EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Faculty of Science
Institute for Astronomy and Astrophysics

The rotation-activity relation of M dwarfs: From K2 to PLATO

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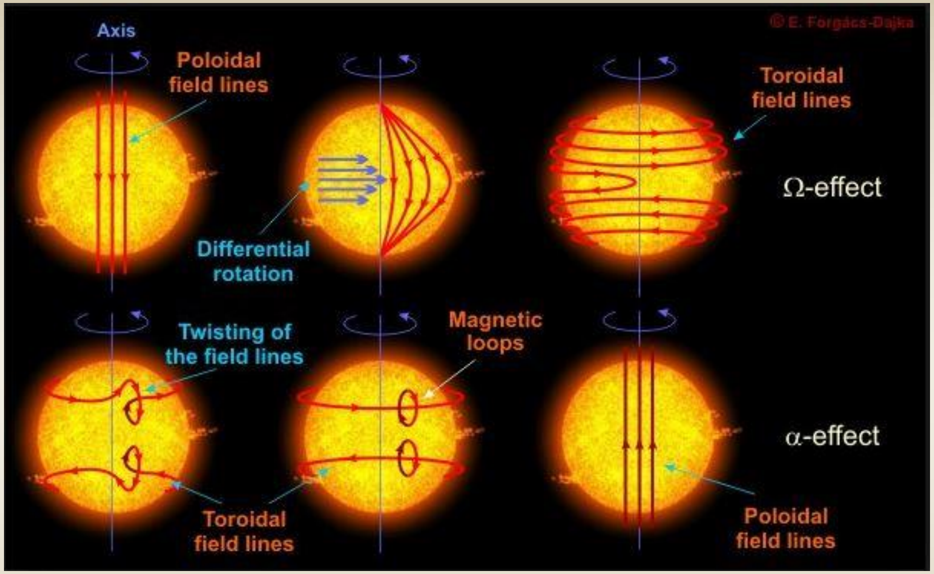
Stellar Activity

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

  - Example: α - Ω Dynamo for solar-like stars



→ rotation and stellar activity are intimately linked

- Magnetic activity affects all atmospheric layers of late-type stars
- Phenomena are:
  - * photospheric star spots
  - * chromospheric line emission (e.g. Ca II , Hα)
  - * strong UV, X-ray, and radio emissions
  - * *multi-wavelength flares*

The Activity-Rotation Relation

- The relation between rotation and activity for late-type stars (FGKM) was first observed some decades ago (e.g. Pallavicini et al. 1981, Vilhu 1984)

- They used: * Spectroscopic measurements to determine v*sin(i)
  * Different activity diagnostics: - Hα, Ca-II H&K
  - X-ray (more sensitive to low activity levels)

relationship between stellar rotation and activity → vital probe of the stellar dynamo

- X-ray luminosity ↑ with ↓ P_{rot} until a plateau is reached

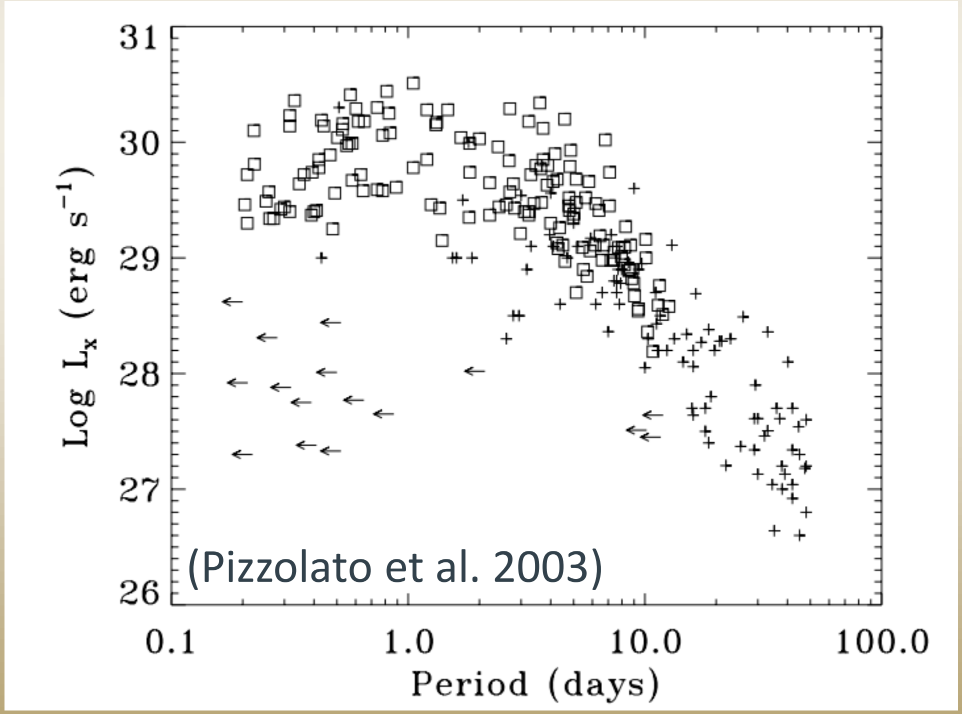


Fig. Activity-Rotation-Relation for FGKM stars, but only few constraints for M stars

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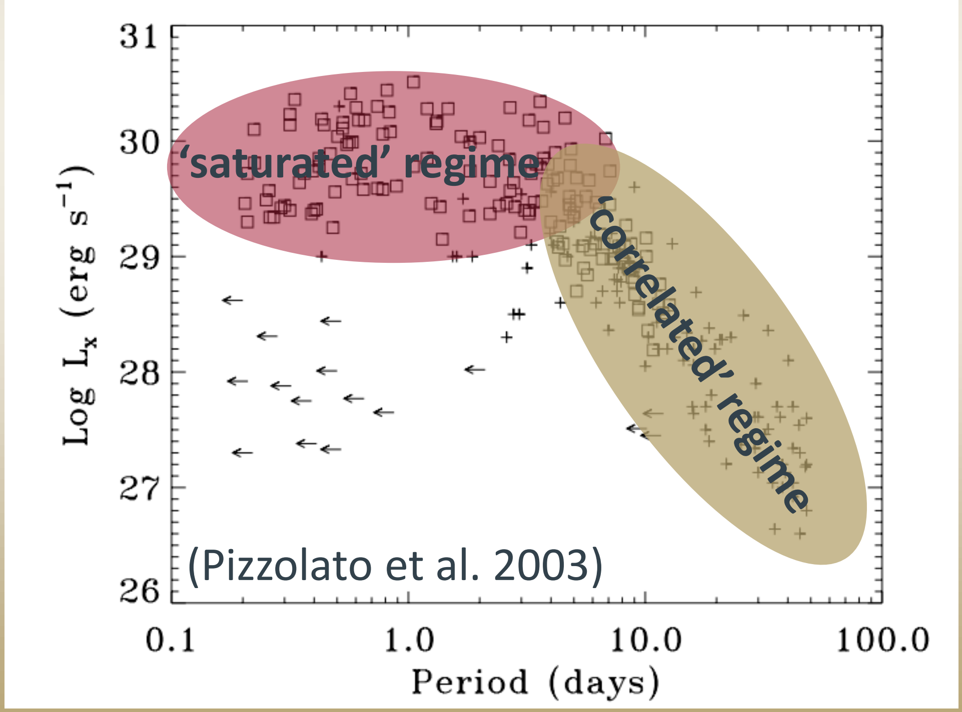
  * long period
    - 'correlated' regime

  * short period
    - 'saturated' regime, L_x independent of rotation



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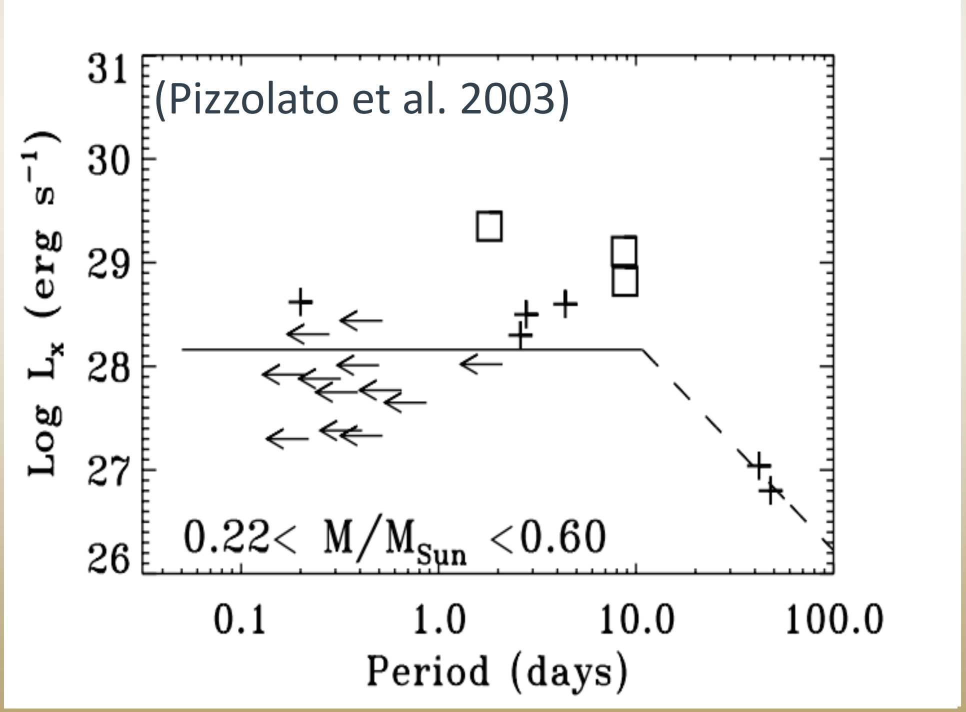
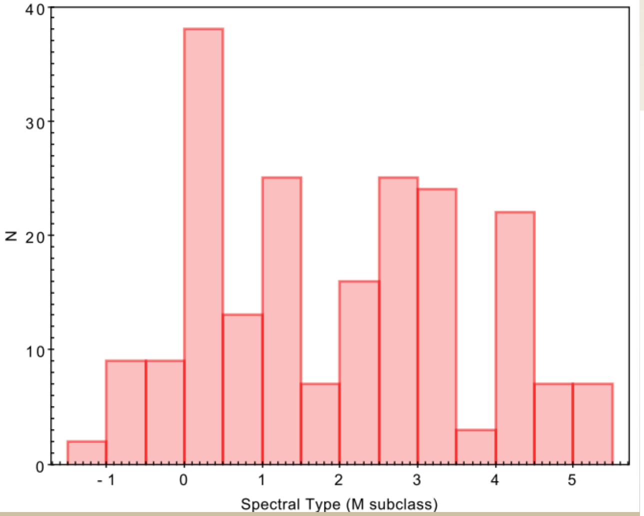


Fig. Activity-Rotation-Relation for FGKM stars, but only few constraints for M stars

