Systematic study of X-ray flaring in the benchmark planet host Proxima Centauri

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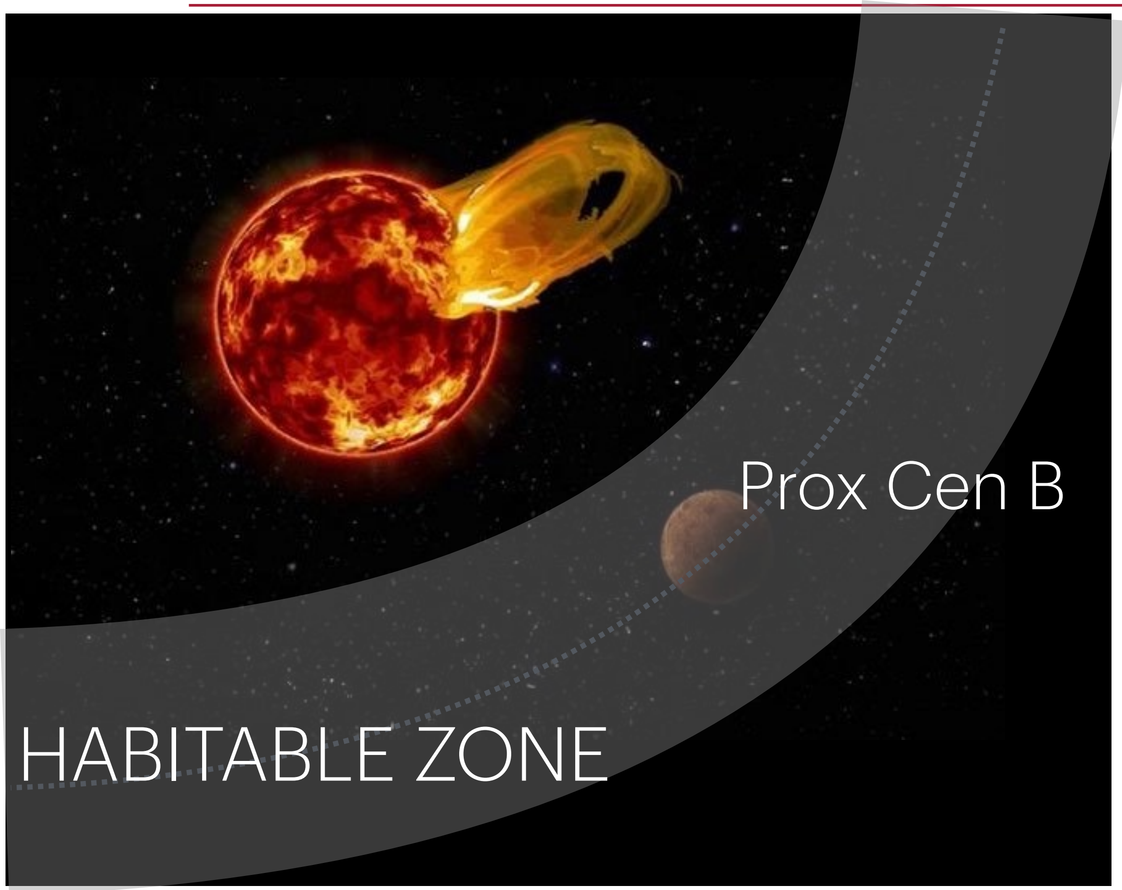
German Research Foundation

