EBERHARD KARLS UNIVERSITÄT TÜBINGEN

Faculty of Science
Institute for Astronomy and Astrophysics

Exploring the Rotation-Activity Relation of M-type main sequence stars with PLATO

Stefanie Raetz[1]

B. Stelzer[1,2], M. Damasso[3], D. Peterson[4], D. Pizzocaro[5,6], A. Scholz[7] and S. P. Matt[8]

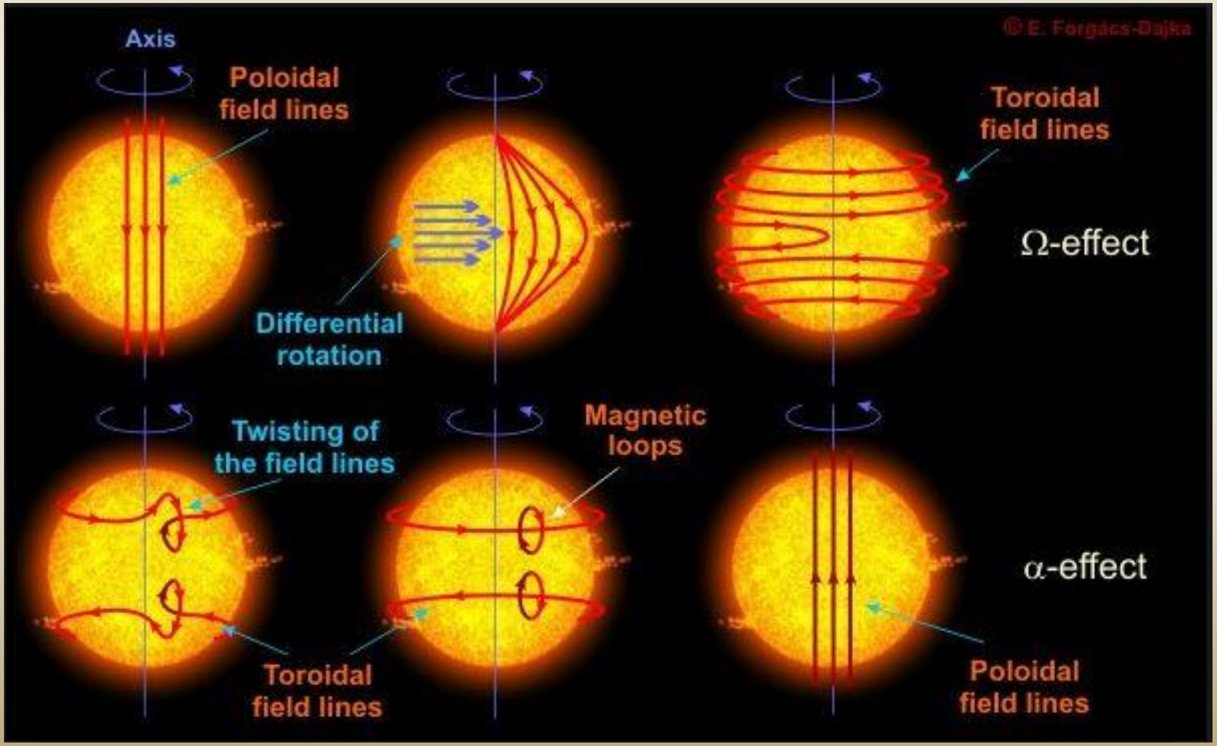
[1]IAAT Tübingen; [2]INAF/OA Palermo
[3]INAF/OA Torino; [4]Space Science Institute; [5]INAF/IASF Milano; [6]University of Insubria; [7]SUPA St.Andrews; [8]Uni Exeter

Stellar Activity

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

  - Ω-effect - shearing of the magnetic field by differential rotation
  - α-effect – lifting and twisting of the magnetic field by helical convective motions

Combining the two effects lead to the α - Ω Dynamo



→ rotation and stellar activity are intimately linked

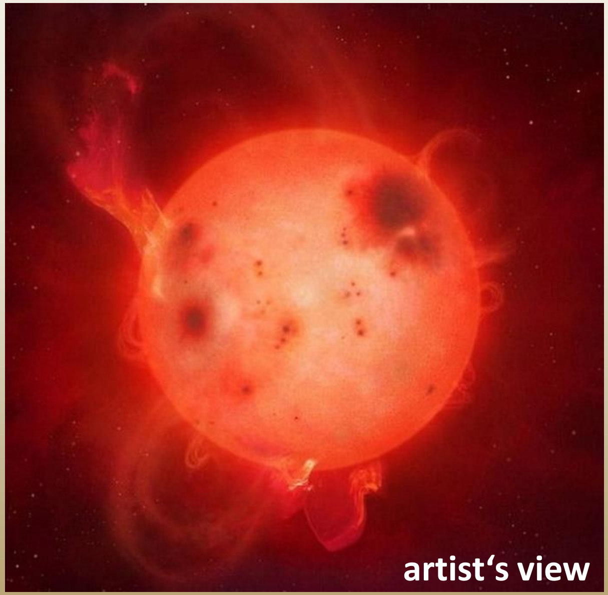
Phenomena of stellar activity

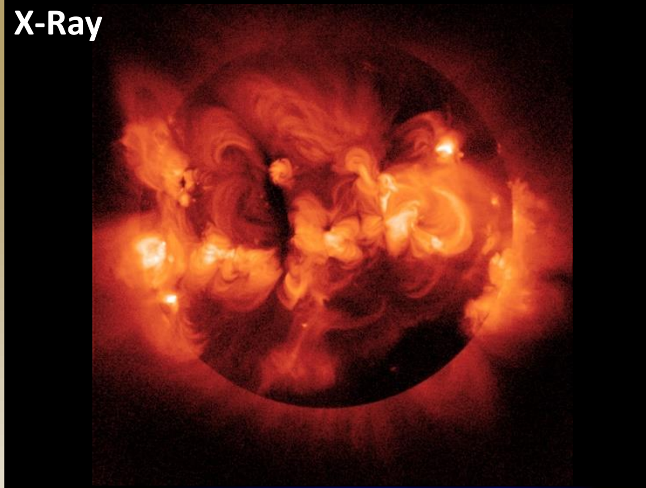
Magnetic activity effects all atmospheric layers:

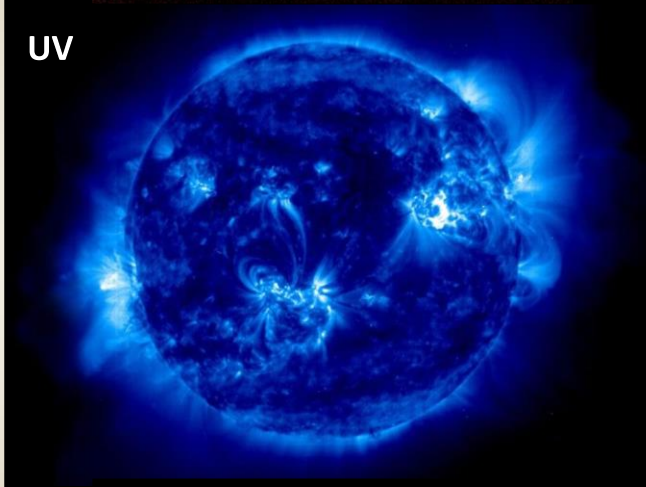
→ from the photosphere to the hot corona

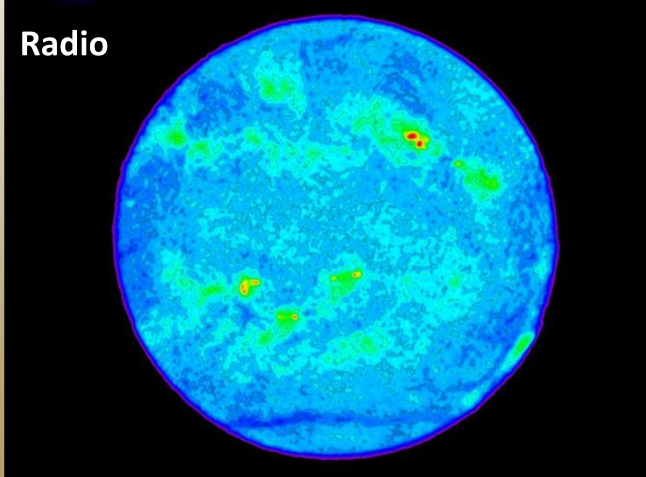
Phenomena are:

- photospheric star spots
- chromospheric line emission (e.g. Ca II , Hα)
- strong UV, X-ray, and radio emissions
- flares









The Activity-Rotation Relation

- Solar- and late-type stars generate X-rays from the corona
  → driven by the stellar magnetic dynamo (driven by differential rotation)