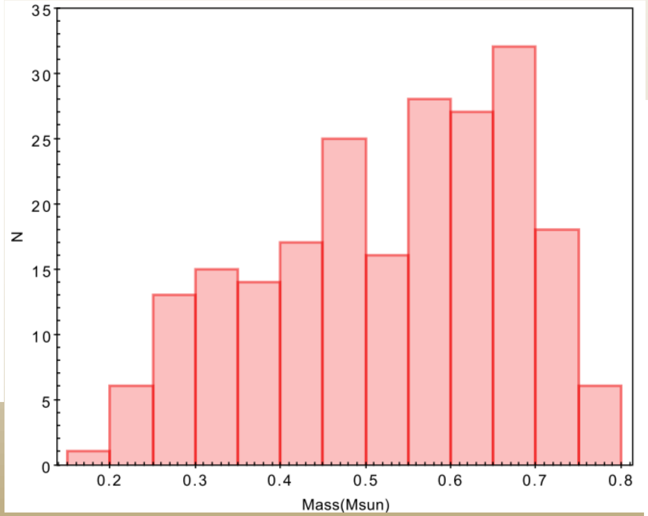
Our study of bright and nearby M dwarfs

- We used M dwarf light curves obtained with the **K2-mission** to measure rotation and investigate the activity
- Study is based on the Superblink proper motion catalogue by Lepine and Gaidos (2011)
  - a catalogue of ~8900 bright and nearby M dwarfs
- **219 M dwarfs** observed in nine K2 campaigns (Stelzer et al. 2016, C0-C4; this work, C5-C8)

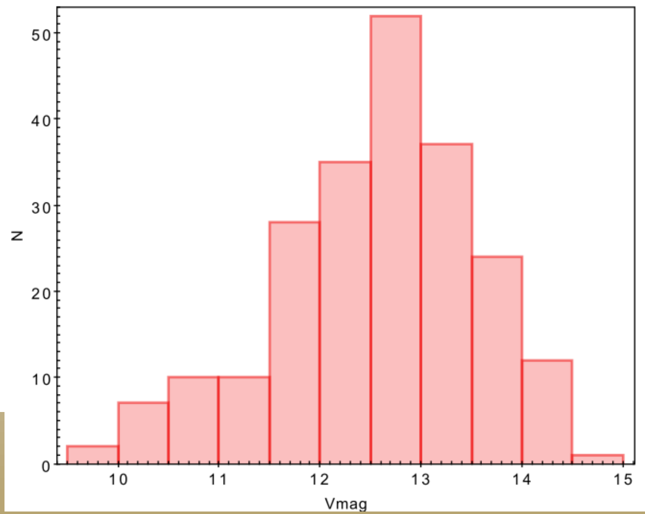
Spectral Type



Mass



Vmag



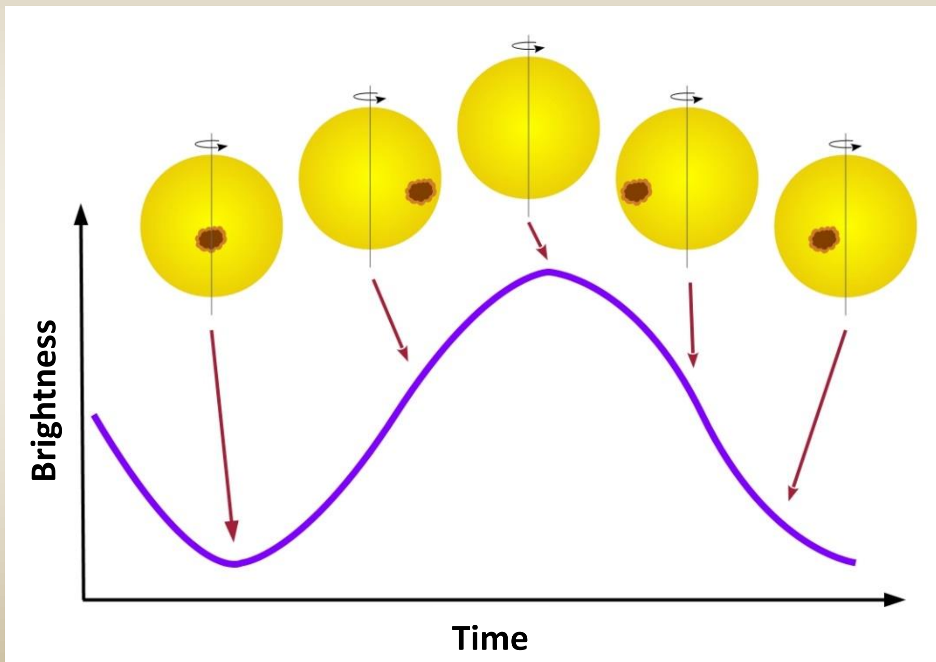
- the K2 detrended light curves of A. Vanderburg (Vanderburg & Johnson 2014) are used

Calibrating the rotation – activity relation of M stars

rotation - activity relation has remained poorly constrained for M stars
(long periods, low spot amplitudes)

Stelzer et al. (2016)

Rotation:
Periodic brightness modulation
By rotating cool star spots
(magnetic field footpoints)

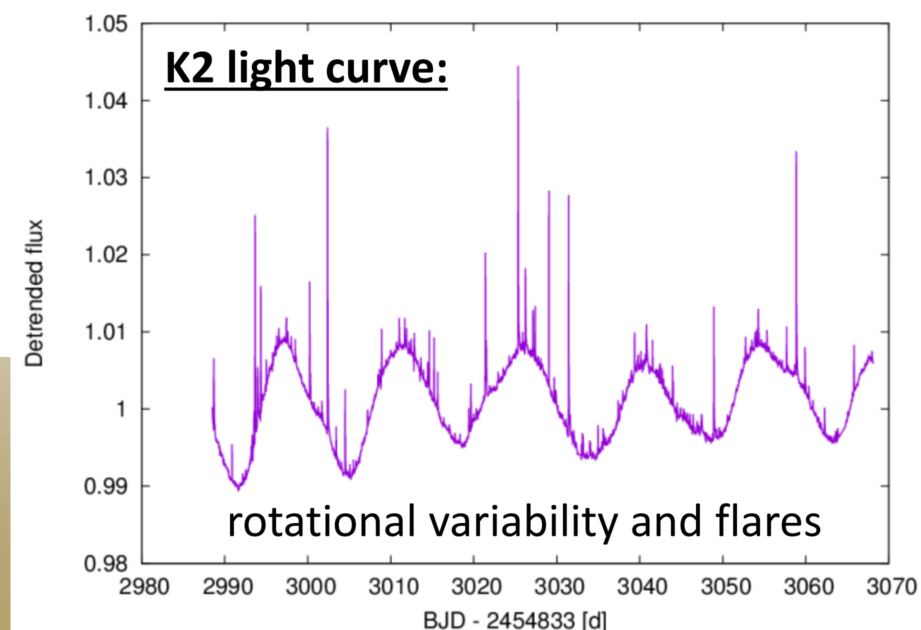


Small amplitudes of M dwarf rotation cycles
→ space-based observations

K2-mission

Activity:

- The amplitude of photometric variability associated with star-spots
- StdDev of the light curve
- Residual variability in flattened light curve
- Flare frequency
- Peak flare amplitude



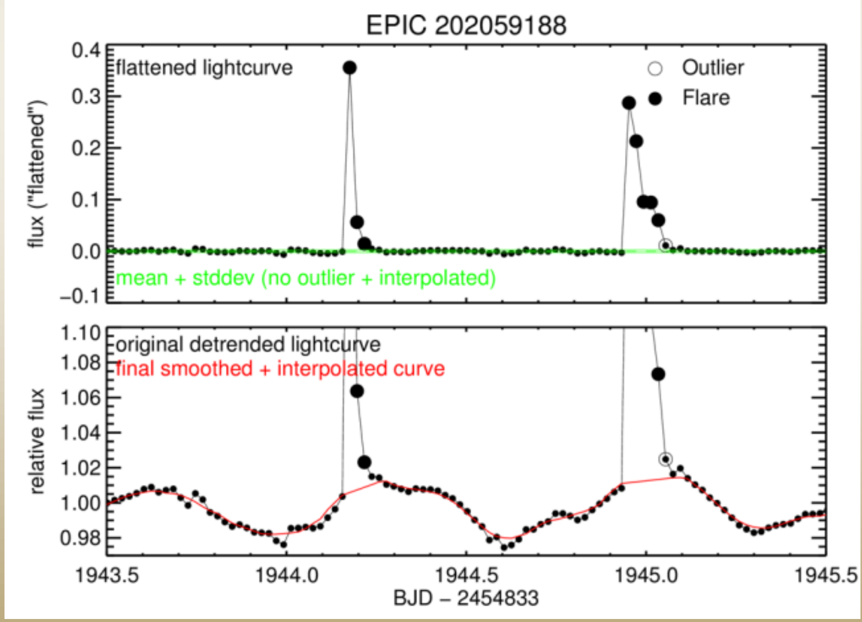
K2 DATA ANALYSIS

LC analysis and Flare detection

Rotation and activity diagnostics are determined with an iterative process (Stelzer et al., 2016):

i. smoothing of the light curve
ii. subtraction of the smoothed from the original light
iii. Flag points that deviate by more than a chosen threshold
   → **'Cleaned' LC** (free from flares)

→ Original LC – 'Cleaned' LC = **'flattened' LC** (rotational variation removed)



measurement of:

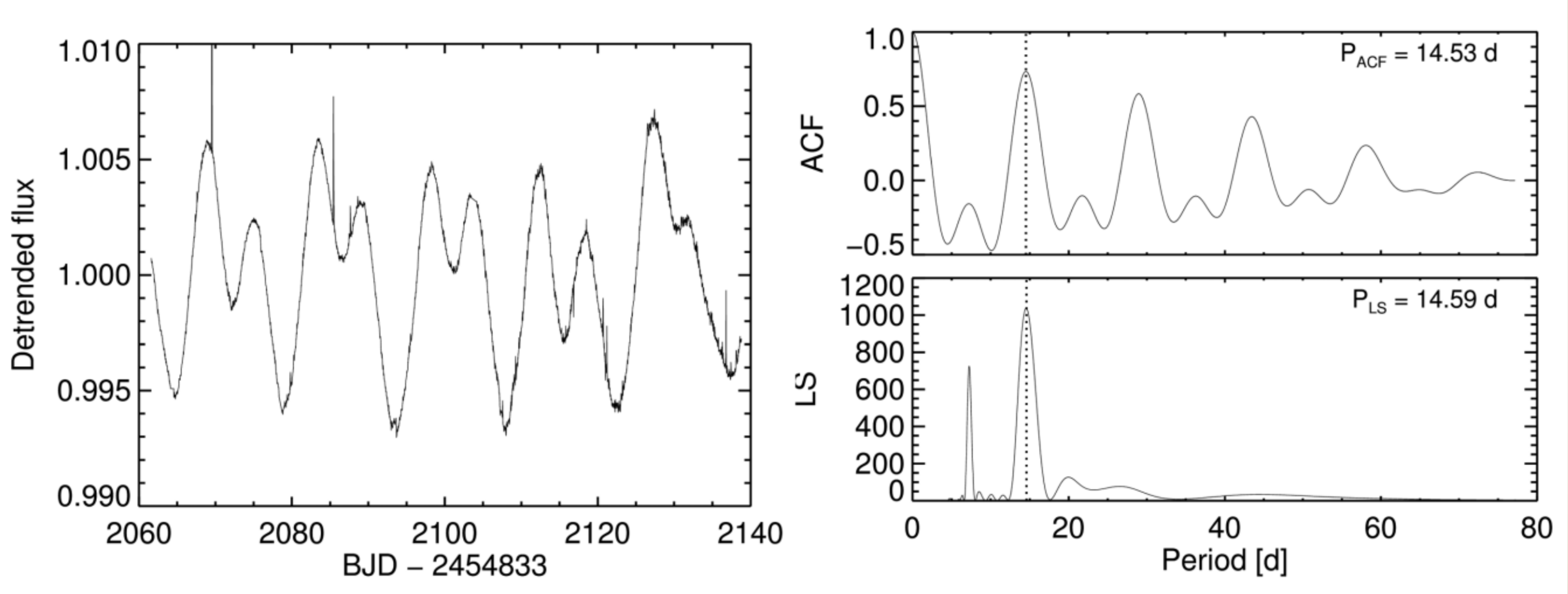
rotation periods, amplitude of the rotational variability, standard deviation of the light curve flare frequency, peak flare amplitude

