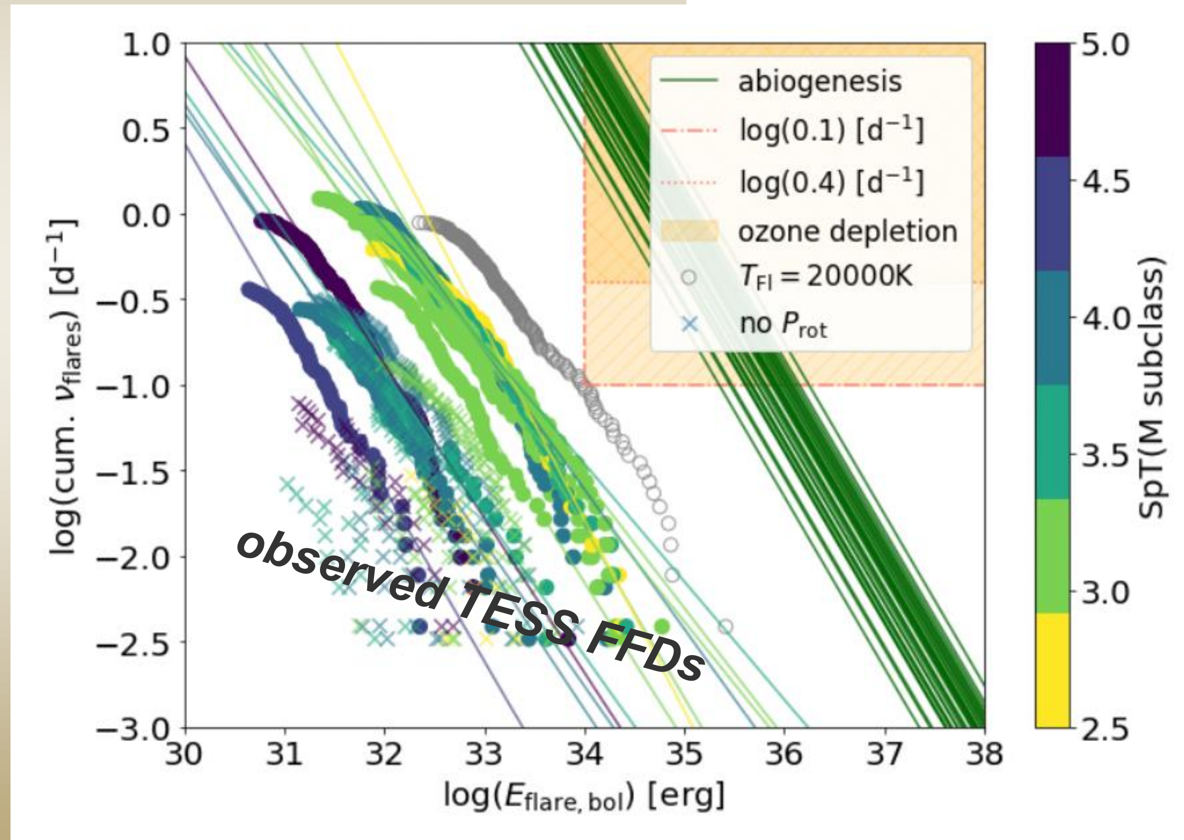
(2) Flares of appropriate energy and frequency can be beneficial for the development of life on exoplanets

- the minimum flare frequency required to enable prebiotic reactions ("abiogenesis zone"):

$$\nu \geqslant 25.5\ \mathrm{day}^{-1}\left(\frac{10^{34}\ \mathrm{erg}}{E_U}\right)\left(\frac{R_*}{R_\odot}\right)^2\left(\frac{T_*}{T_\odot}\right)^4.$$

Guenther et al. (2020)

Fig. from Bogner et al. (2021)



TESS observations of 35 flaring M stars from the TESS Habitable Zone Star Catalog (HZCat, Kaltenegger et al. 2019)

Aims of WP "Stellar flares" (WP123 700)

(A) Removal of flare events to "clean" light curve for other purposes,
e.g. search for periodic signals (planets, rotation, oscillations, …)