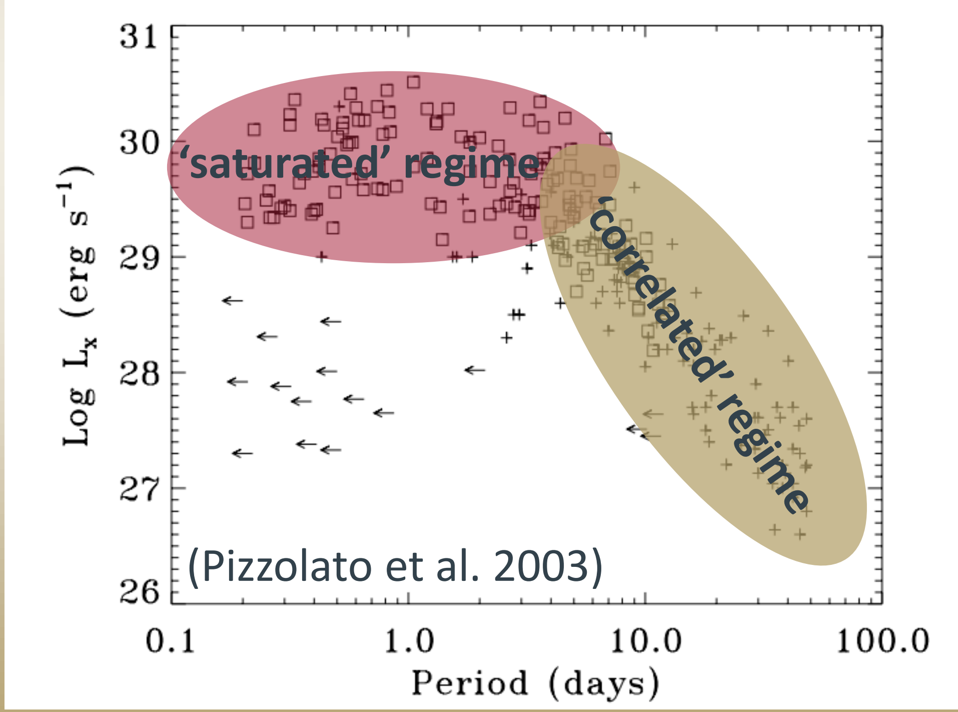
- Decrease in X-ray emission with age
  → spin-down of star --- driven by mass loss through stellar wind (Skumanich 1972)

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

- X-ray luminosity ↑ with ↓ P_{rot} ('correlated' regime) until a plateau is reached ('saturated' regime)

- The transition period increases toward later spectral types (Pizzolato et al. 2003)

  →cause is unclear



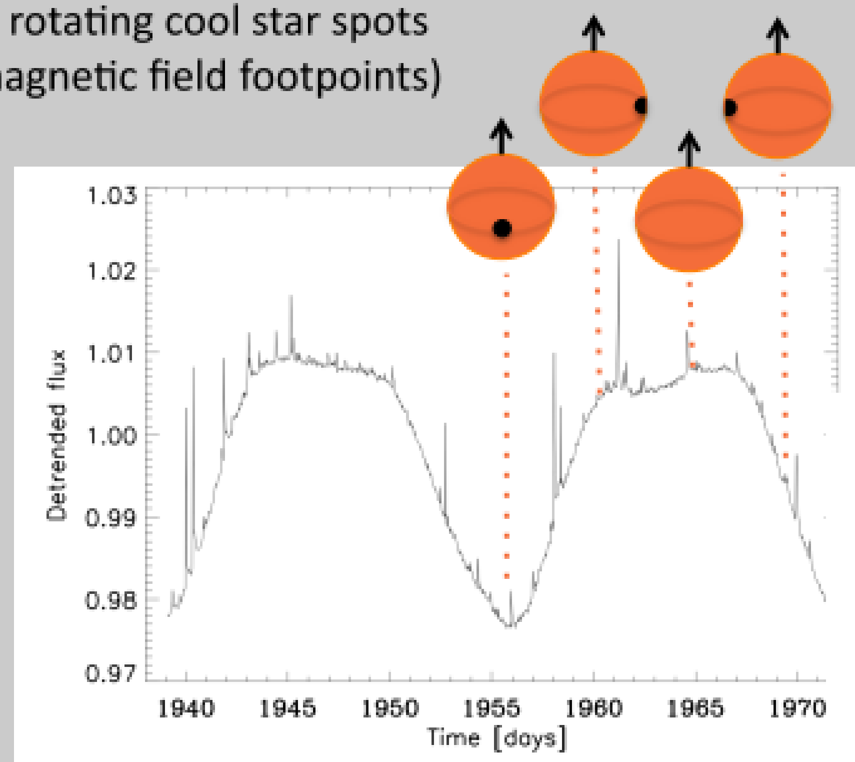
Calibrating the rotation – activity relation

rotation - activity relation has remained poorly constrained for M stars

(long periods, low spot amplitudes)

ROTATION:
Periodic brightness modulation
by rotating cool star spots
(magnetic field footprints)

Stelzer et al. (2016)

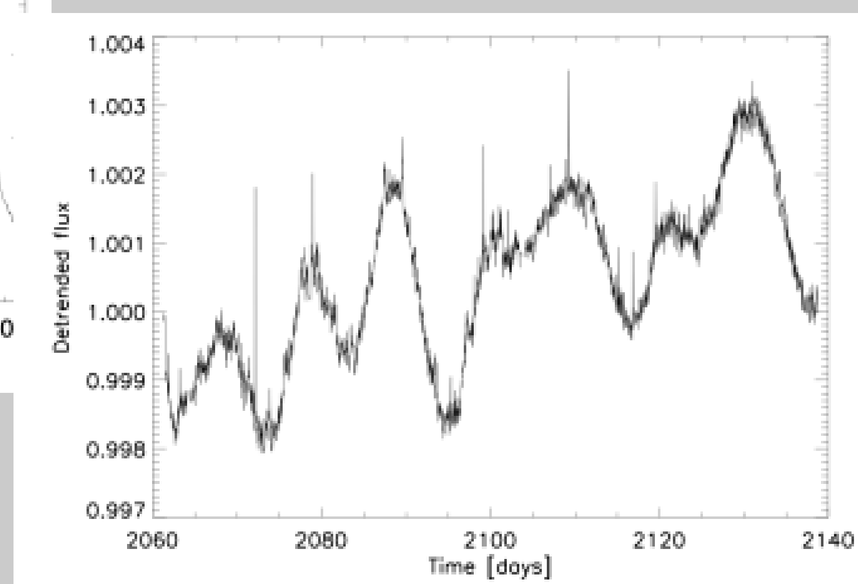


Small amplitudes of M dwarf rotation cycles
→ space-based observations:

K2-mission

ACTIVITY:
X-ray emission
from the stellar corona

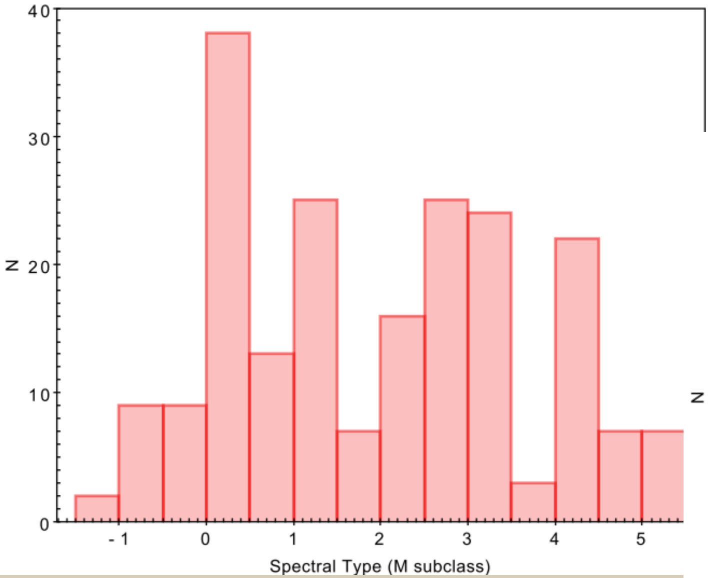
ROSAT (All-Sky Survey),
XMM archive,
Chandra follow-up,
(XMM follow-up)



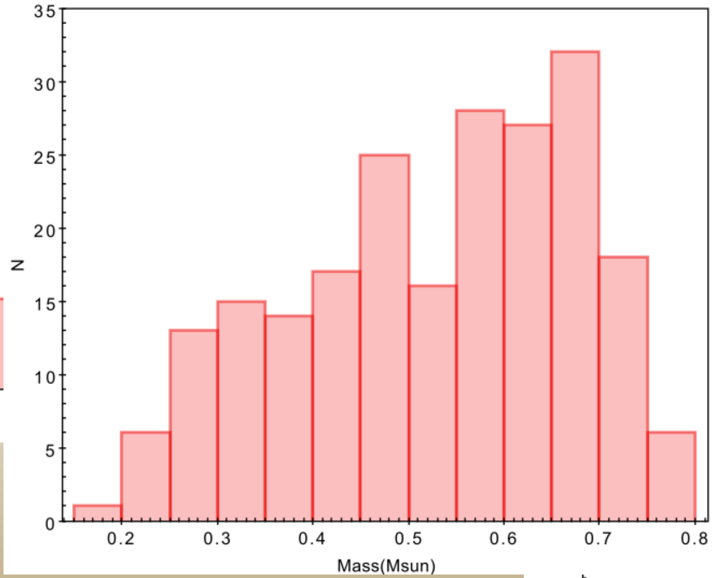
The sample

- Study is based on the Superblink proper motion catalogue by Lepine and Gaidos (2011)
- **219 M dwarfs** observed in nine K2 campaigns (Stelzer et al. 2016, C0-C4; this work, C5-C8)
- Stellar parameters derived by adopting semi-empirical calibrations from Mann et al. (2015)