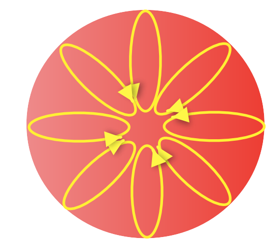
Readapted image from NASA/SDO, NASA/JPL

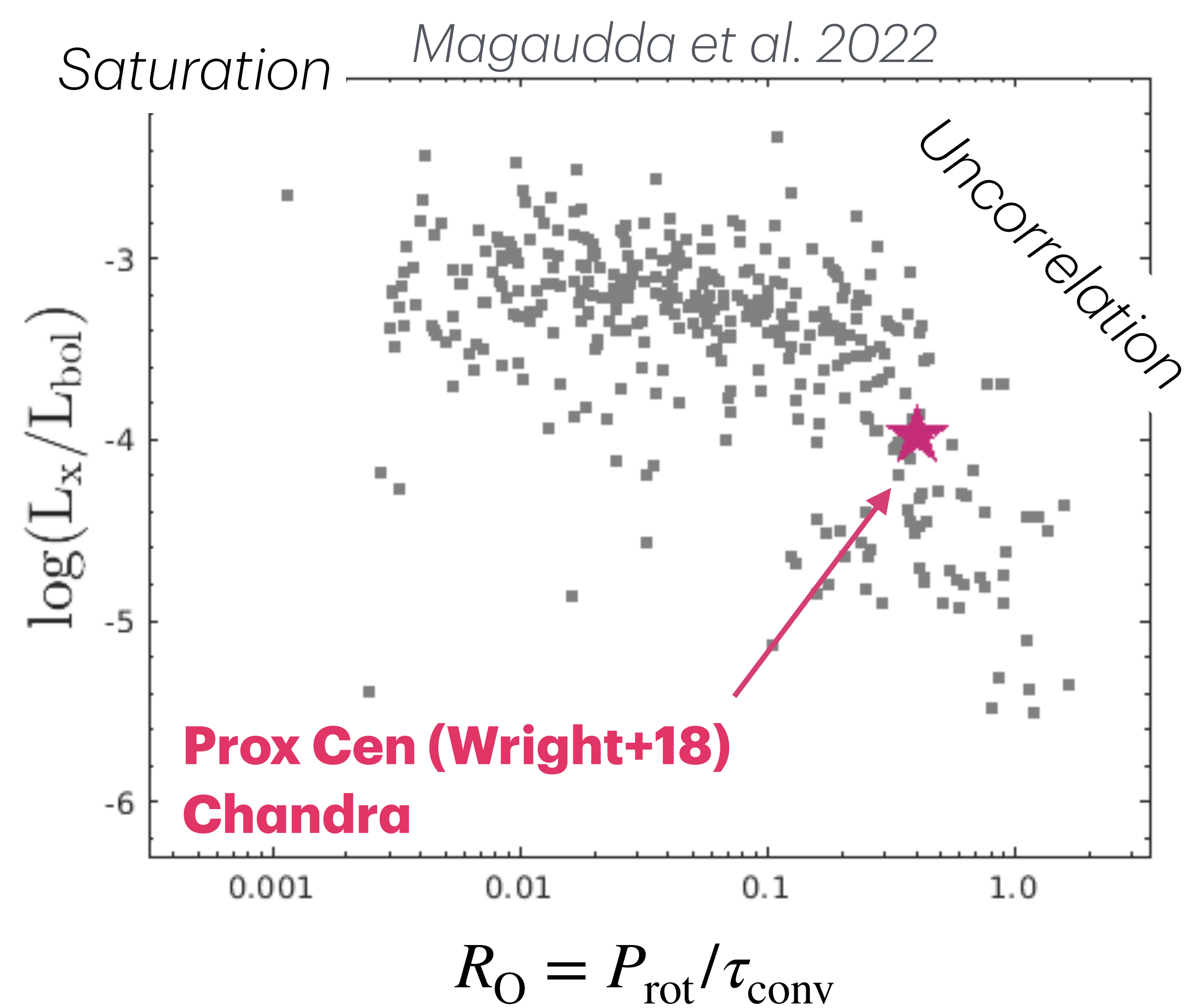
Our nearest neighbor: Proxima Centauri (α Cen)



- Main-sequence M5.5 dwarf with Age ~ 5 Gyr
- Gaia-DR3 Dist = 1.3 pc & $P_{rot} = 89.8\,d$ *(Wright+18)*
- Hosts three planets:
  Prox Cen B is located within the habitable zone, influenced by the magnetic activity of Prox Cen

SpT = M3.5…later
fully convective main-sequence
active dwarfs





X-ray (& EUV) radiation influences the evolution and formation of planet's atmospheres, also determining whether liquid water can be formed or not

Observational diagnostic:

Impact of X-ray flares in coronal emission

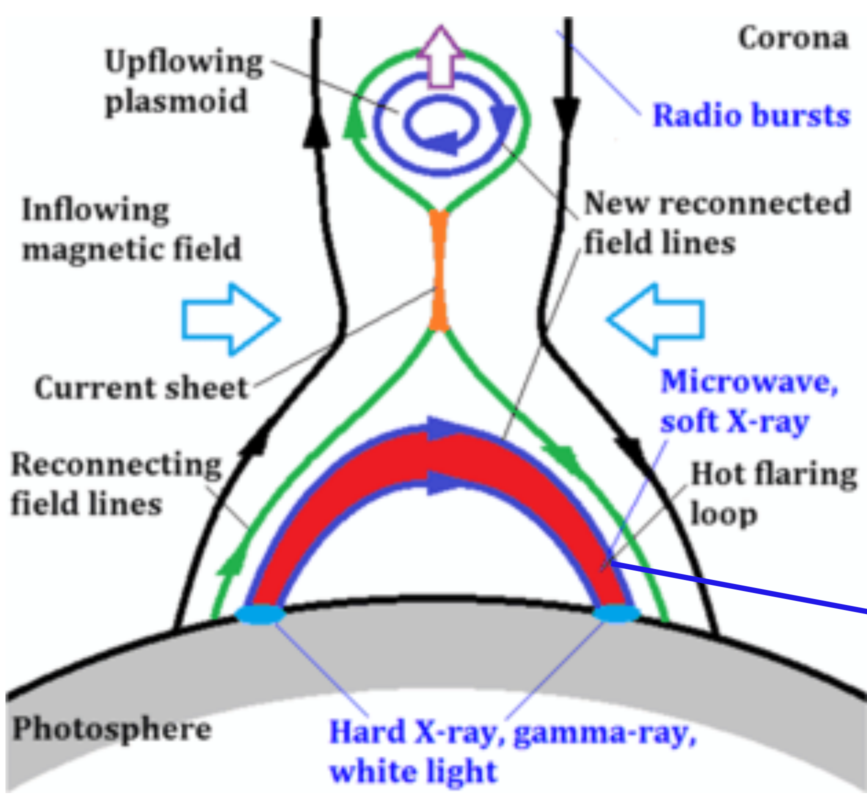
Solar model: $\alpha\Omega-$dynamo

convective buoyancy + differential rotation

→ re-configuration of the magnetic field

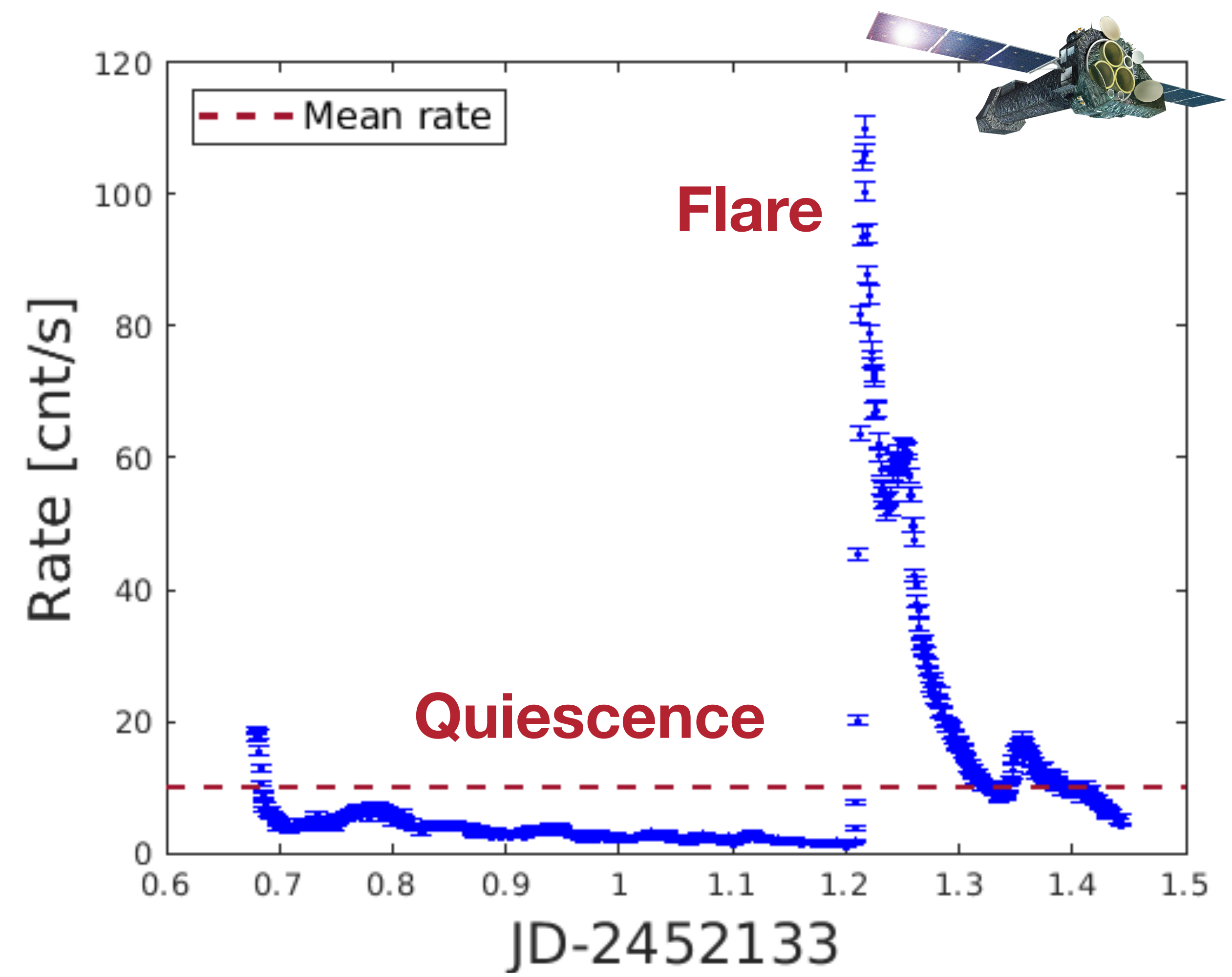
X-ray flares:

→ energy is released into accelerating electrons traveling down along the field lines



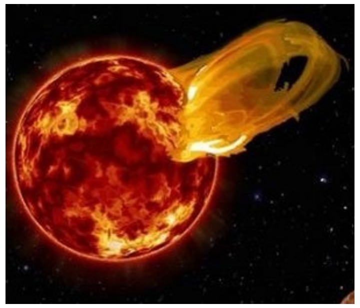
Soft X-rays are produced through evaporation