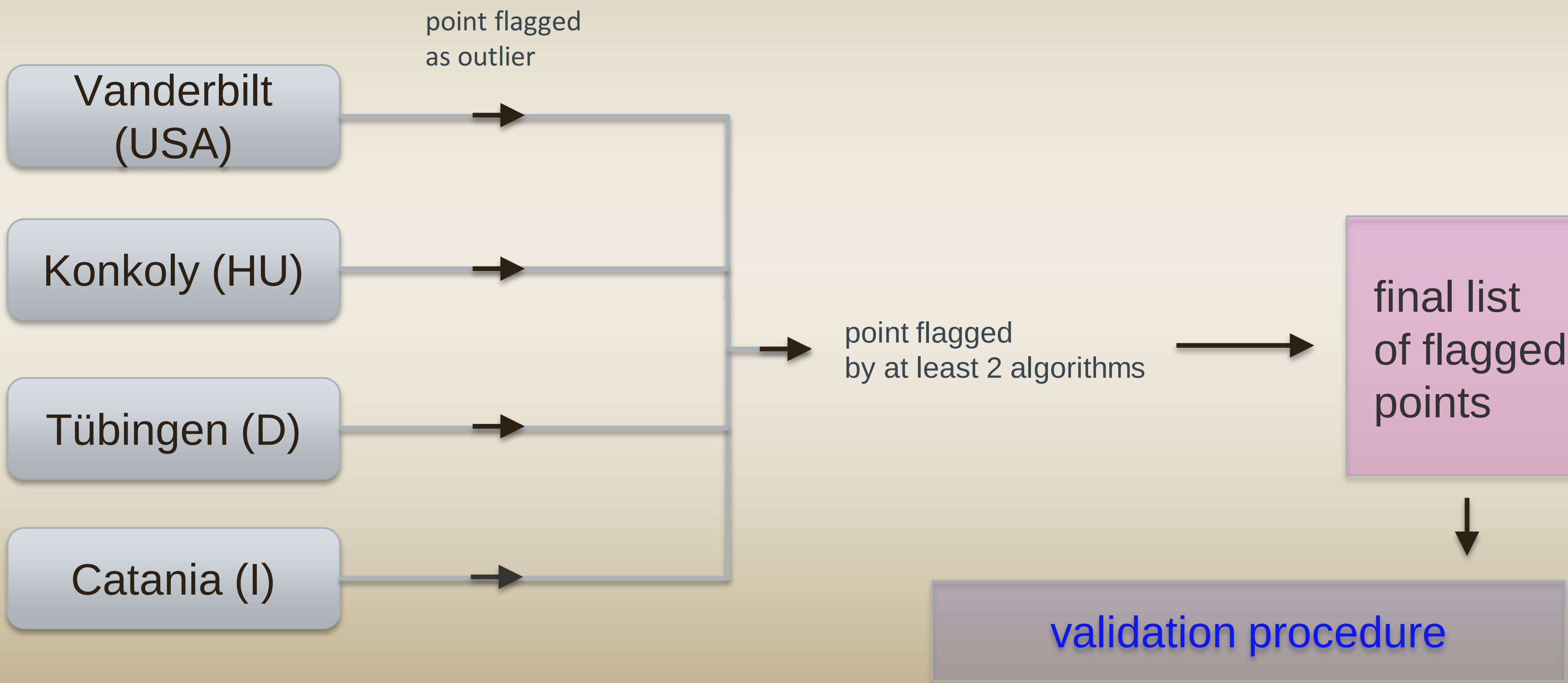
(B) Study the physics of stellar flares → save ADP with flare parameters

Status of WP "Stellar flares"

- Prototype algorithm **identifying** flare data points → delivered to PDC
- Flare **validation**
  & determination of physical parameters of flares → work in progress