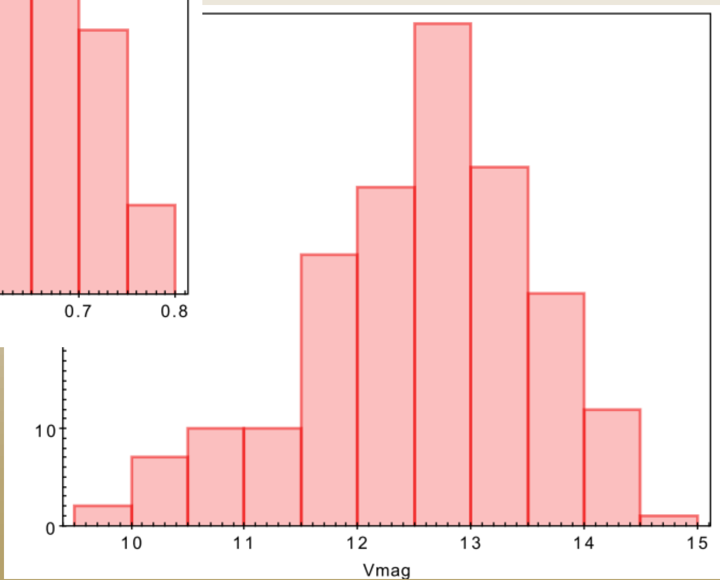
Spectral Type



Mass



Vmag



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

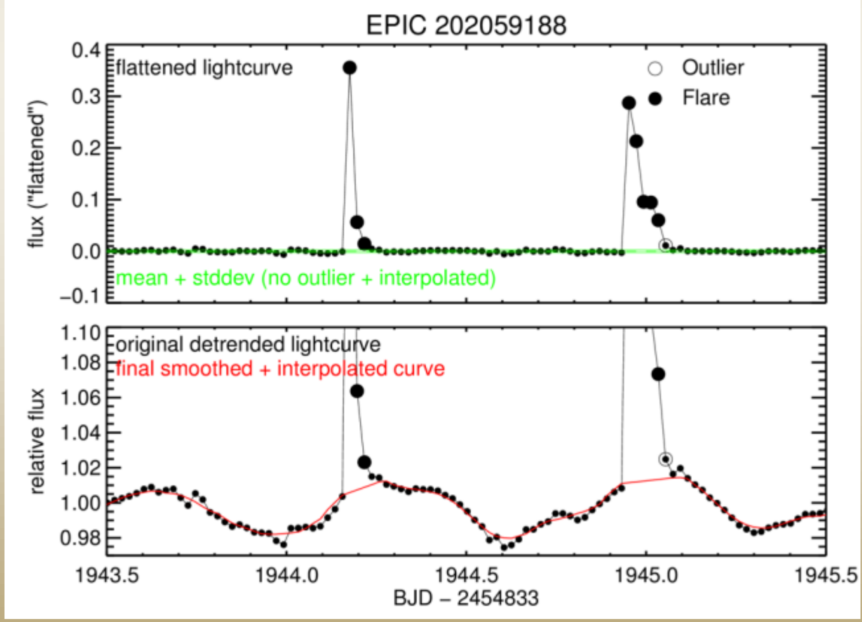
K2 DATA ANALYSIS

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)

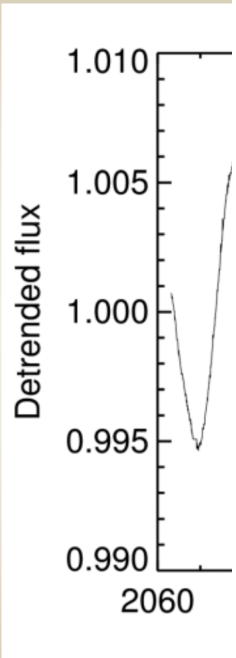


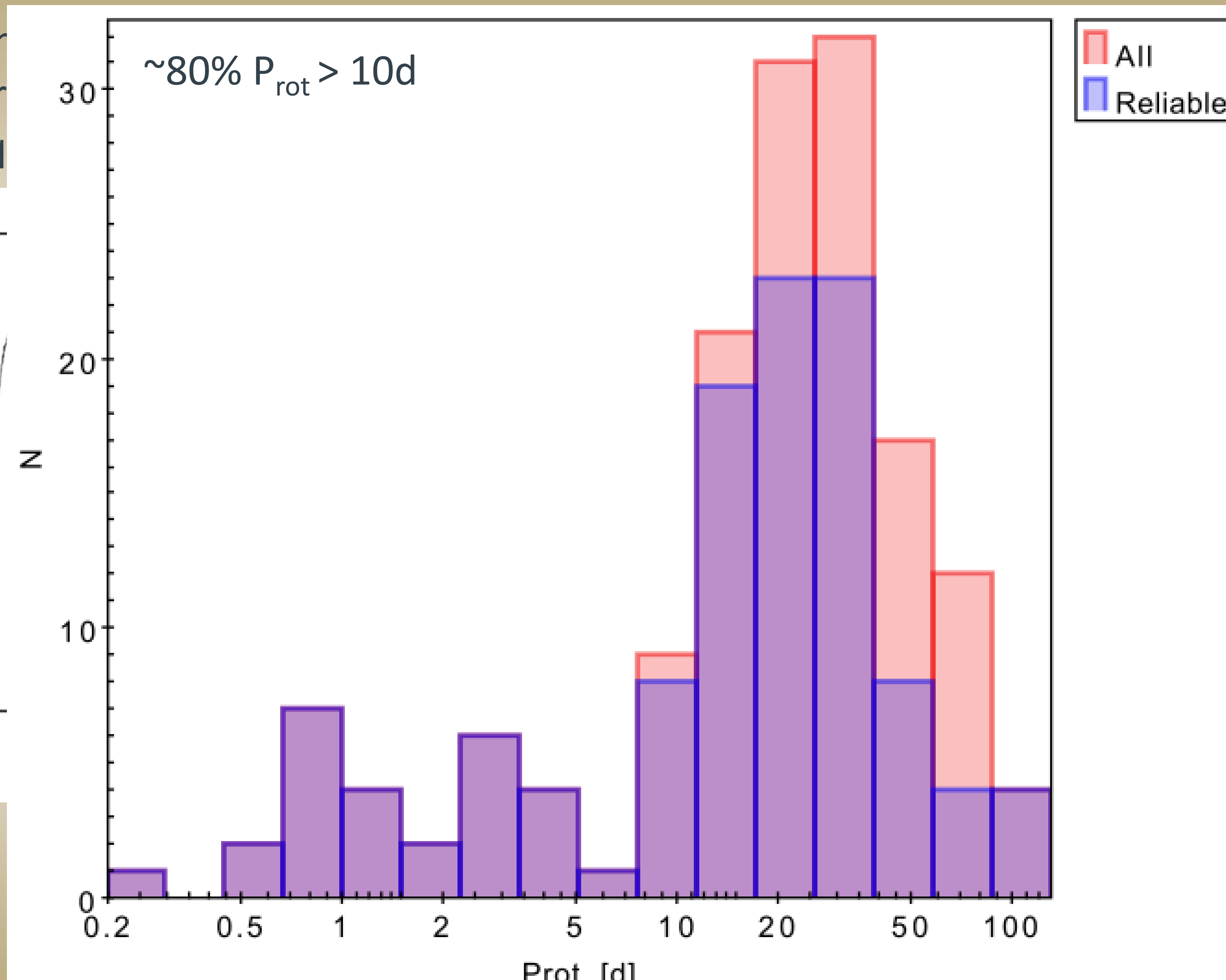
measurement of:
rotation periods, variability amplitude, flare frequency, peak flare amplitude

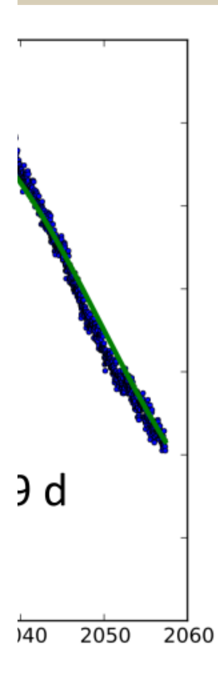
Period Search

Standard time series analysis techniques were applied:

- the Lom
- autocor
- least-sq







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

X-ray emission

systematic archive search for X-ray observations of the K2 Superblink M stars

- XMM–Newton Serendipitous Source Catalogue (3XMM-DR5; Rosen et al. 2016)
- XMM–Newton Slew Survey Source Catalogue(XMMSL1_Delta6; Saxton et al. 2008)
- the Second ROSAT Source Catalog of Pointed Observations (2RXP)
- ROSAT Bright and Faint Source catalogues (BSC and FSC)

cross-matching the K2 targets with these catalogues

→ **deriving X-ray fluxes and luminosities**

Results

Investigating photometric activity indicators

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

~ 70% shows periodic variability on time-scales up to ~ 100 d
~ 10% of the periods are longer than 70 d

McQuillan et al. (2014):