Period Search

Standard time series analysis techniques were applied:

- the Lomb Scargle (LS) periodogram
- autocorrelation function (ACF)

} (limited to periods shorter than the duration of the K2 campaigns)



Period Search

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- autocorrelation function (ACF)
- least-squares sine fit

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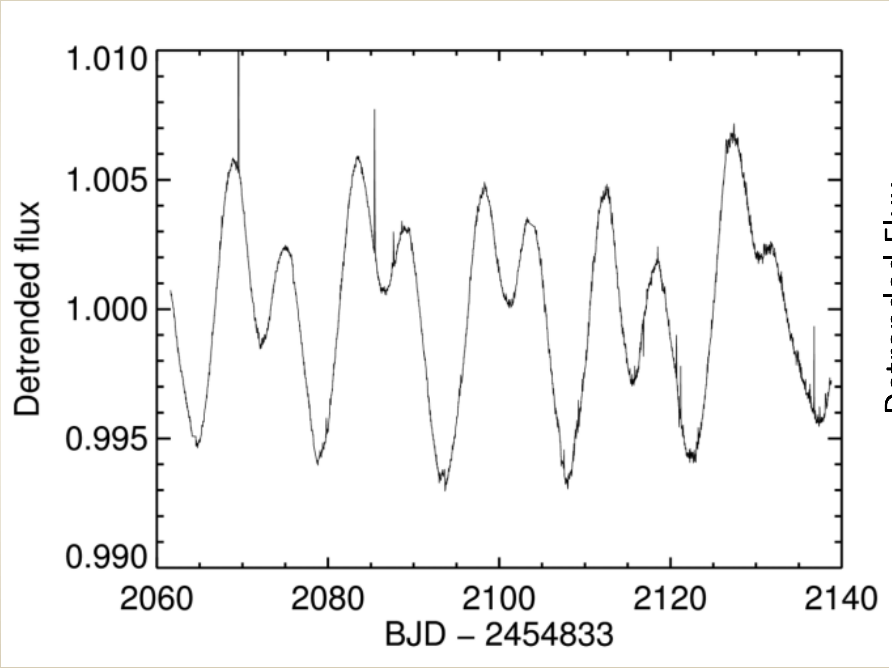

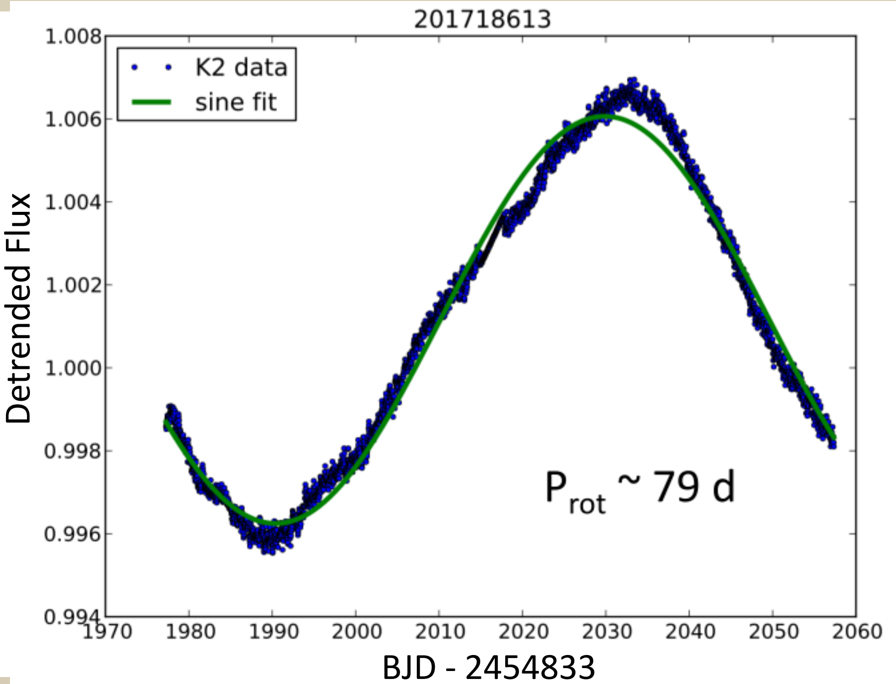

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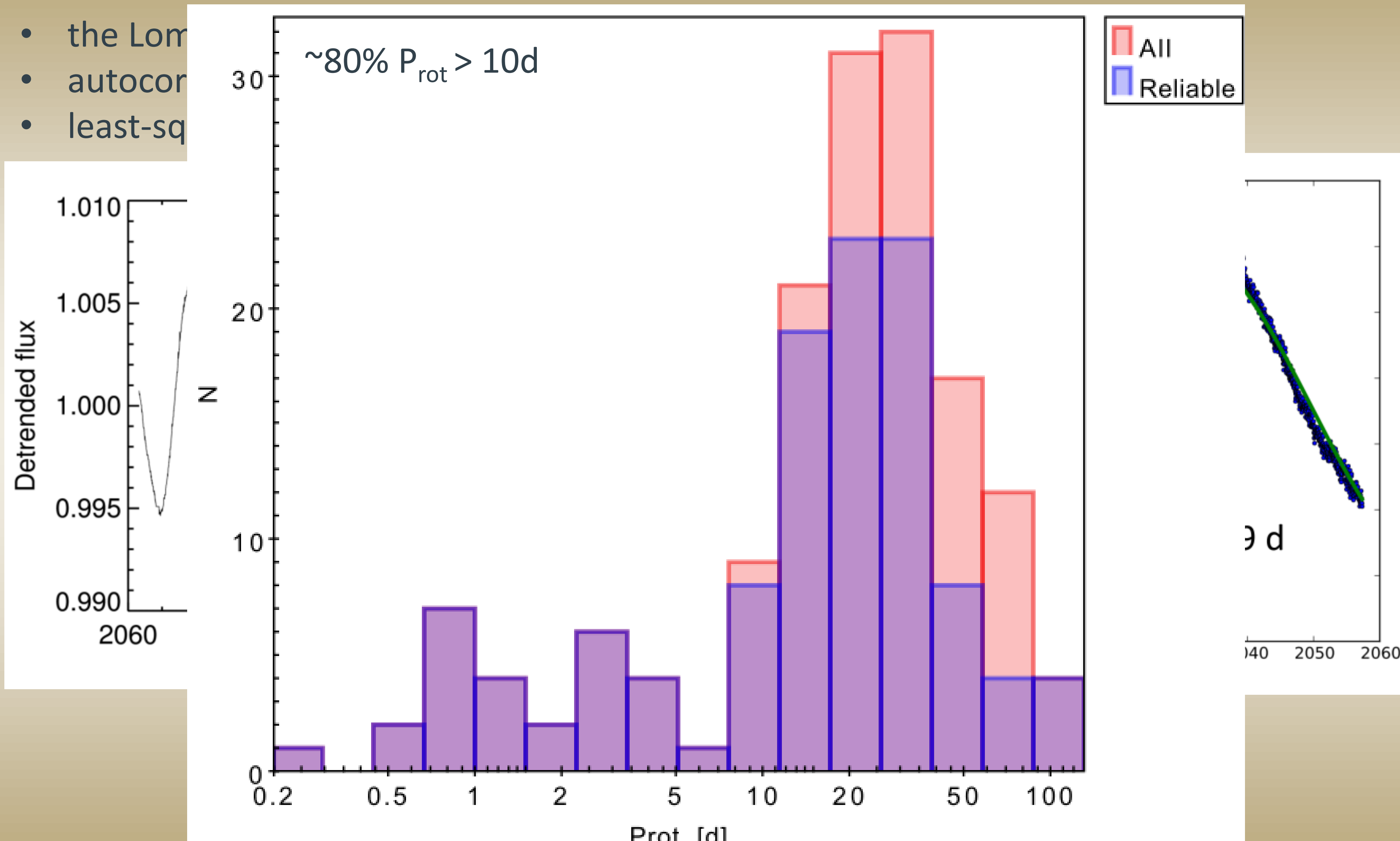
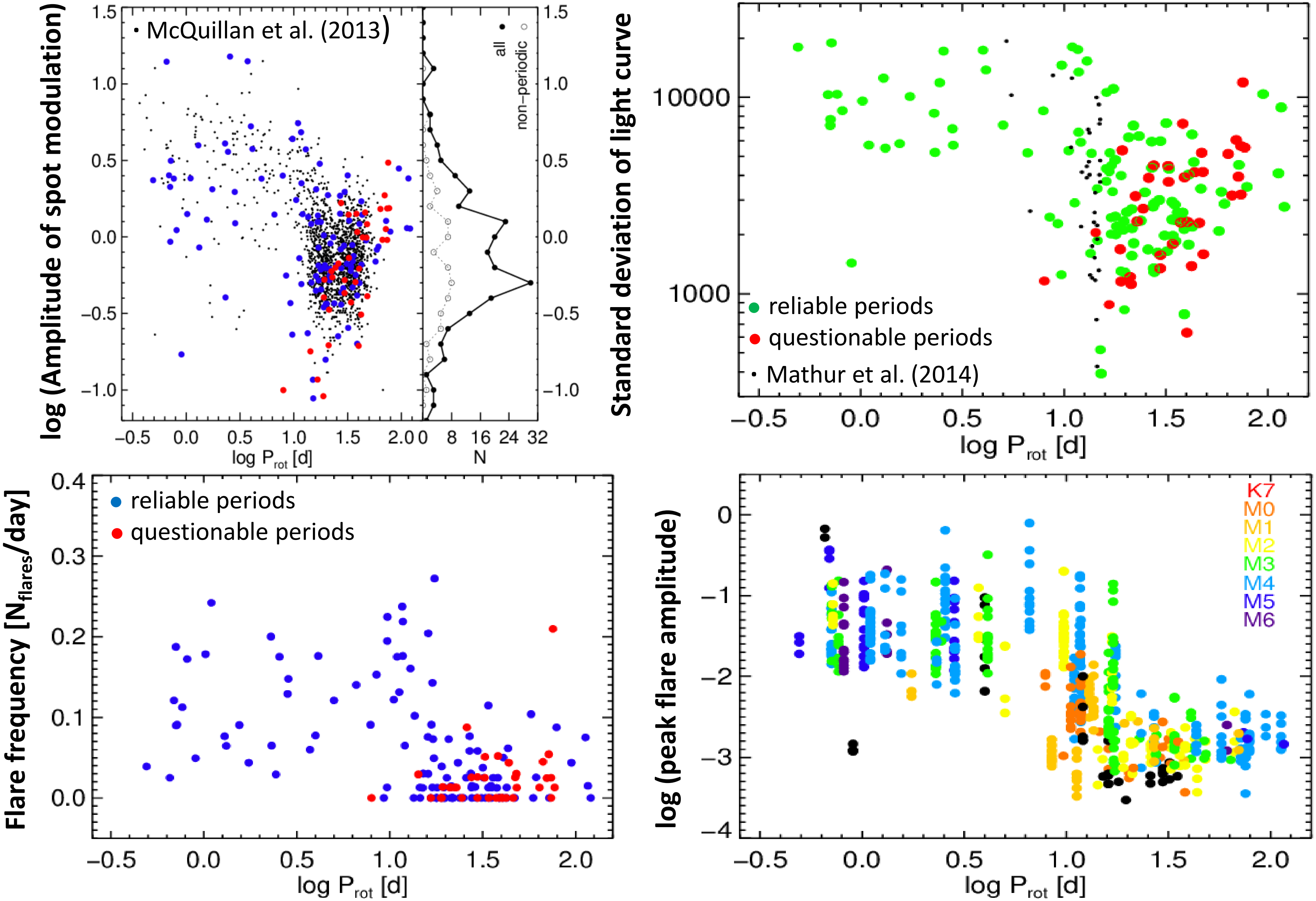
- the Lom
- autocor
- least-sq