Nakariakov et al. 2016



In absence of flares: Quiescence

→ fainter X-ray emission caused by convective currents at the stellar spots



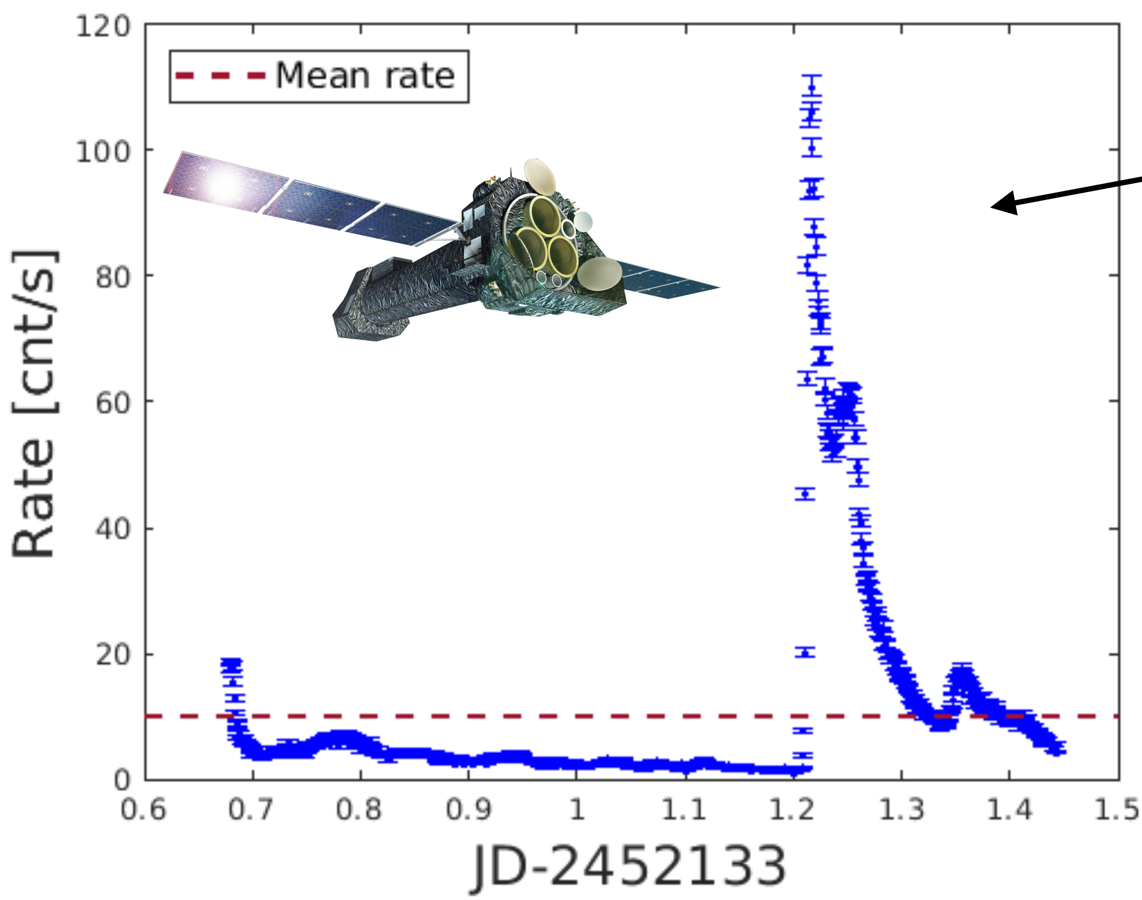
X-ray variability:
XMM-Newton & eROSITA

→ Search for X-ray flares along the X-ray light curves

XMM-Newton archival data:
8 pointed EPIC/pn observations from 2001 to 2017

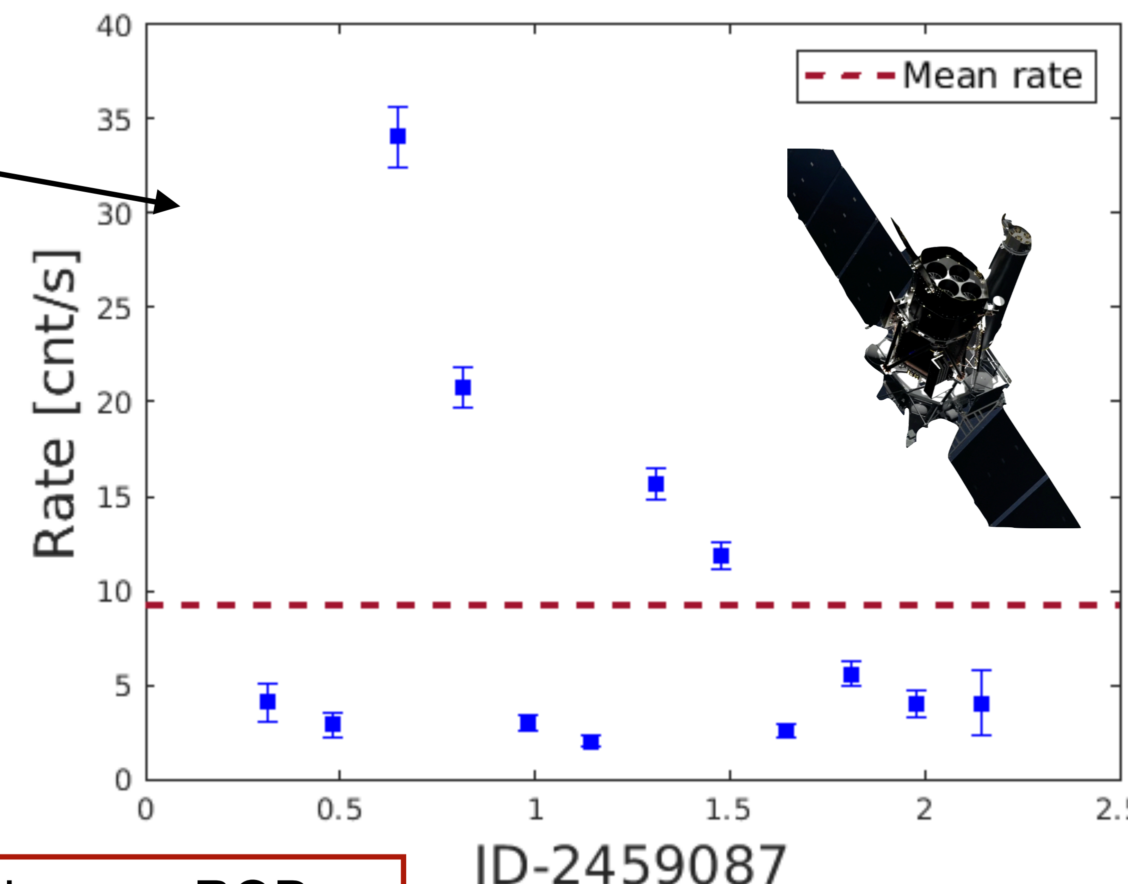
eROSITA: detections along the four All-Sky Surveys (eRASSs) 2019-2021