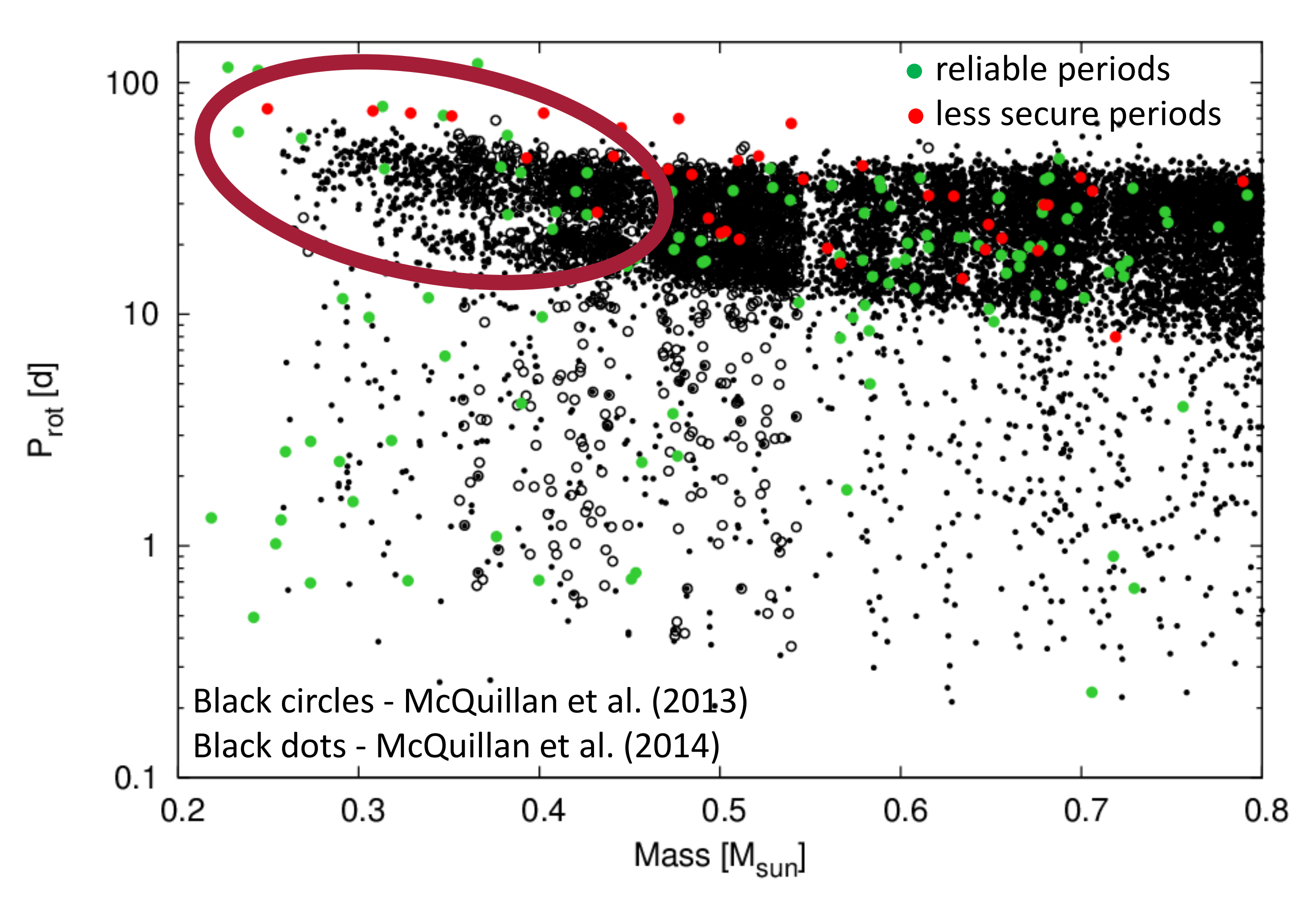
increasing upper envelope for decreasing mass

we confirm upwards trend

→ the longest periods detected towards stars with lower mass

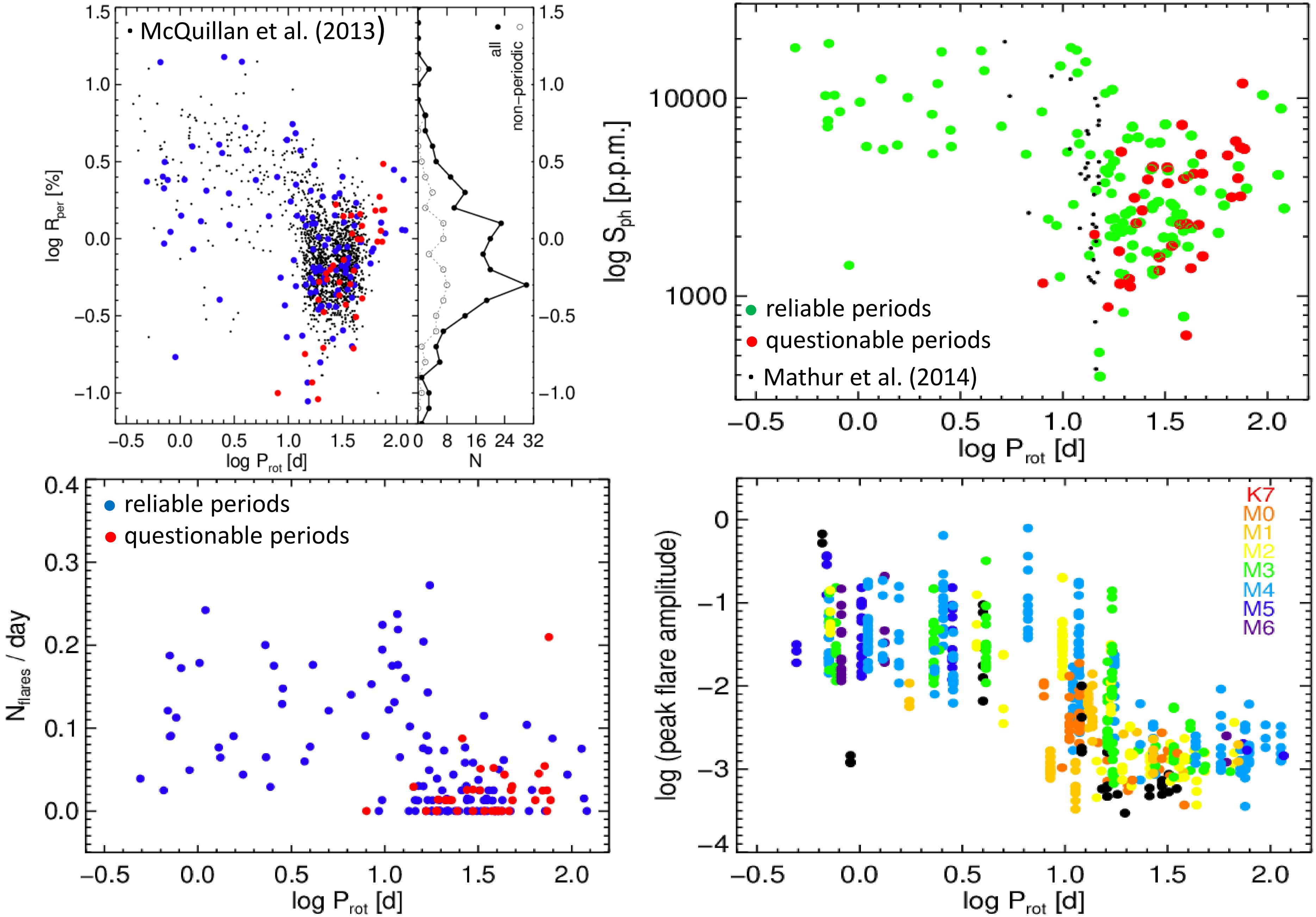
Interpretation

- mass-dependent spin-down efficiency
- mass-dependent spot properties
  → detection bias



other diagnostics for rotation and activity derived from K2 data

→ variability amplitude, flare frequency, peak flare amplitude



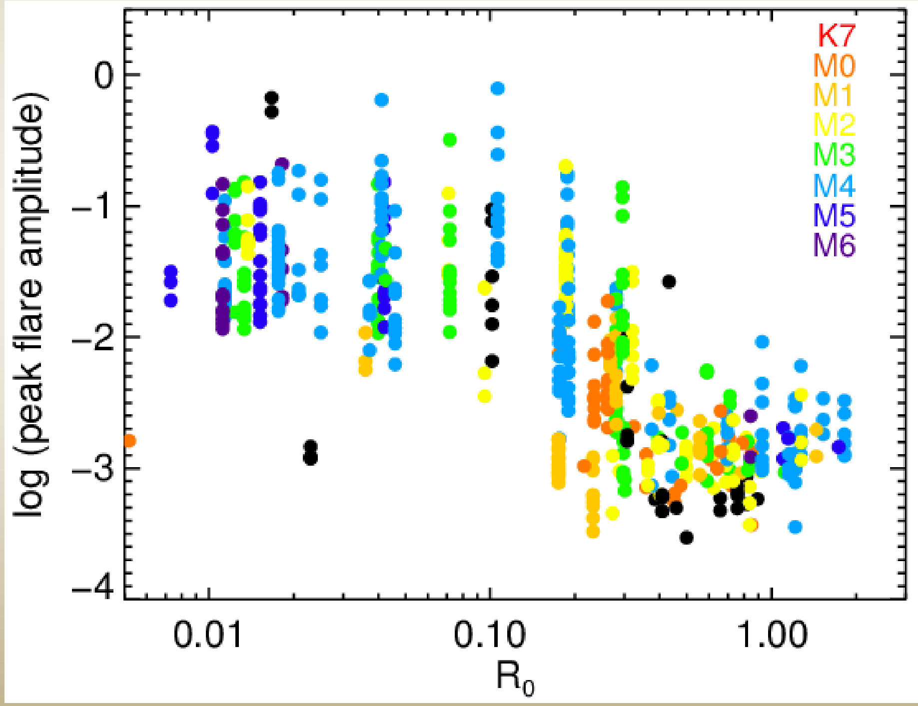
Rossby-Number characterizes the importance of rotation on fluid flow

$$R_0 = P_{rot} / \tau_{conv}$$

τ_{conv} …convective turnover time

$$\tau_c = 314.24 \exp\left[-\left(\frac{T_{\rm eff}}{1952.5\ \rm K}\right) - \left(\frac{T_{\rm eff}}{6250\ \rm K}\right)^{18}\right] + 0.002,$$