Rotation periods detected for 154 out of 219 M dwarfs (116 reliable, 38 less secure)



At P_{rot}~10 d the spot and flare activity undergoes a dramatic change

→ rotation-dependent rapid transition in magnetic properties of M dwarf photospheres

K2 Limitations

Cadence:

Long cadence (29 min):

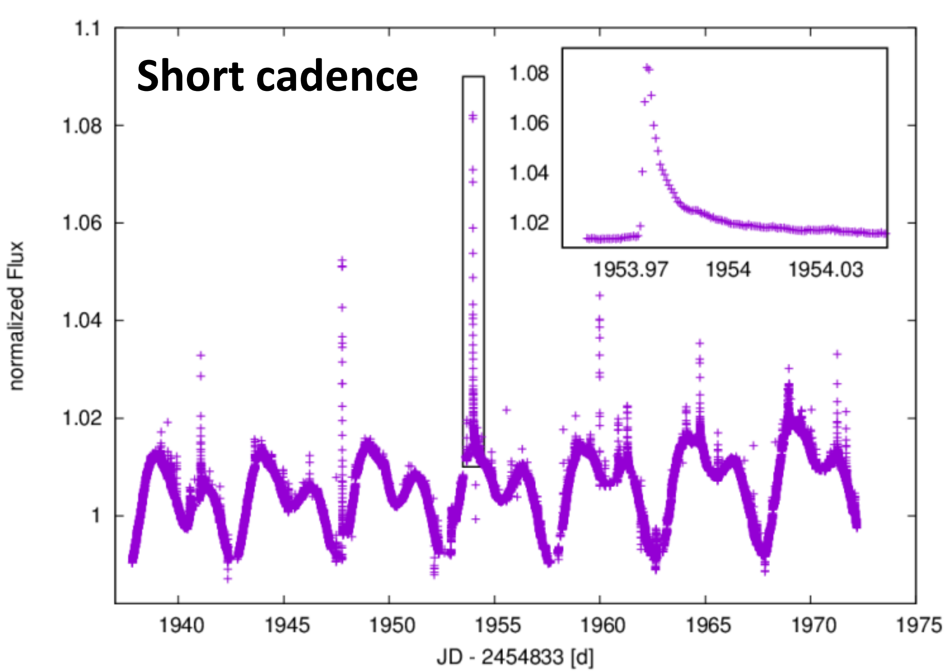
- Minimum detectable flare duration: 1h
- Binning obscures true flare amplitude

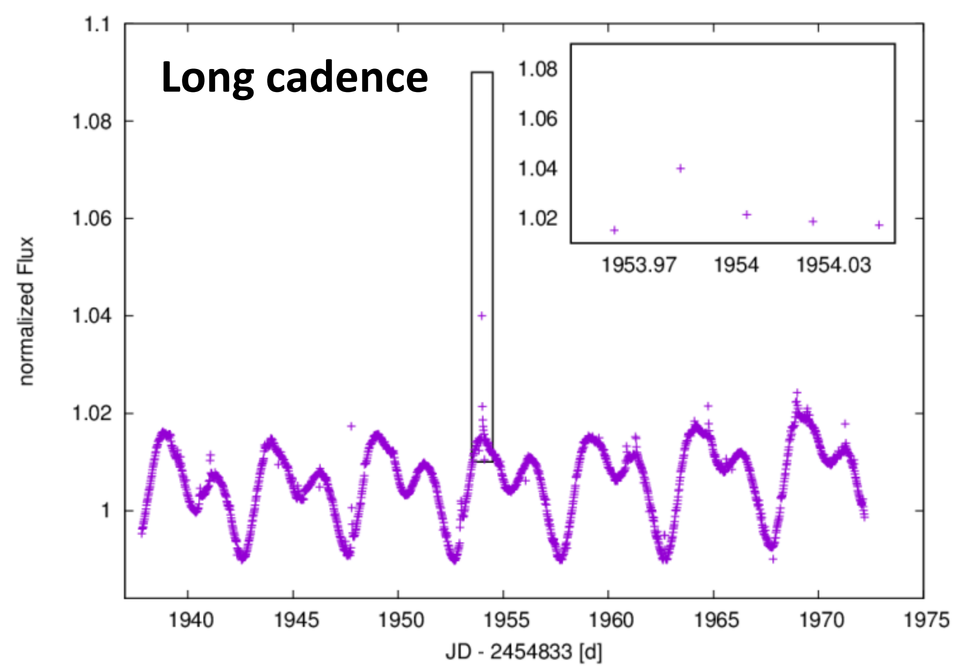
→Flare detection biased towards long and strong flares

Short cadence (1 min):

- Rise time for most flares in the order of a few minutes

→ very little information about morphology





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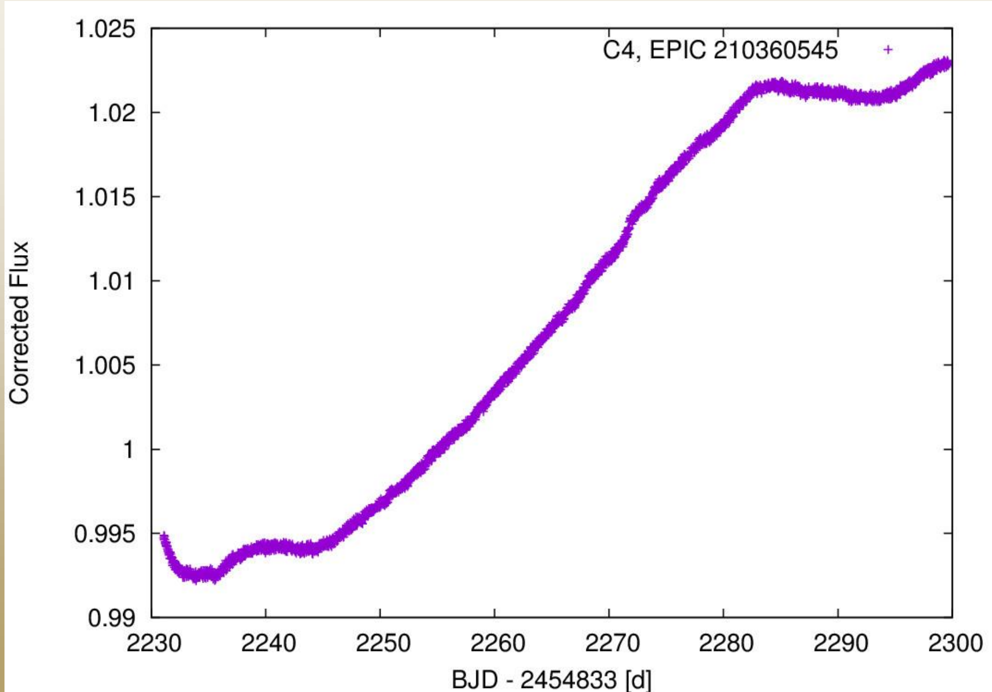
Observational Baseline:

Of the detected rotation periods:

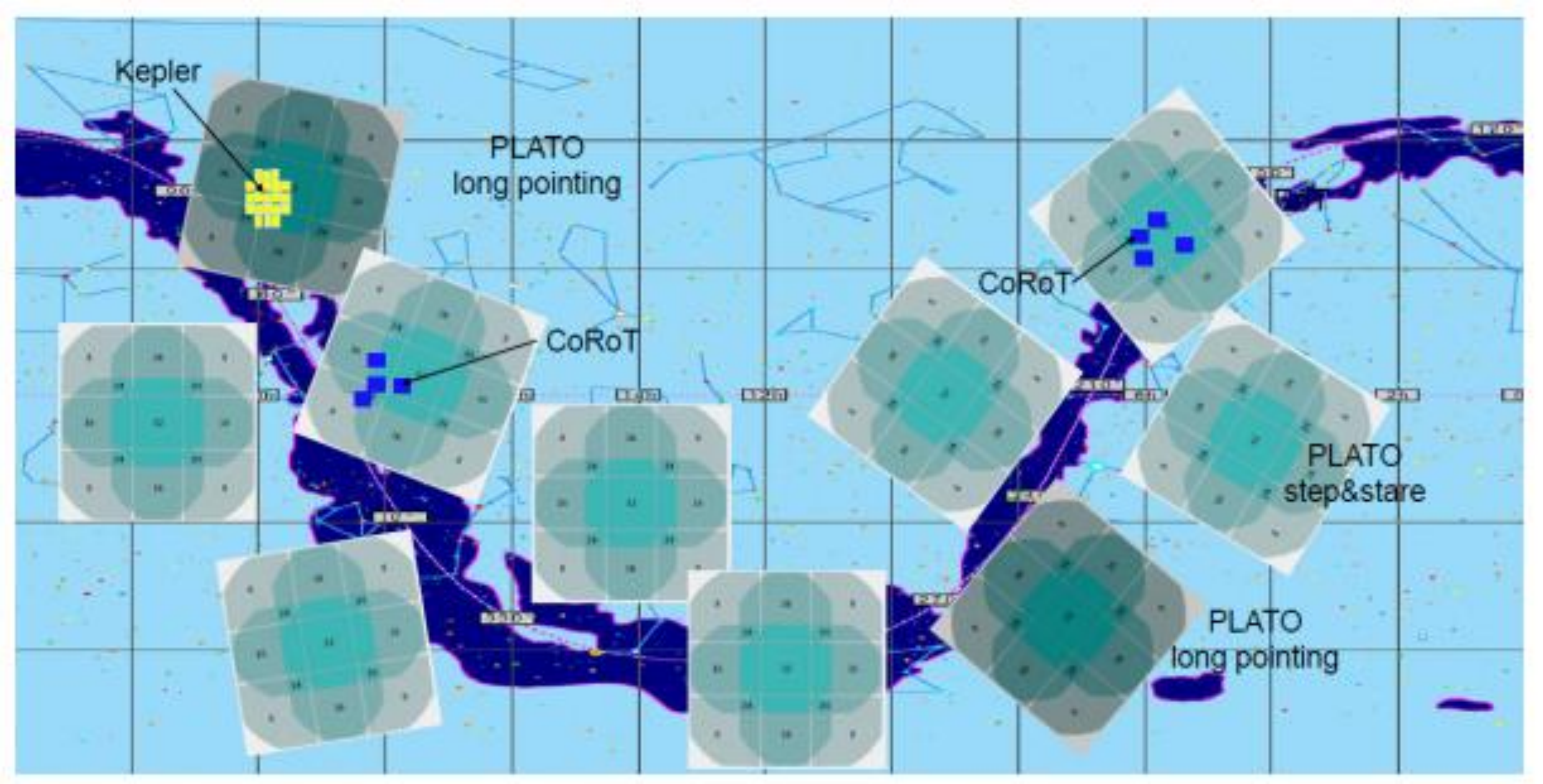
~ 70% shows periodic variability on time-scales up to ~ 100 d