EPIC/pn — PI: Dr. M. Güdel — August 2001



Flare

eRASS2 mean date Oct. 12, 2020



binsize == eRODay

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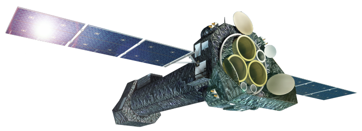
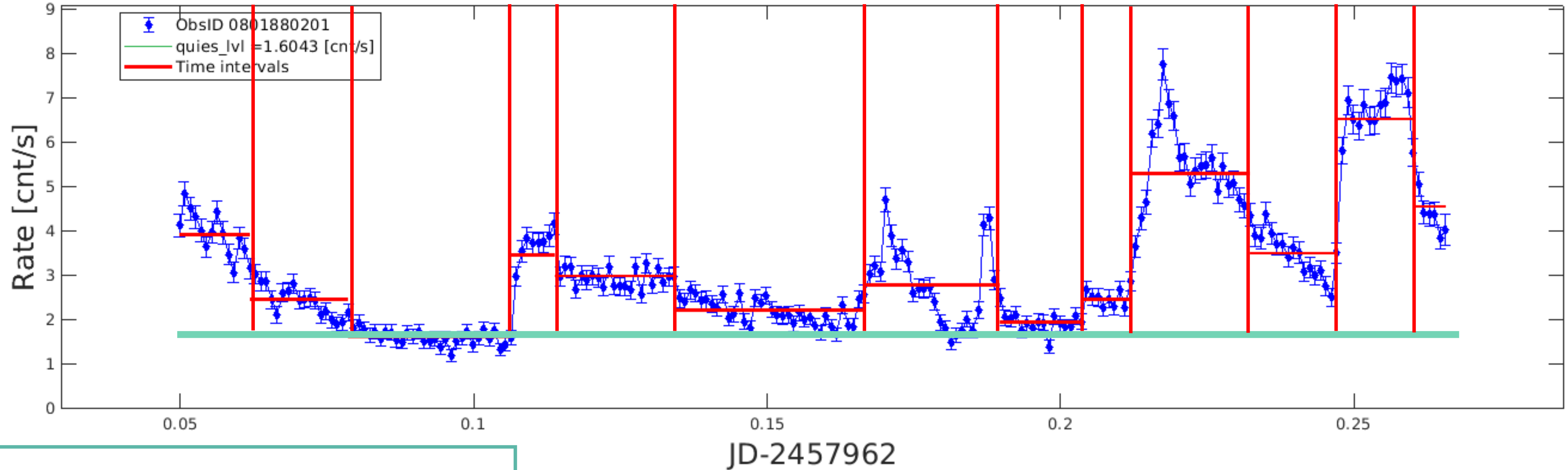
Search for X-ray flares along the light curve

Deutsche Forschungsgemeinschaft



XMM-Newton data:

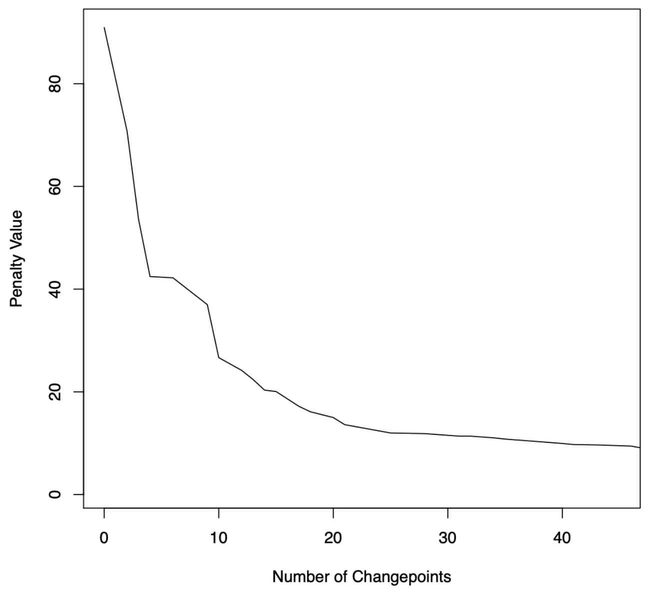
Time intervals of constant mean count rate