Cranmer & Saar (2011)



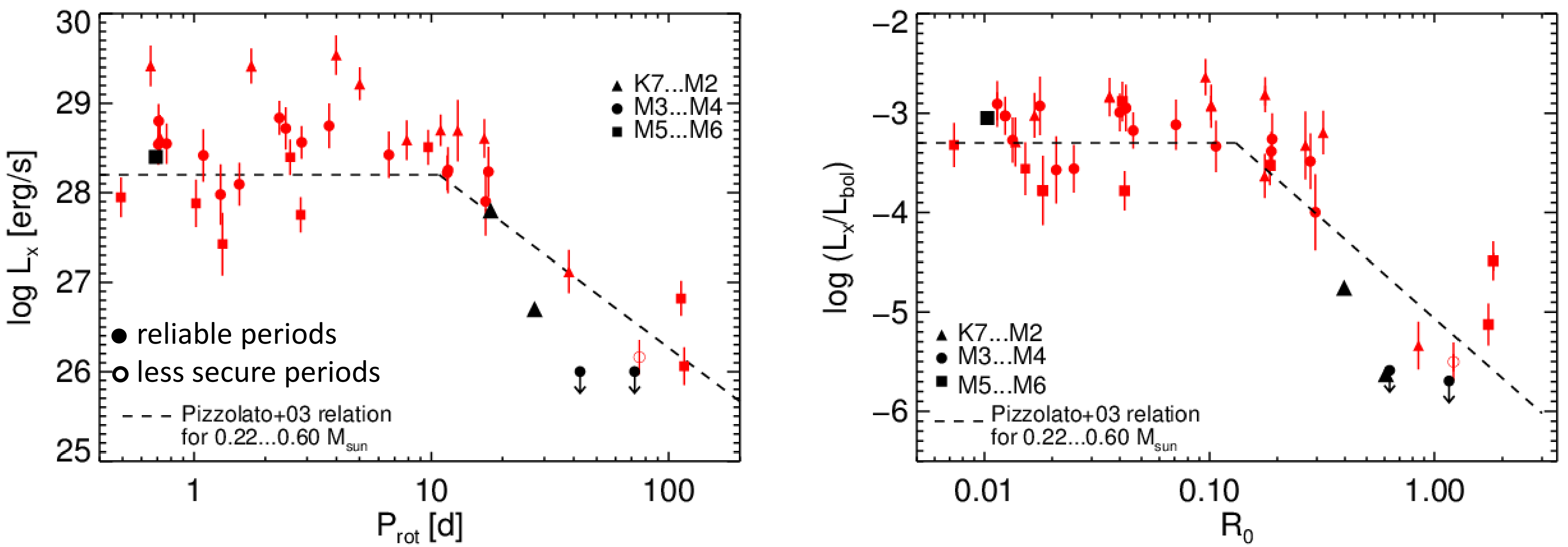
At P_{rot}~10 d the spot and flare activity undergoes a dramatic change

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

The X-ray activity–rotation relation

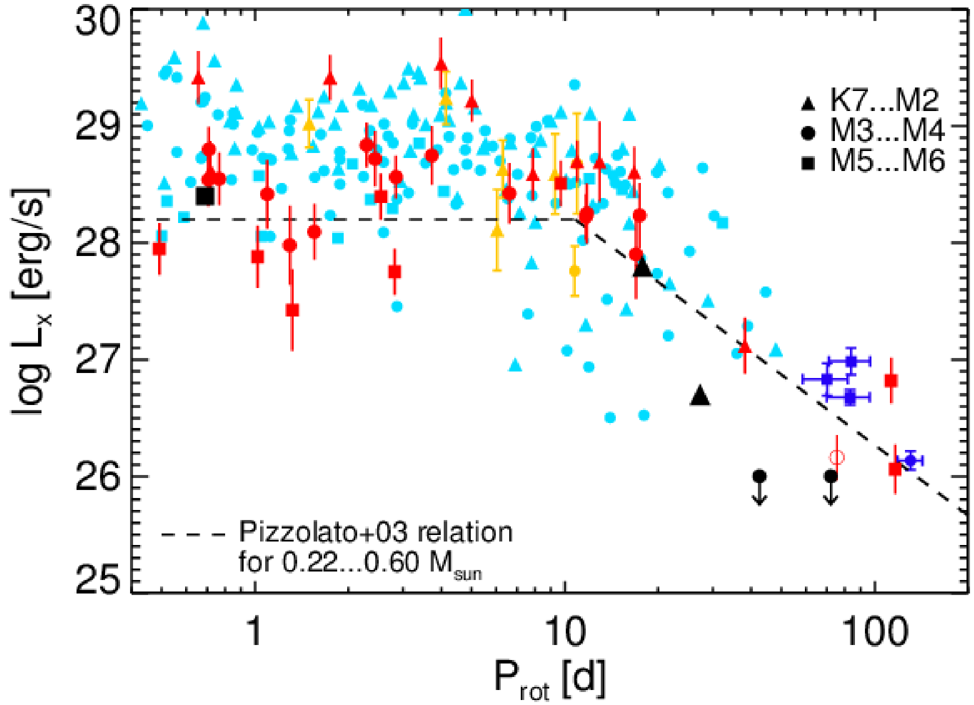
Key questions: coronal emission of M dwarfs: dramatic change or continuous decrease?

34/154 of M dwarfs with detected rotation period with X-ray detection (33/34 reliable periods)



- decrease of the activity levels for the slowest rotators
- division in a saturated and a correlated regime
- X-ray saturation turn-off corresponds to transition period seen for photometric activity
- still poorly populated for slow rotators

  → turn-over point and slope of the decaying part cannot be well constrained



Red: Stelzer et al. (2016, C0-C4) & this work (C5-C8)

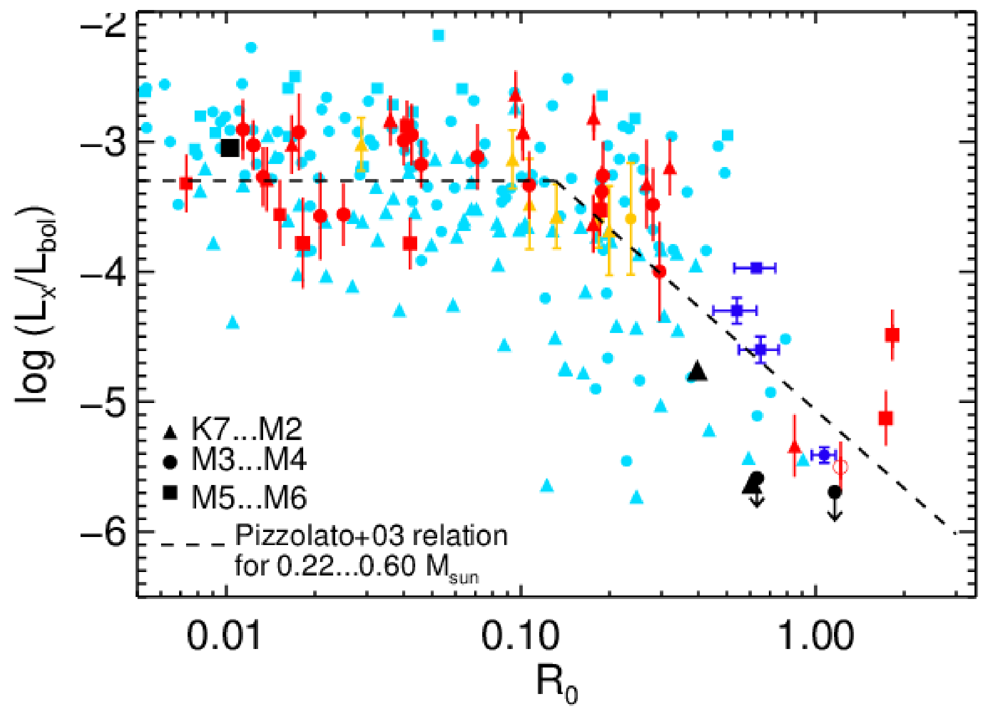
- reliable periods
- less secure periods

Black: Chandra Follow up for stars with
(1) reliable long periods
(2) Late SpT (M5..M6)
Stelzer et al., in prep.