~ 10% of the periods are > 70 d

→ K2 campaign duration of ~80 d too short to characterize long periods

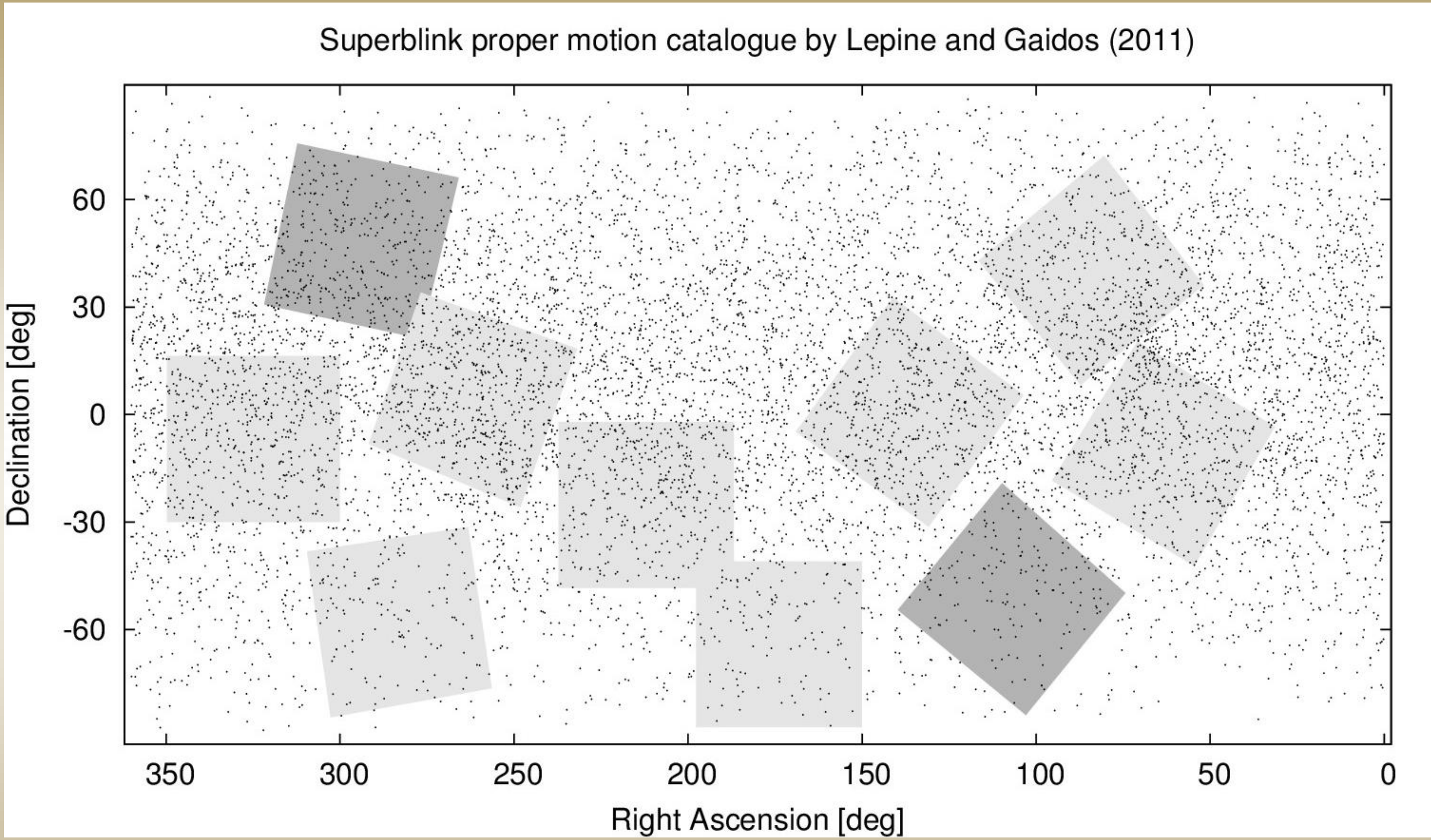


PLATO Observations of M dwarfs



PLATO Yellow book (2013)

PLATO Observations of M dwarfs

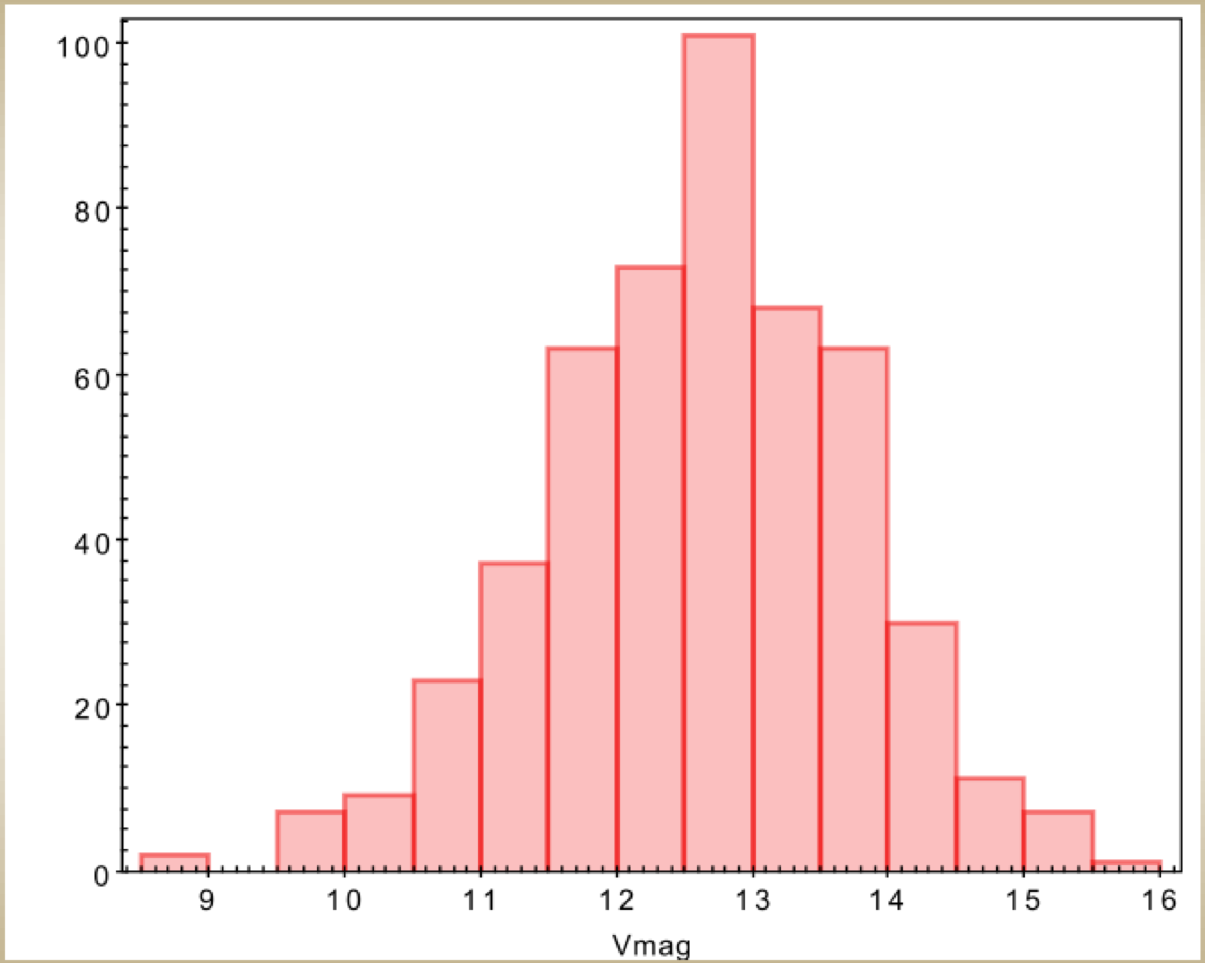


PLATO will observe on the order of ~3500 M dwarfs from the Superblink cataloque

will provide light curves with noise level < 800 ppm with rotation periods up to hundreds of days

PLATO Long Fields

~500 M dwarfs from the Superblink cataloque will be observed in the PLATO Long Fields



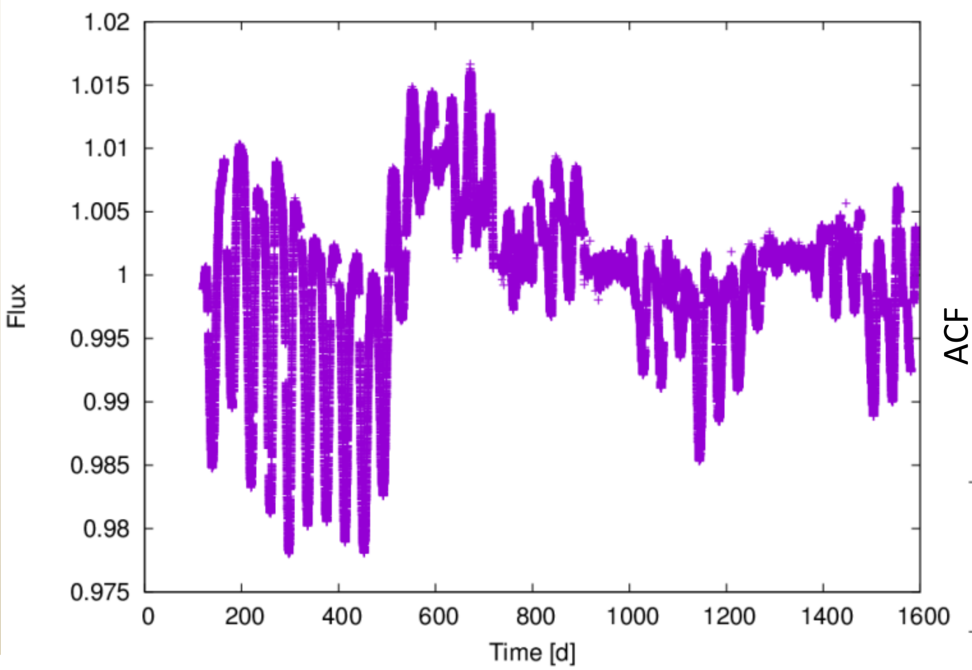
~10% with V < 11mag → light curves with noise level 34ppm; periods up to ~2 years
→ low amplitudes and long periods will be detectable for this subsample