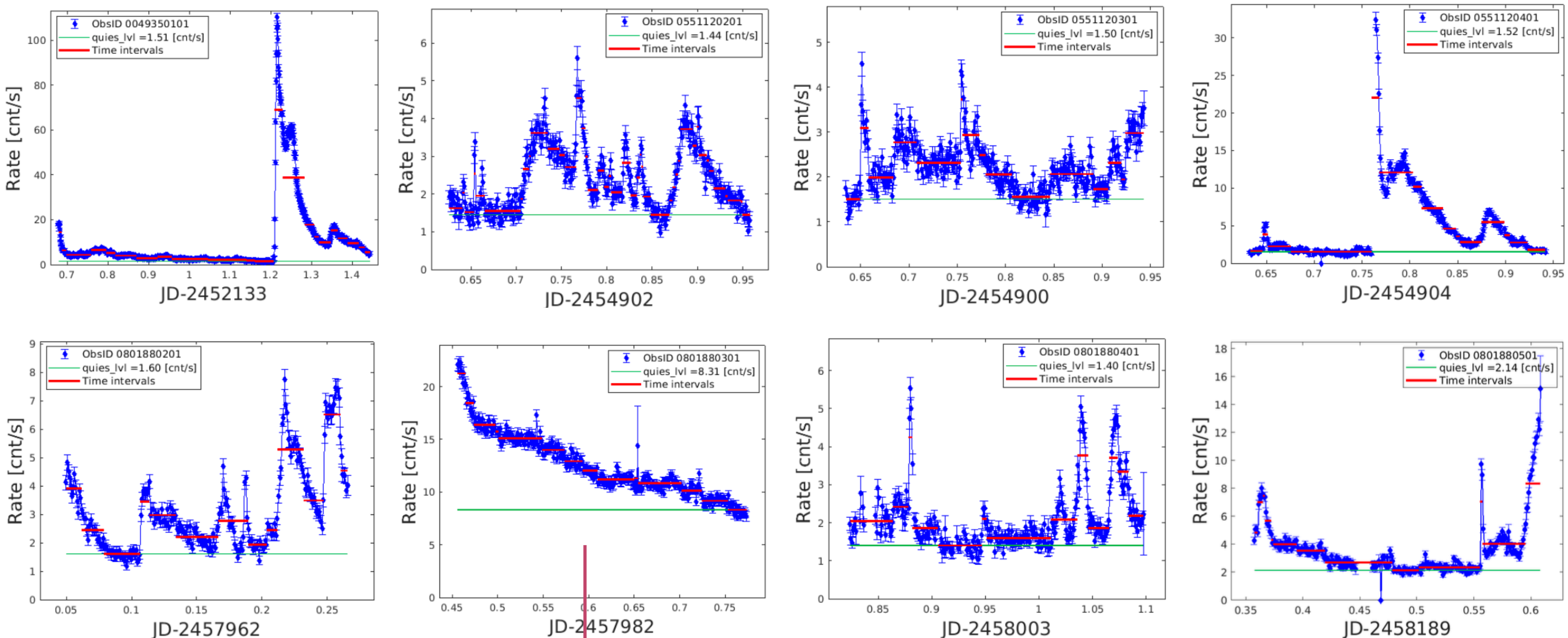
Quiescent level $\sim 1.6\,\mathrm{cnt/s}$

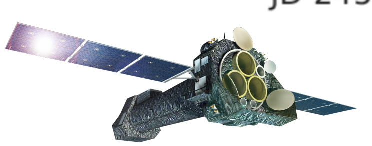
→determination of the quiescent level == minimum mean count rate

Search for change points:
where the probability distribution of a time series changes