Orange: Pizzocaro et al. (2017, submitted)

Cyan: Wright et al. (2011) Field M dwarfs

Blue: Wright & Drake (2016)

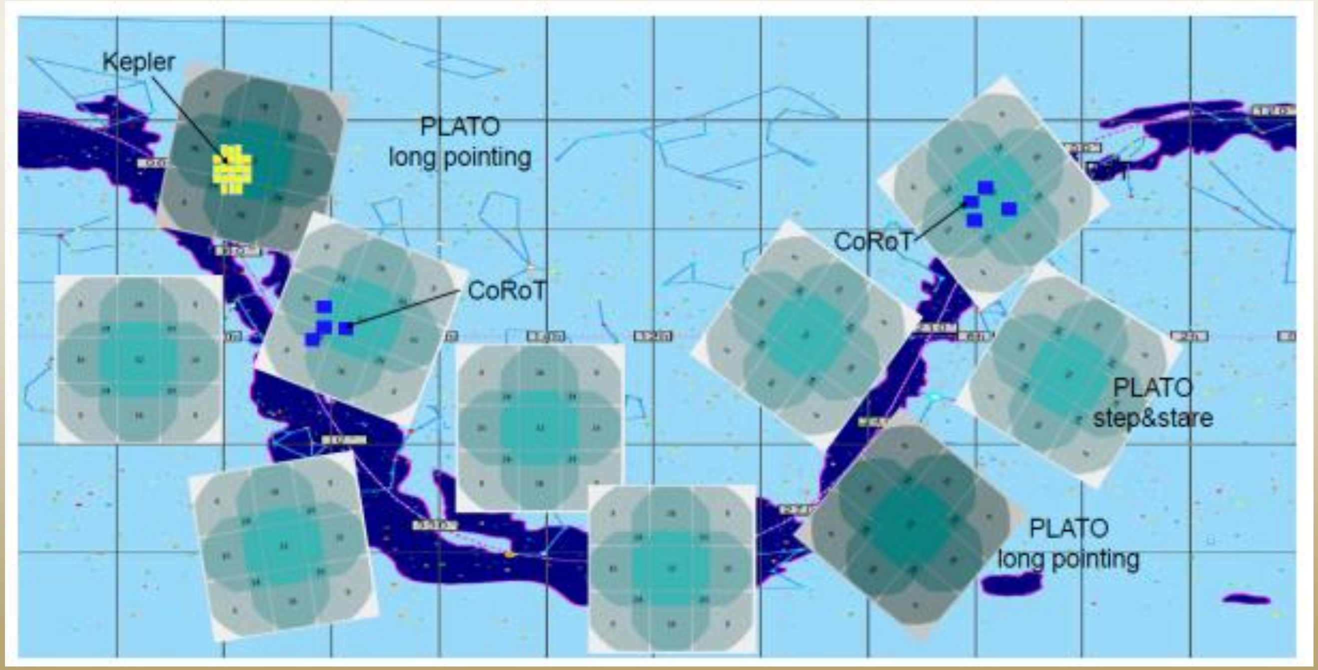


PLATO Observations of M dwarfs

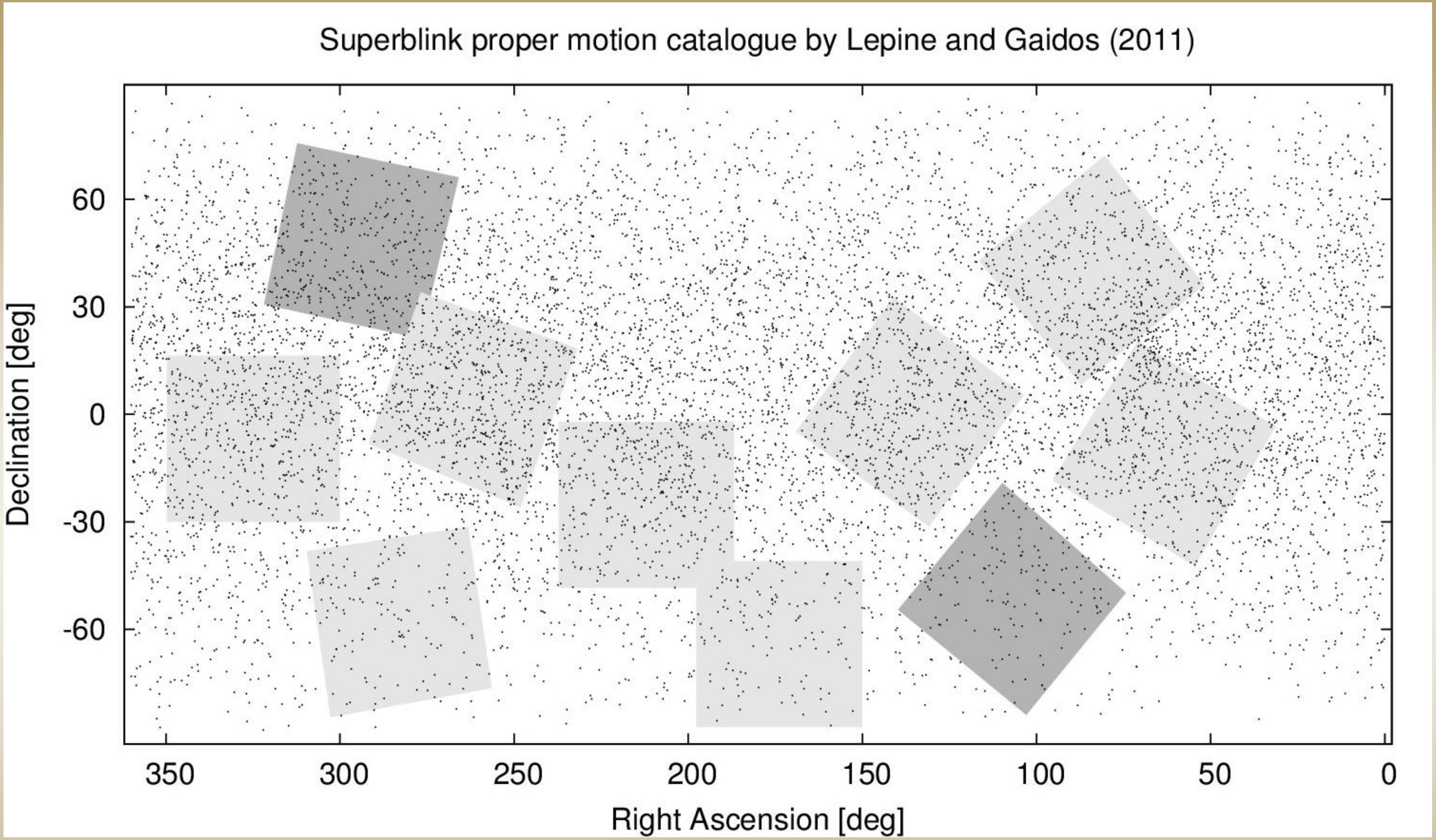
core star sample:
cool dwarf and sub giant stars that are bright enough for the photometric precision required for the detection of small planets

→ M dwarf mainly included in P1, P4 and P5 target sample:

P1: highest priority sample: noise level below 34 ppm in 1 hour, $8 \leq m_V \leq 11$
P4: cool dwarfs brighter than $m_V = 16$, noise level better than 800 ppm
P5: 80 ppm in 1 hour, $8 \leq m_V \leq 13$



PLATO Yellow book (2013)