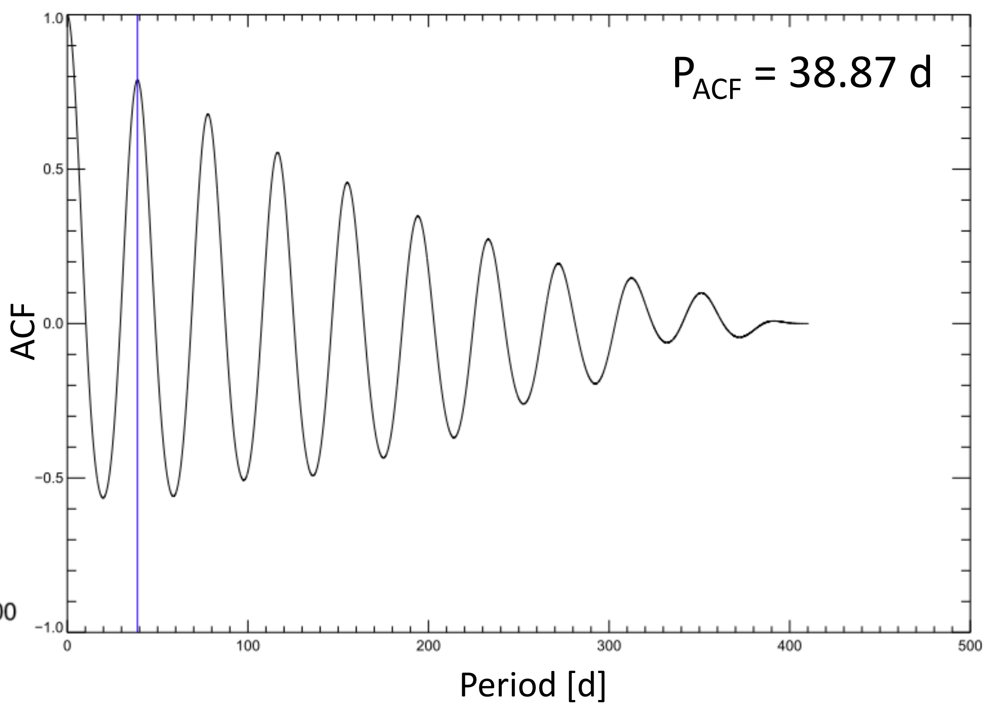
Simulation of PLATO light curves with Flares

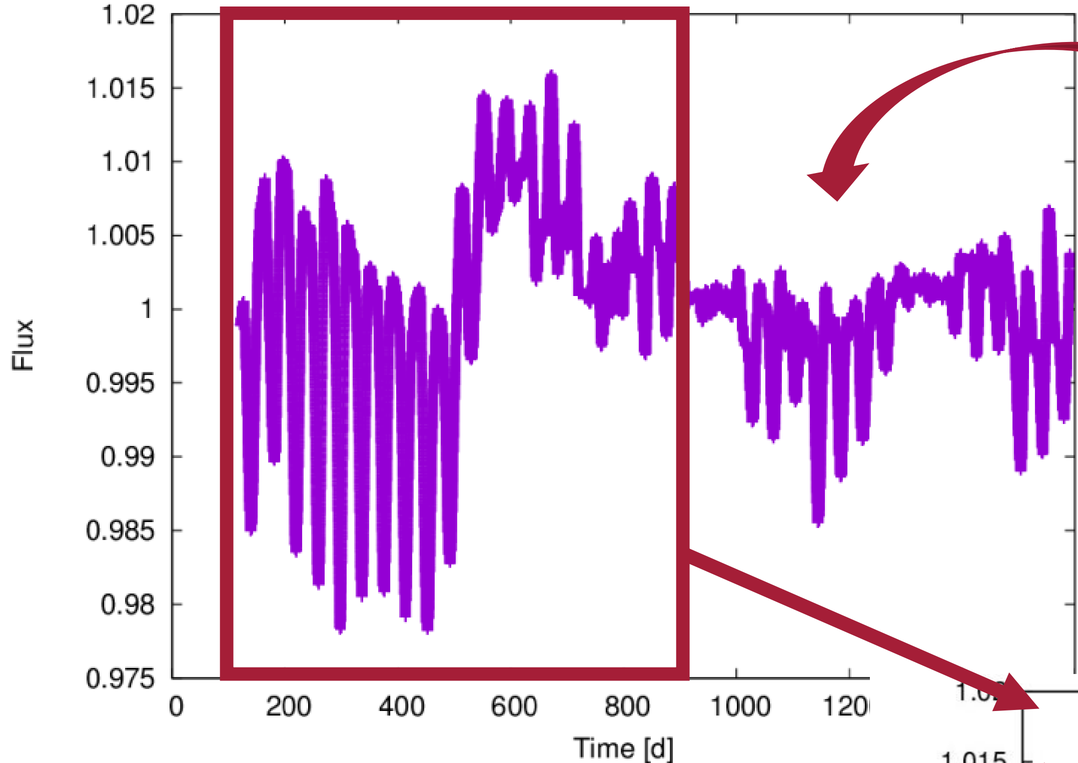
First preliminary Example:

Based on Kepler light curve of KIC 4043389

M2-dwarf, $0.62R_{\odot}$, $0.62M_{\odot}$
Kep = 11.38 mag
Rotation period: P ~ 39d
Observed by Kepler in 18 Quarters (LC)





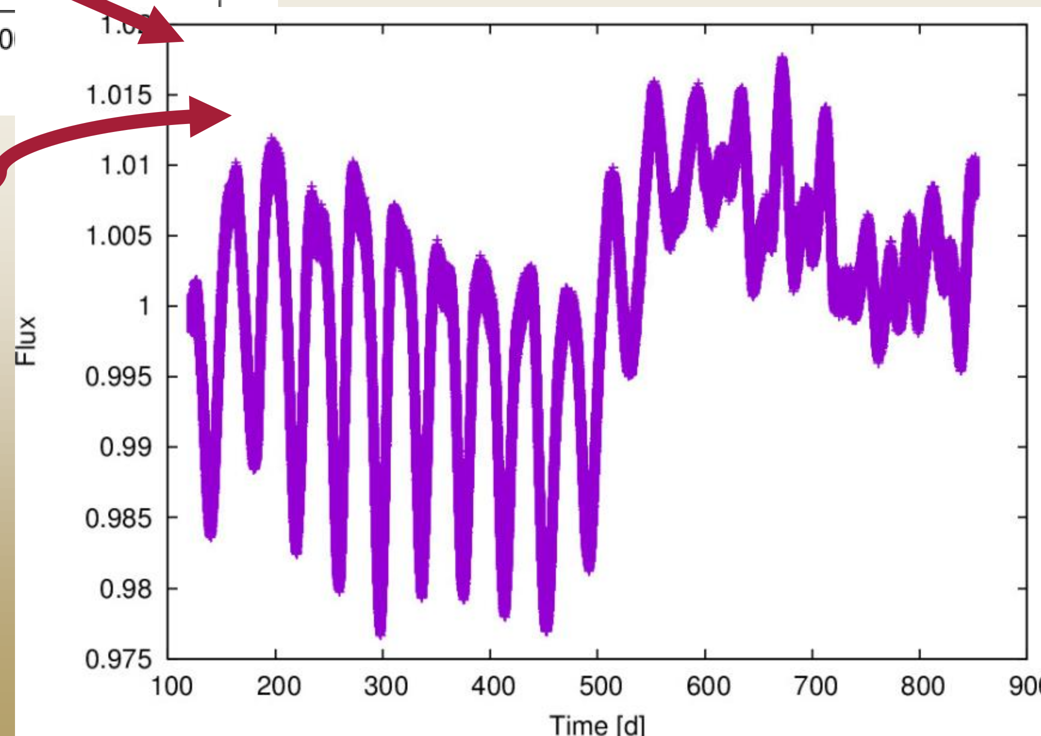


Theoretical light curve:

- Based Kepler light curve
  - Long cadence
  - 4 yr observation
- Smoothed
- Outliers removed
- Gaps interpolated

Simulated PLATO light curve:

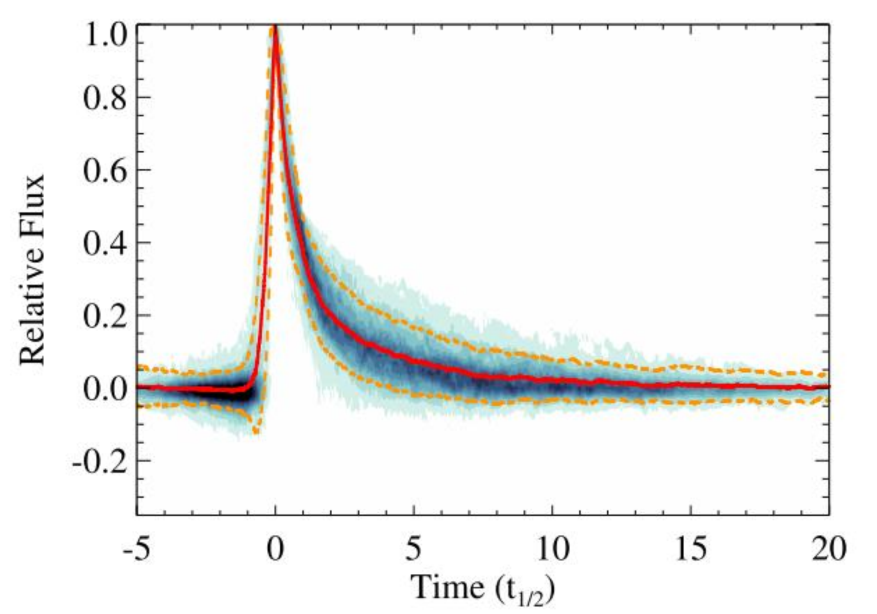
- Noise simulated with the PSLS
  ('PLATO solar-like light curve simulator',
  Samadi 2015)
- Noise added to theoretical light curve
- 730 d continous observations
- Interpolated to 25s cadence
  - ➢ ~2.5*10^6 data points