Search for X-ray flares along the light curve



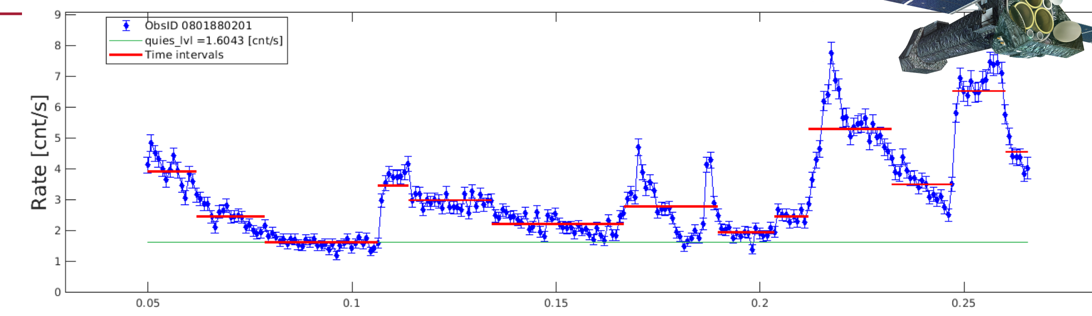


duration ~ obs. Time = 8.5 h **vs** the typical of ~2 h

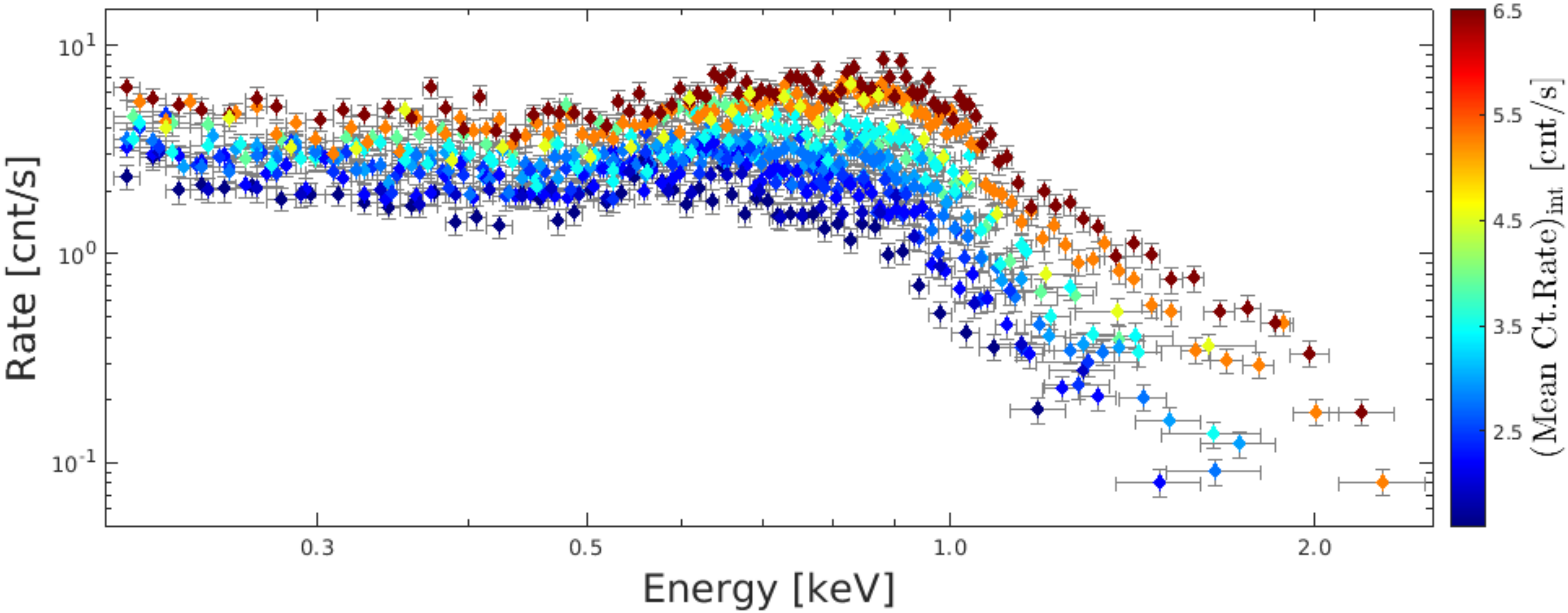
8 *XMM-Newton* LCs discretized in *n* time intervals

→ very variable and complex flaring emission

Spectrum extraction from each time interval



Spread of Ct.Rate:
variation of the mean rate along the time intervals



EM: emission measure

$$\int n_{\mathrm{e}} n_{\mathrm{H}} dV$$

Fit Analysis with XSPEC: 1T/2T thermal emission models - APEC

$$< kT_{\mathrm{corona}} > = \frac{\Sigma_n (kT_n \cdot \mathrm{EM_n})}{\Sigma_n \mathrm{EM_n}}; \;\; n = 1{,}2 \quad \rightarrow \quad F_{\mathrm{x}} \;\; \text{w/ } \textit{Gaia}\text{-DR3 distance}$$

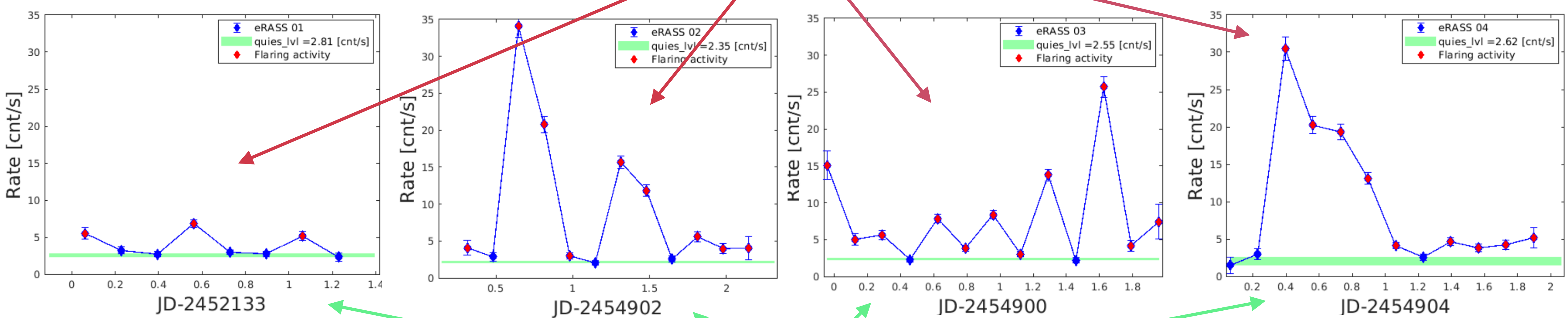
$$\rightarrow \quad L_{\mathrm{x}} \quad [0.2\text{-}5.0 \text{ keV}]$$