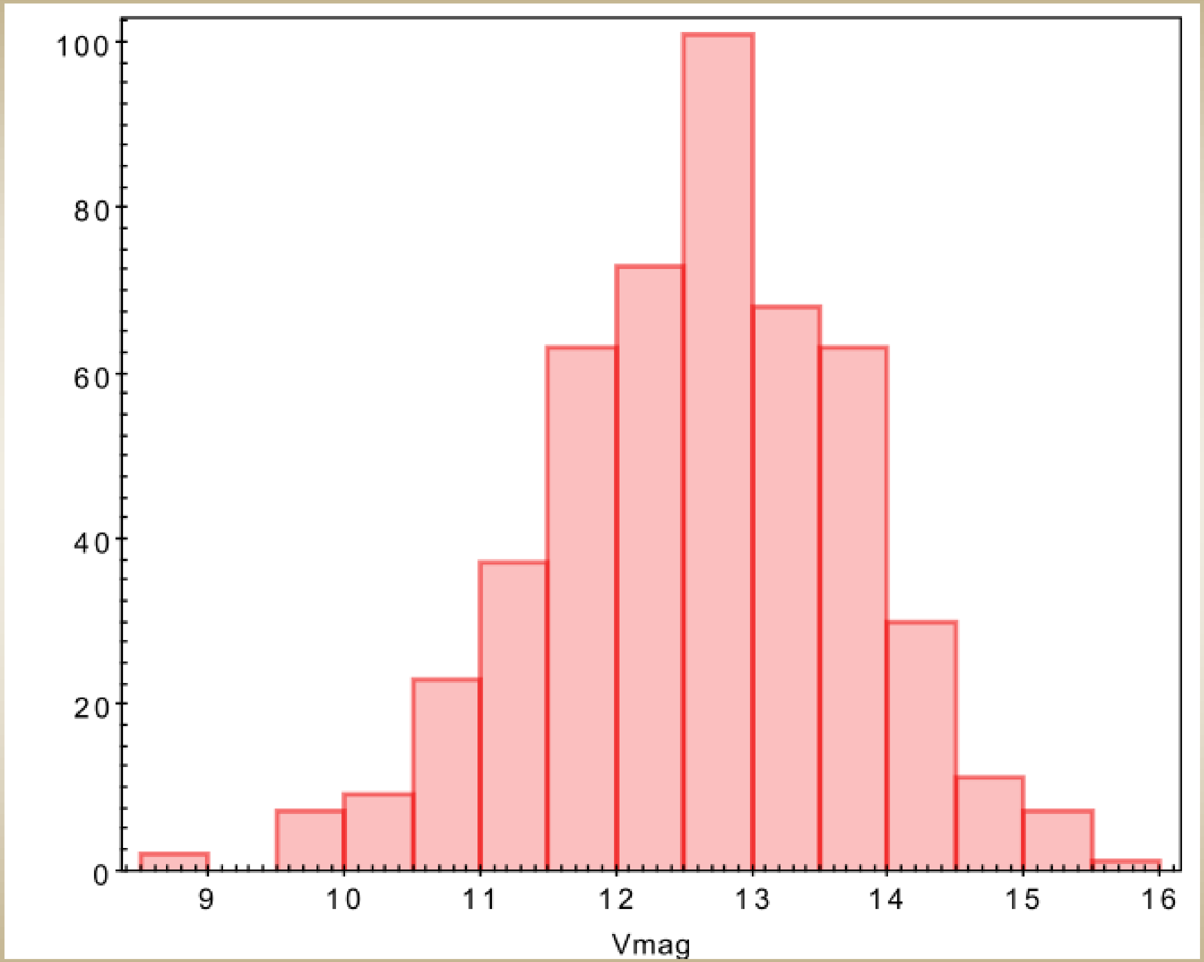


PLATO will observe in the order of ~3500 targets from the Superblink cataloque

PLATO will provide LCs with noise level < 800 ppm with rotation periods up to hundreds of days

PLATO Long Fields

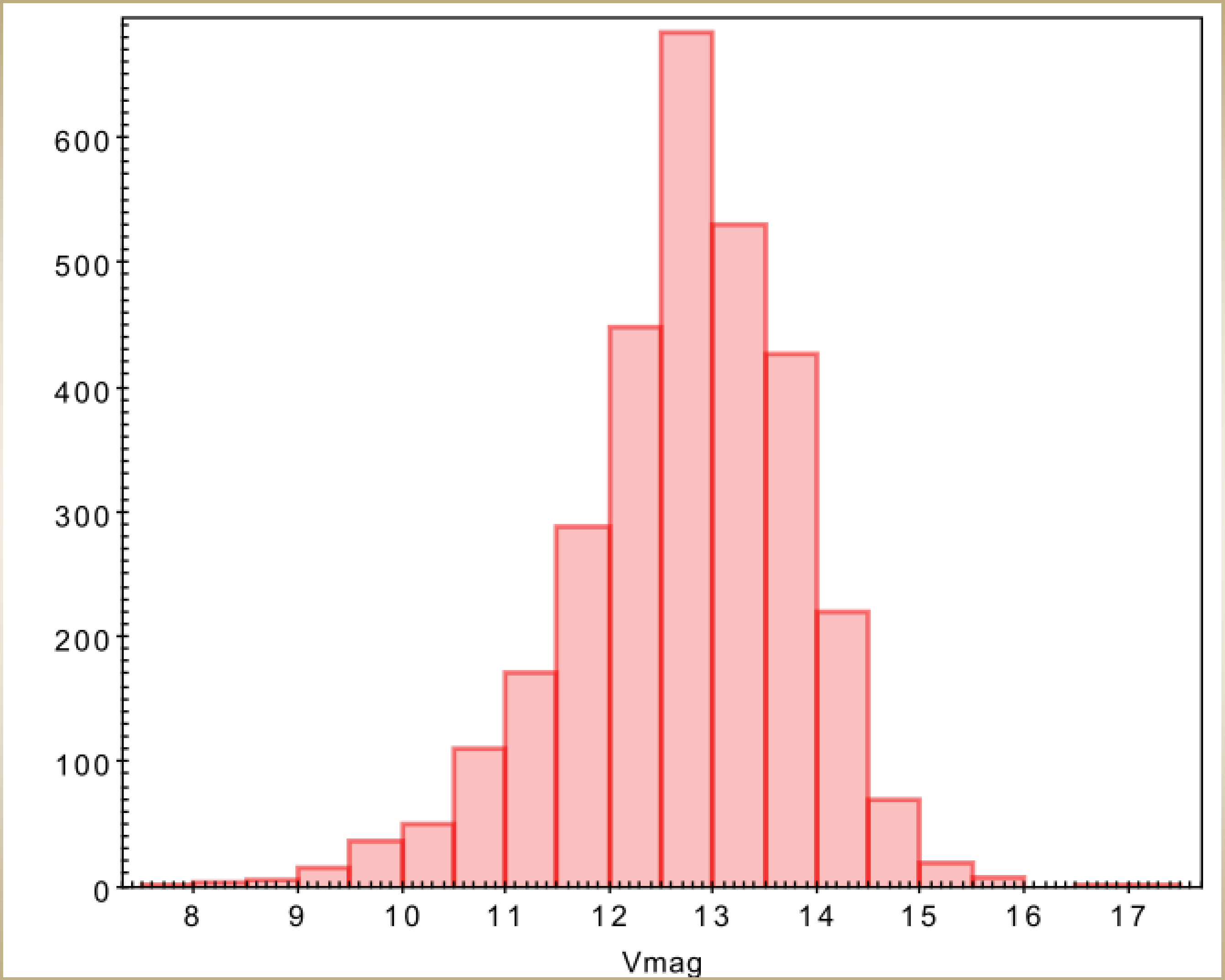
~500 M dwarfs from the Superblink cataloque will be observed in the PLATO Long Fields



~10% within P1 → LC with noise level 34ppm periods up to 2-3 years

→ low amplitudes and long periods will be detectable for this subsample

PLATO step-and-stare phase

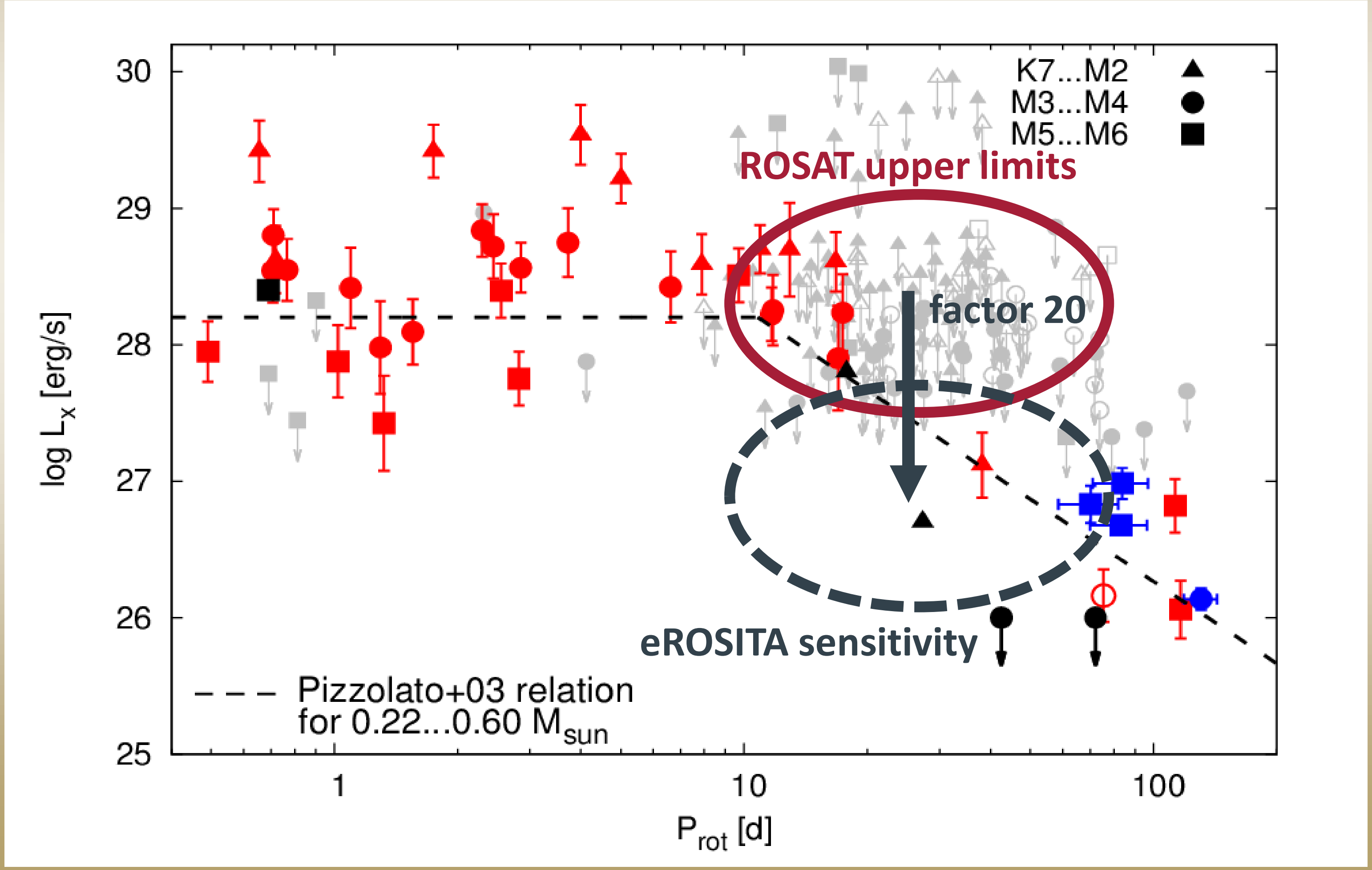


Rotation periods with up to 2-3 month for ~3000 M Dwarfs

eROSITA X-ray measurements

- P_{rot} in ~70% of our sample of nearby M dwarfs
- Only 22% of those have archival X-ray detections (15.5% of the full sample)

eROSITA: german instrument on russian SRG satellite (launch in 2018)
X-ray All Sky Survey - 20 times more sensitive than the ROSAT All Sky Survey