The “flare data point identification” prototype code

4 different algorithms
detect upwards outliers
in the light curve



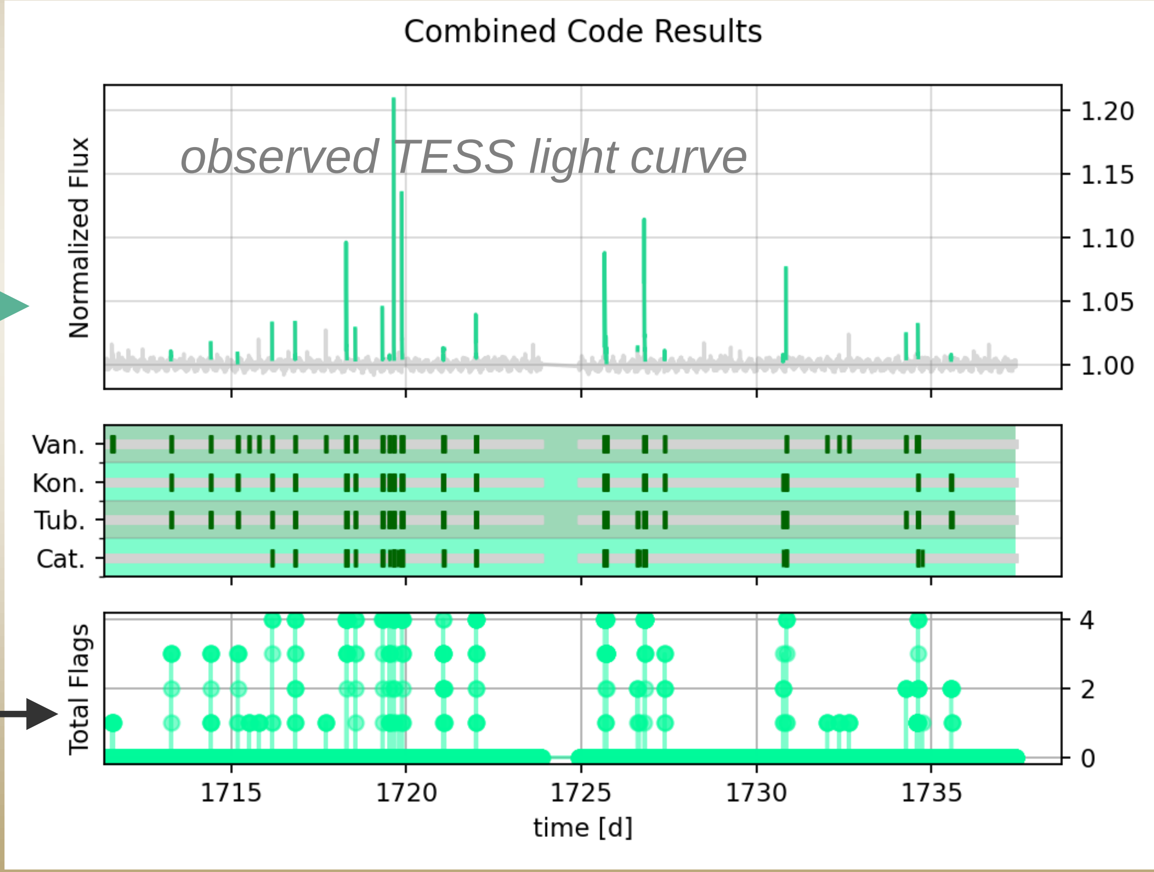
Performance of flare identification prototype code