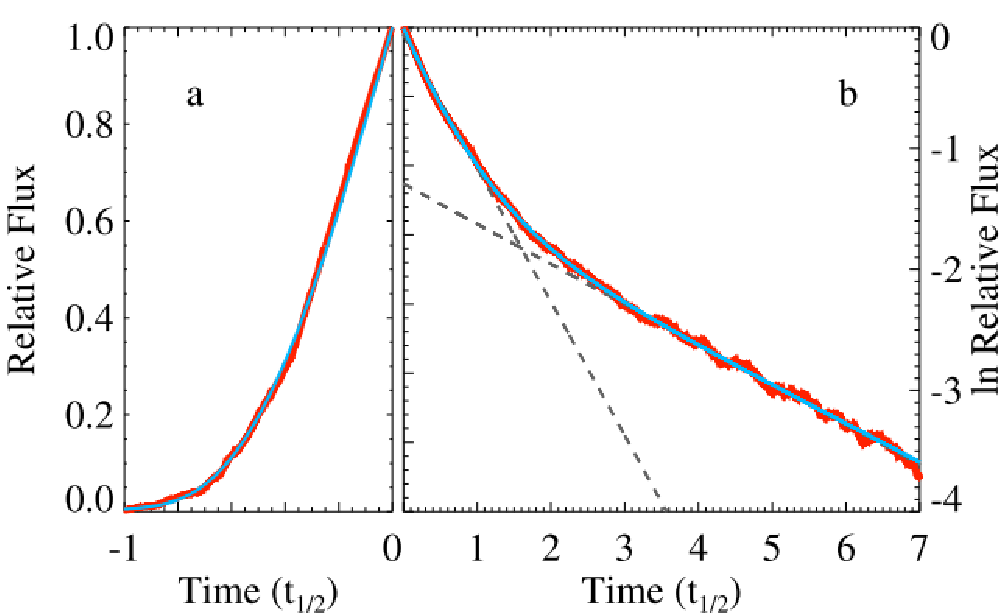


Empirical Flare Template

Davenport et al. (2014)

- 885 'classical' flares of active M4 dwarf GJ 1243 observed with Kepler were used to construct a template
- Template is scaled to relative time/amplitude
- a single timescale was used for the template





Rise: 4th order polynomial

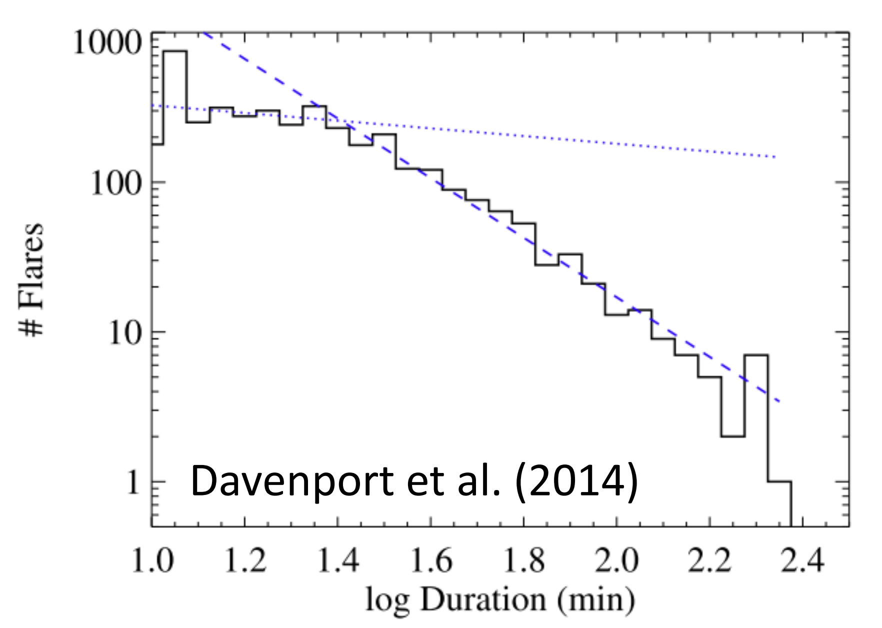
$$F_{\rm rise} = 1 + 1.941(\pm 0.008)t_{1/2} - 0.175(\pm 0.032)t_{1/2}^2 - 2.246(\pm 0.039)t_{1/2}^3 - 1.125(\pm 0.016)t_{1/2}^4$$

Decay: a two-phase model, continuous function (sum of two exponential curves)

$$F_{\rm decay} = 0.6890(\pm 0.0008)\, e^{-1.600(\pm 0.003)\, t_{1/2}} + 0.3030(\pm 0.0009)\, e^{-0.2783(\pm 0.0007)\, t_{1/2}}$$

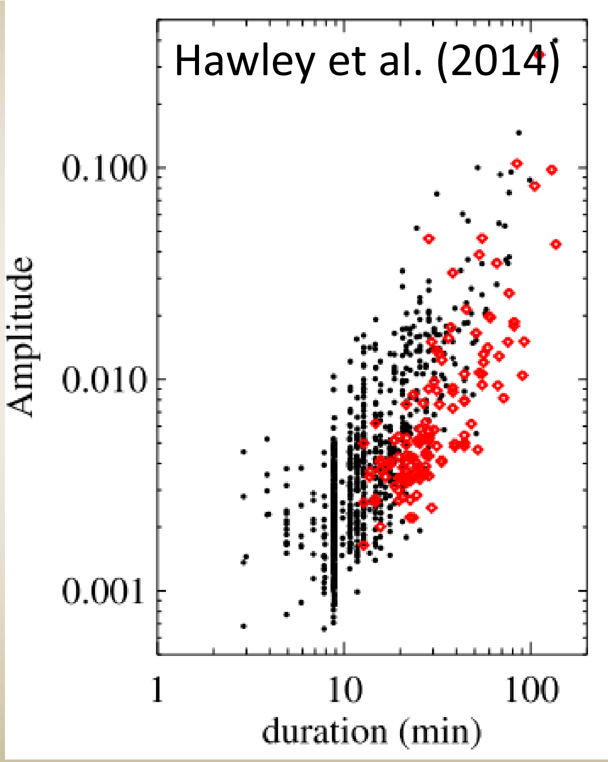
Input parameters for Flare simulations

1. Flare duration: power law distribution



2. Flare amplitude:

$$Amplitude = (F_{peak} - F_{localmean})/F_{localmean}$$



3. Flare rate:

0.11 Flares/day (Stelzer et al. 2016)
(note: Flare rate lower limit)
→ ~ 80 Flares in PLATO light curve

100 different sets of flares for this M-dwarf light curve were simulated
→ ~8000 simulated Flares

Input parameters for Flare simulations

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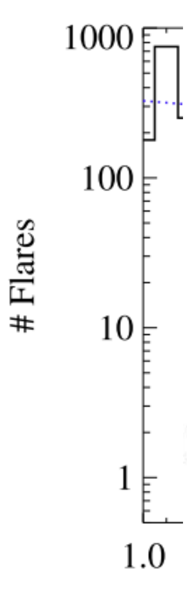

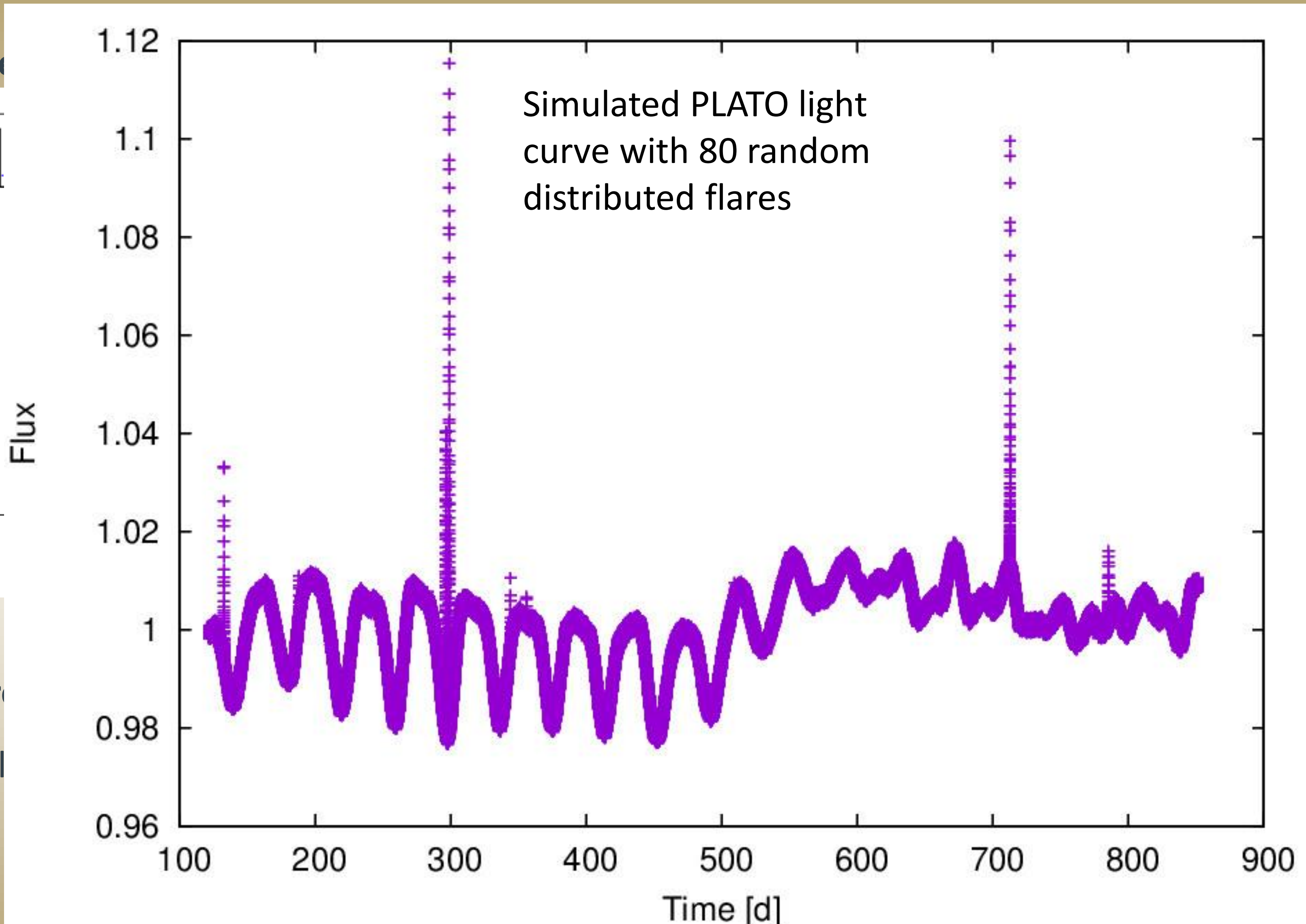

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(note:

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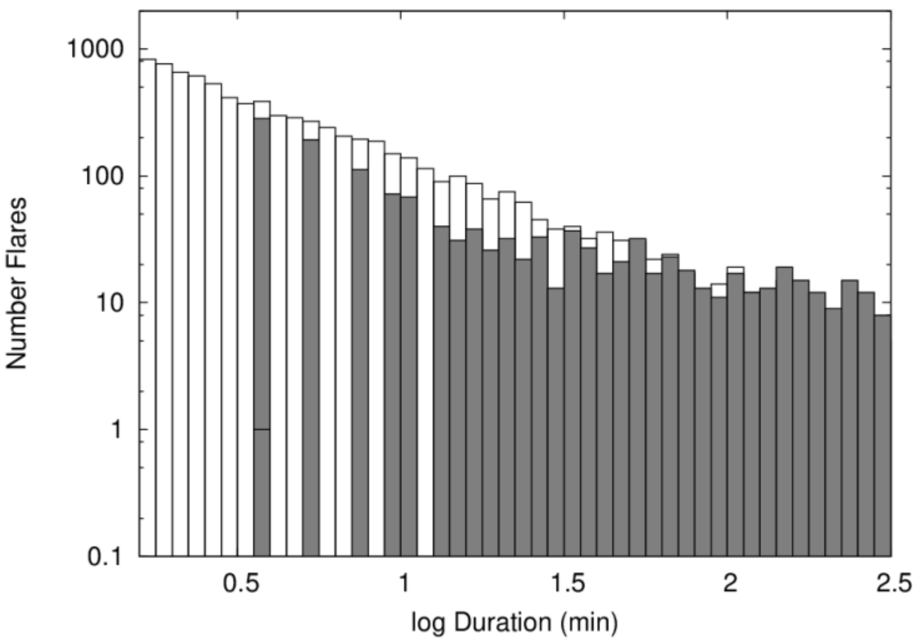
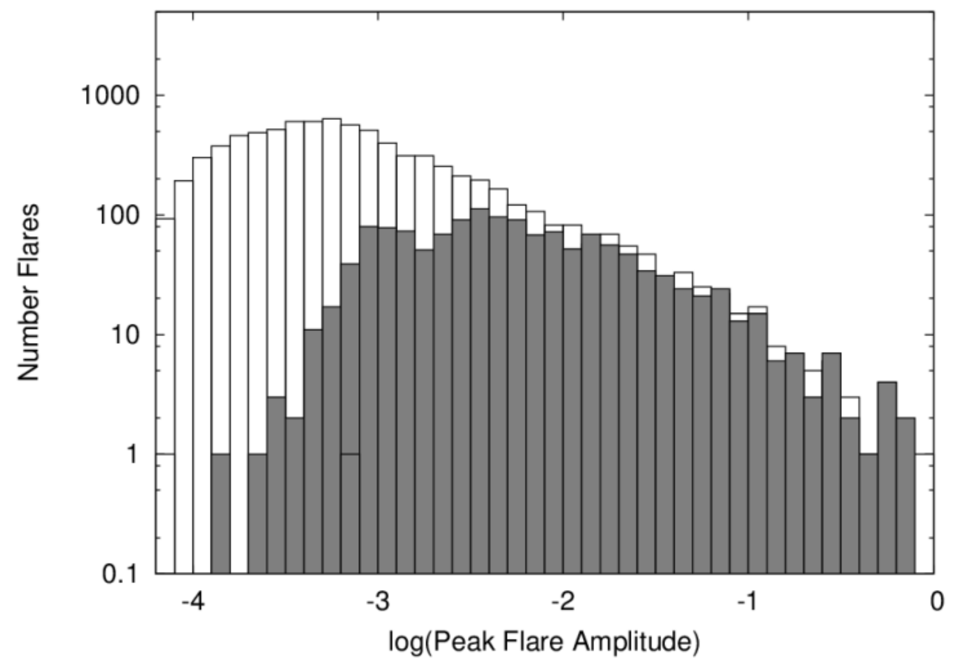
Preliminary results of the Flare simulations





- Only ~17% of the injected flares were recovered by the detection algorithm
- Short Flares down to ~ 3min duration were detected
- Most low amplitude flares up to a peak flare amplitude of 0.025 are missed
- (Detection algorithm underestimates duration, artificially corrected by factor of ~4.5)

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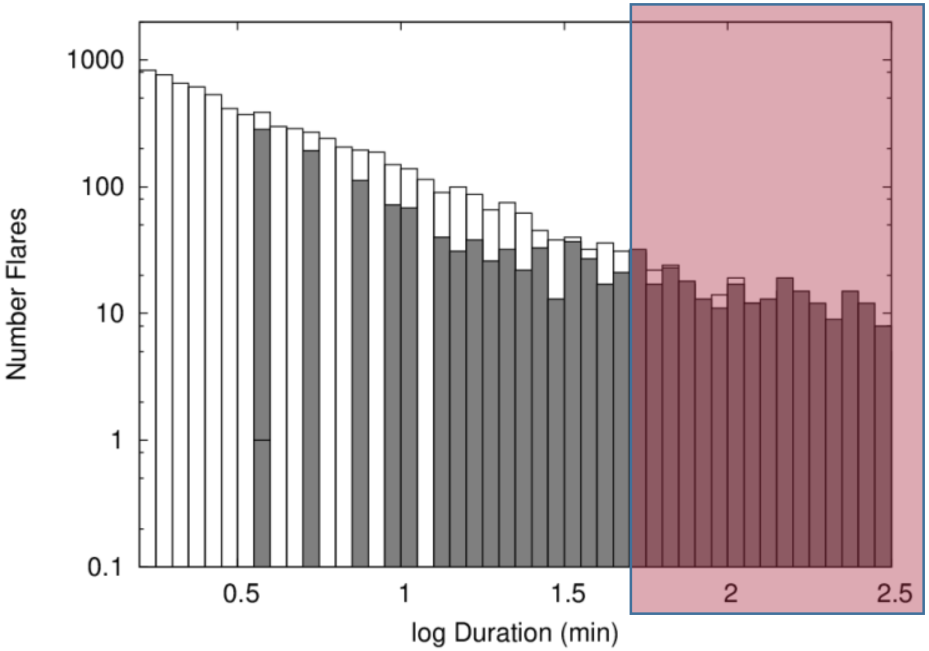

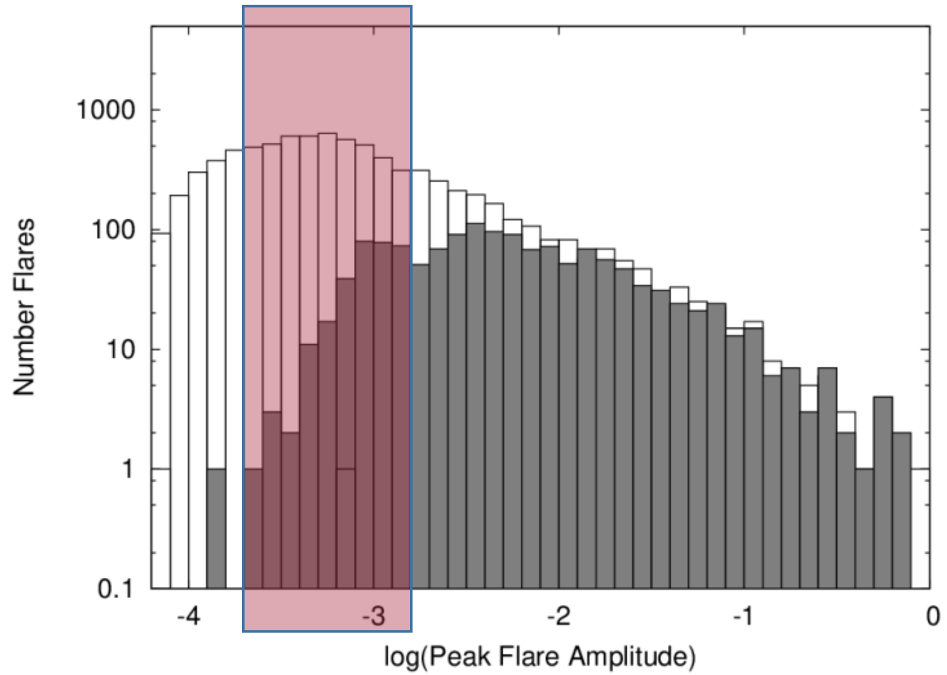

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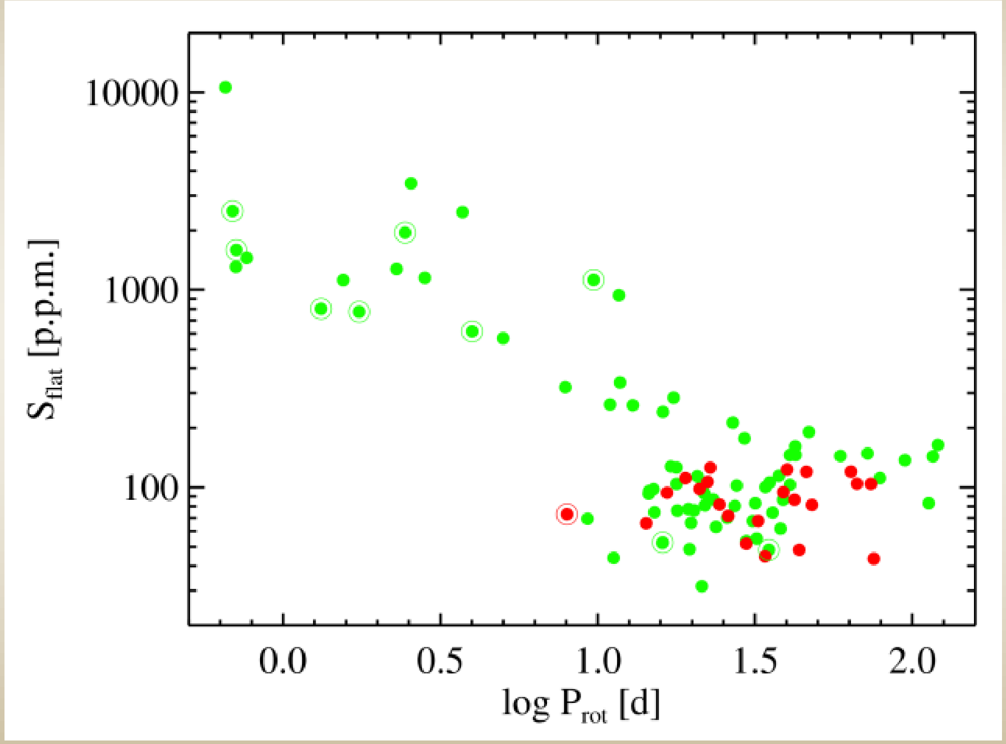
- Detected flares: original Kepler light curve

Conclusions

- rotation, activity and variability study of nearby M dwarfs observed in K2 campaigns C0–C8
- transition between the saturated and correlated regime was found to be much sharper than expected when photometric activity indicators are used
  - At a critical period of ∼10 d the spot and flare activity undergoes a dramatic change
- With PLATO it will be possible to characterize the transition at the critical period of ∼10 d in up to now unprecedented detail

Outlook

- Flare detection code will be optimized for short cadence data
- Investigating the astrophysical in origin of the residual variability S_{flat}



– The standard deviation of the “flattened” lightcurves (after removal of spot and flare variations)
– The bimodal distribution suggests that there is a contribution to the ‘noise’ in the K2 photometry that is astrophysical in origin


Thank you
for your attention!