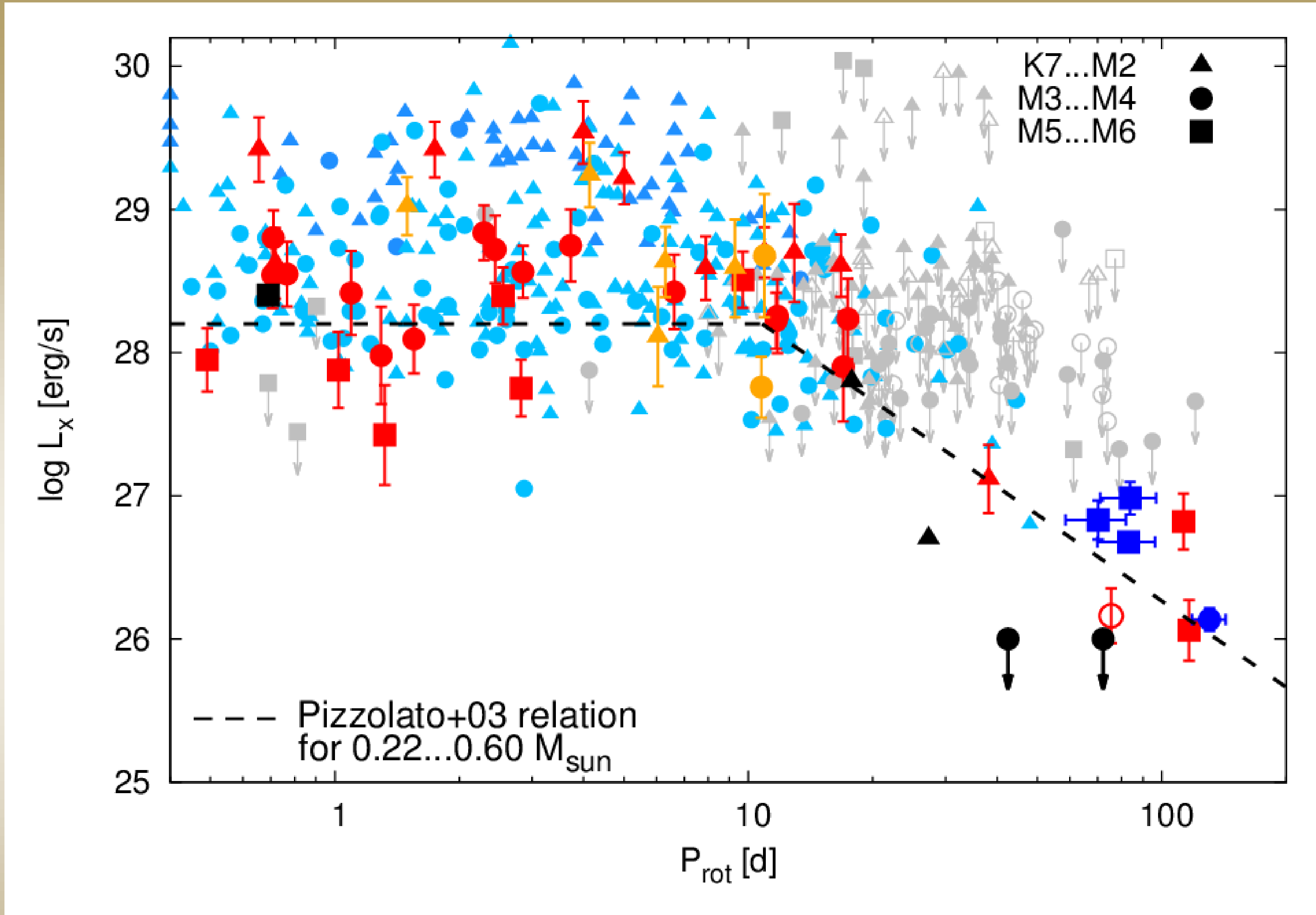
Conclusions

- joint rotation and multiwavelength 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
- X-ray saturation turn-off corresponds to transition period seen for photometric activity
- Our analysed sample has strongly increased the known number of long-period M dwarfs in the X-ray–rotation relation

Outlook

- Ongoing observations of the M dwarf sample with K2
- eROSITA X-ray All Sky Survey for detection of faint X-ray emission
- Detection of low amplitudes and long periods for a large M-dwarfs sample with PLATO

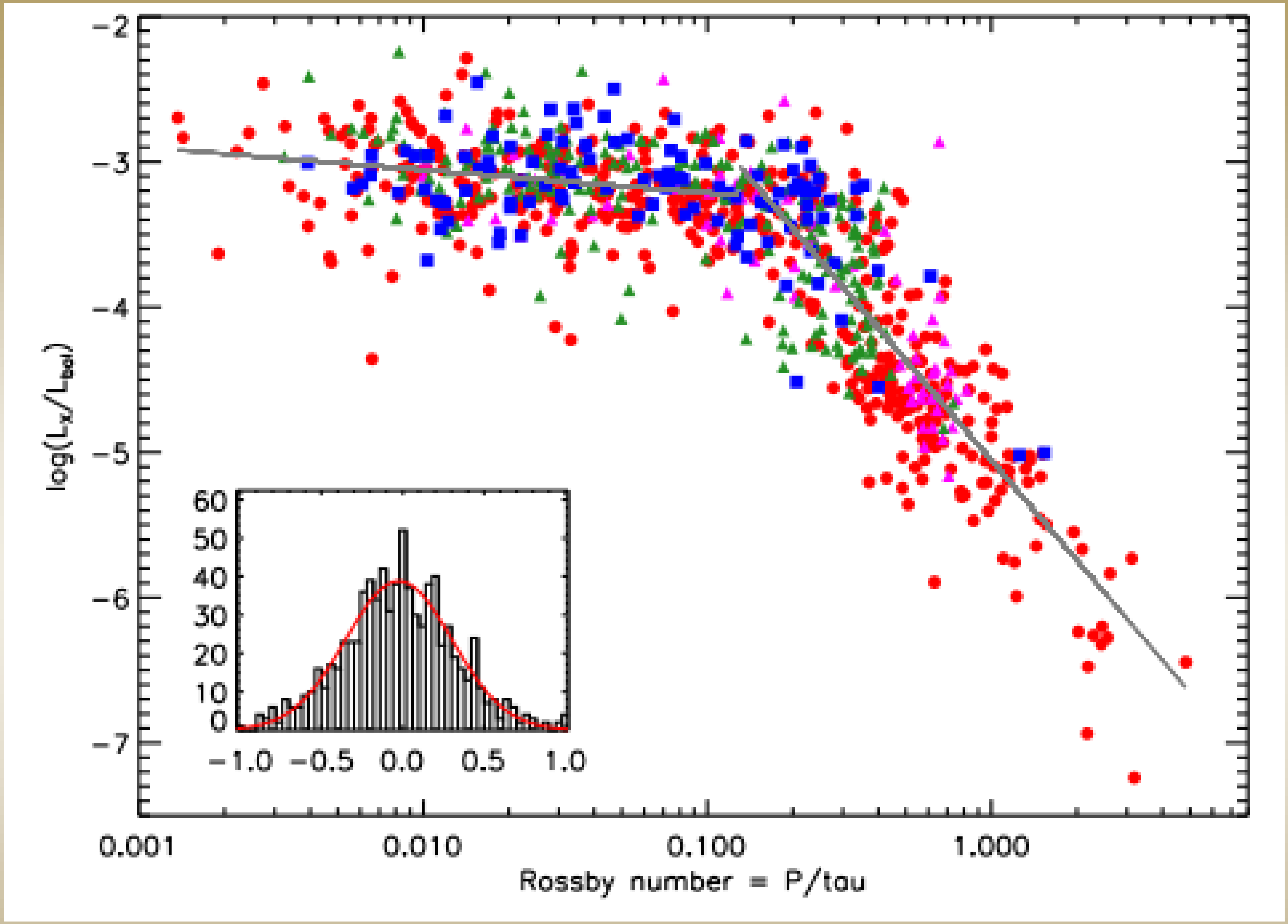

Thank you
for your attention!



Cyan: Wright et al. (2011), Field M dwarfs

Light blue: Wright et al. (2011), Cluster M dwarfs

Blue: Wright & Drake (2016)



Reiners, Schüssler & Passegger (2014)
821 stars with masses below 1.4 Msun
Blue: very young stars (up to 50 Myr); green: young stars (between 85 and 150 Myr); magenta: intermediate-age stars (600–700 Myr); red: field stars.