Example: TESS light curve of an M dwarf

Flagged points retained
= points flagged
by at least 2 algorithms

Flare data points flagged
by 4 individual algorithms

Number of algorithms
that have flagged the data point



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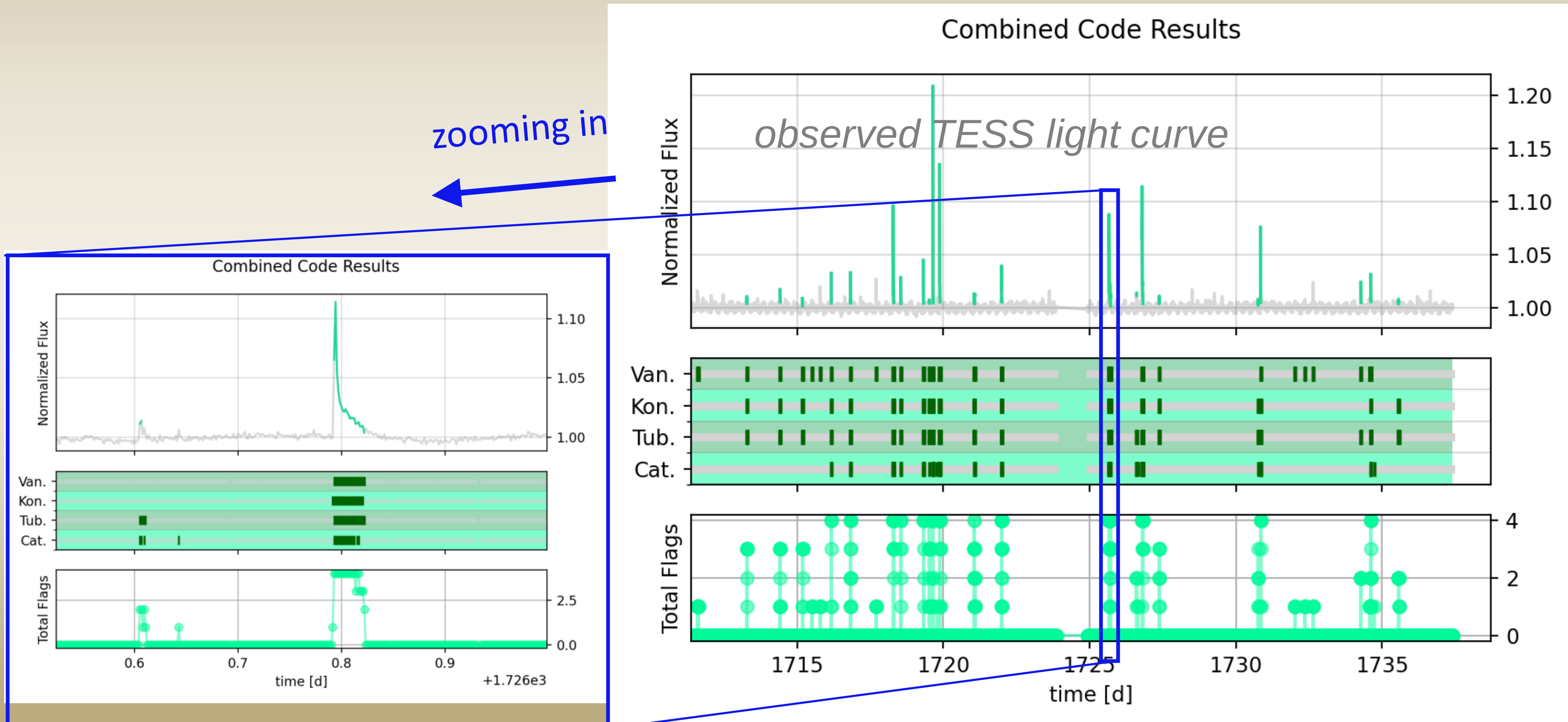
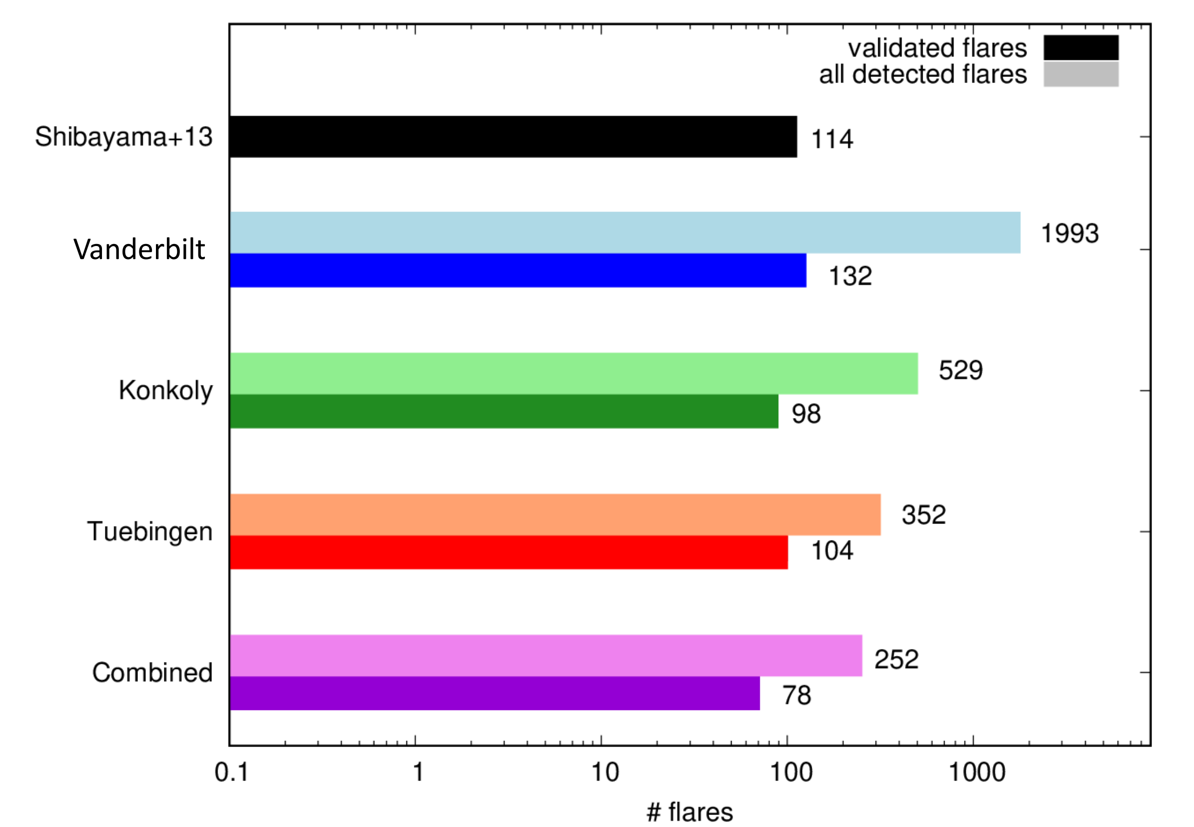


Performance of flare identification prototype code

Results for the Kepler Superflare sample

Kepler Superflare sample:

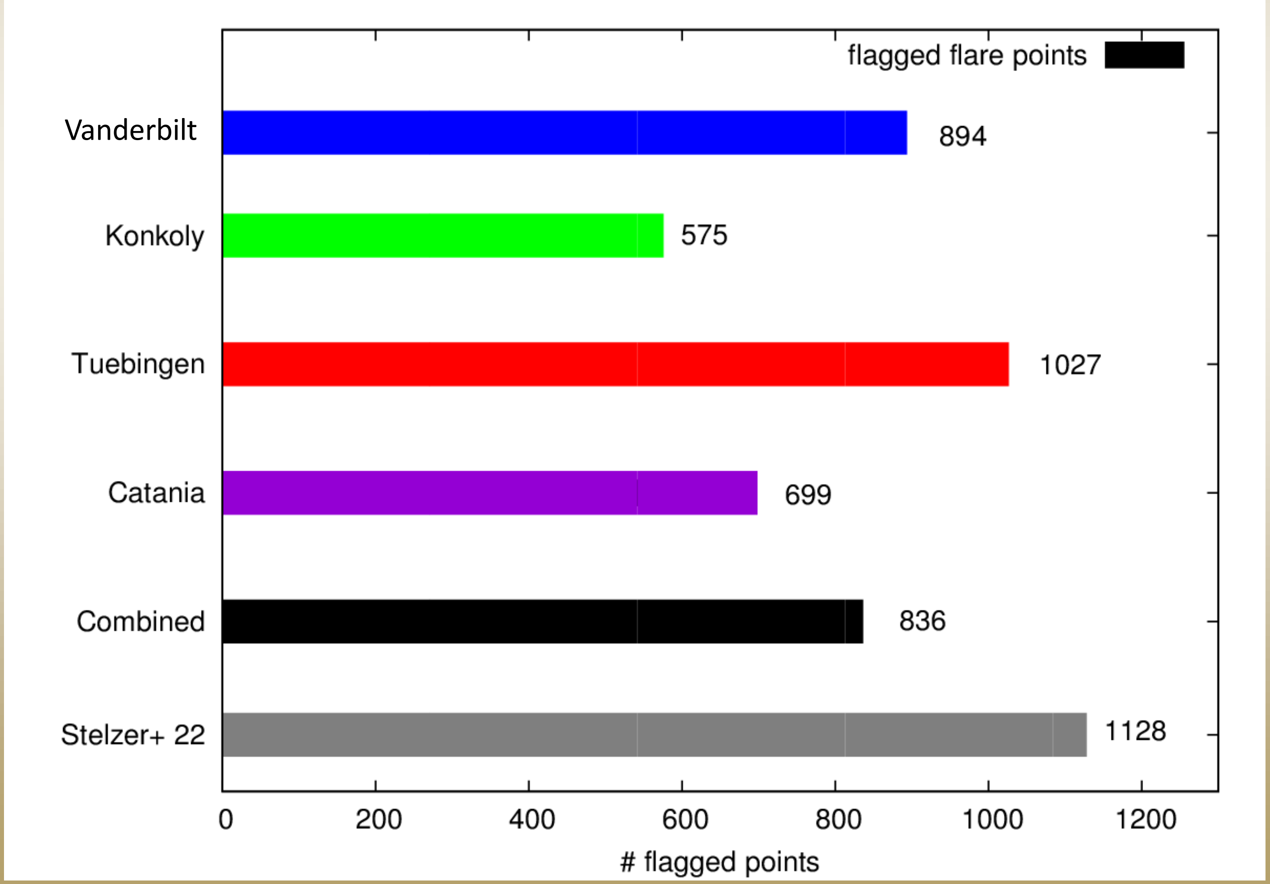
- Shibayama et al. (2013) based on the initial sample of Maehara et al. (2012)
- 279 flaring G-type stars
- 15 of these stars have Kepler short cadence data in multiple quarters
  - ➢ 53 light curves were analysed in the early test phase of the prototype code



Performance of flare identification prototype code

Results for selected light curves from the TESS HZCat sample

- Three out of the 35 flaring stars from our TESS HZCat sample were selected
- Selection Criteria for this test:
  - Clear rotation signal
  - High number of flares
- Light curves of 2 sectors were analysed with the prototype code



Next steps / Open problems

- Performing flare injection test on realistic PLATO light curves
  - Inject flares with physical input distributions
- Implementing a Flare **validation** procedure
  & determination of physical parameters of flares
- Complex flare shapes are not considered
  & flare code is not adapted to recover them


Thank you
for your attention!