eROSITA: A spectrum from each *active* eRODay

eROSITA LCs divided into equally sized count rate bins based on the Rate distribution

Quiescence == Lowest Count Rate bin

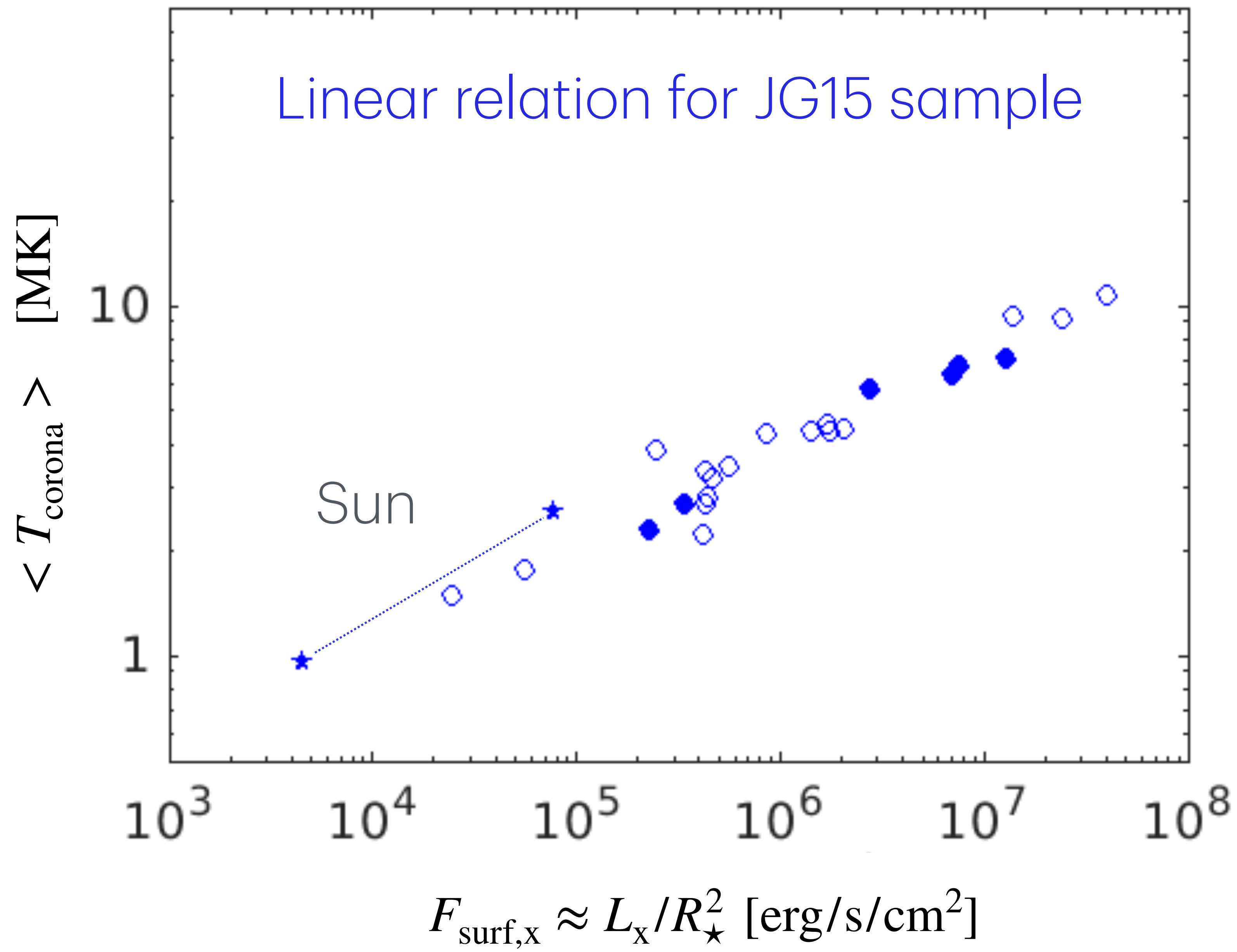
One spectrum from each active bin



One spectrum from quiescence

Coronal temperature vs X-ray brightness

Johnstone & Güdel 2015 (JG15):
Lit. collection of X-ray data for FGK + 6 M dwarfs



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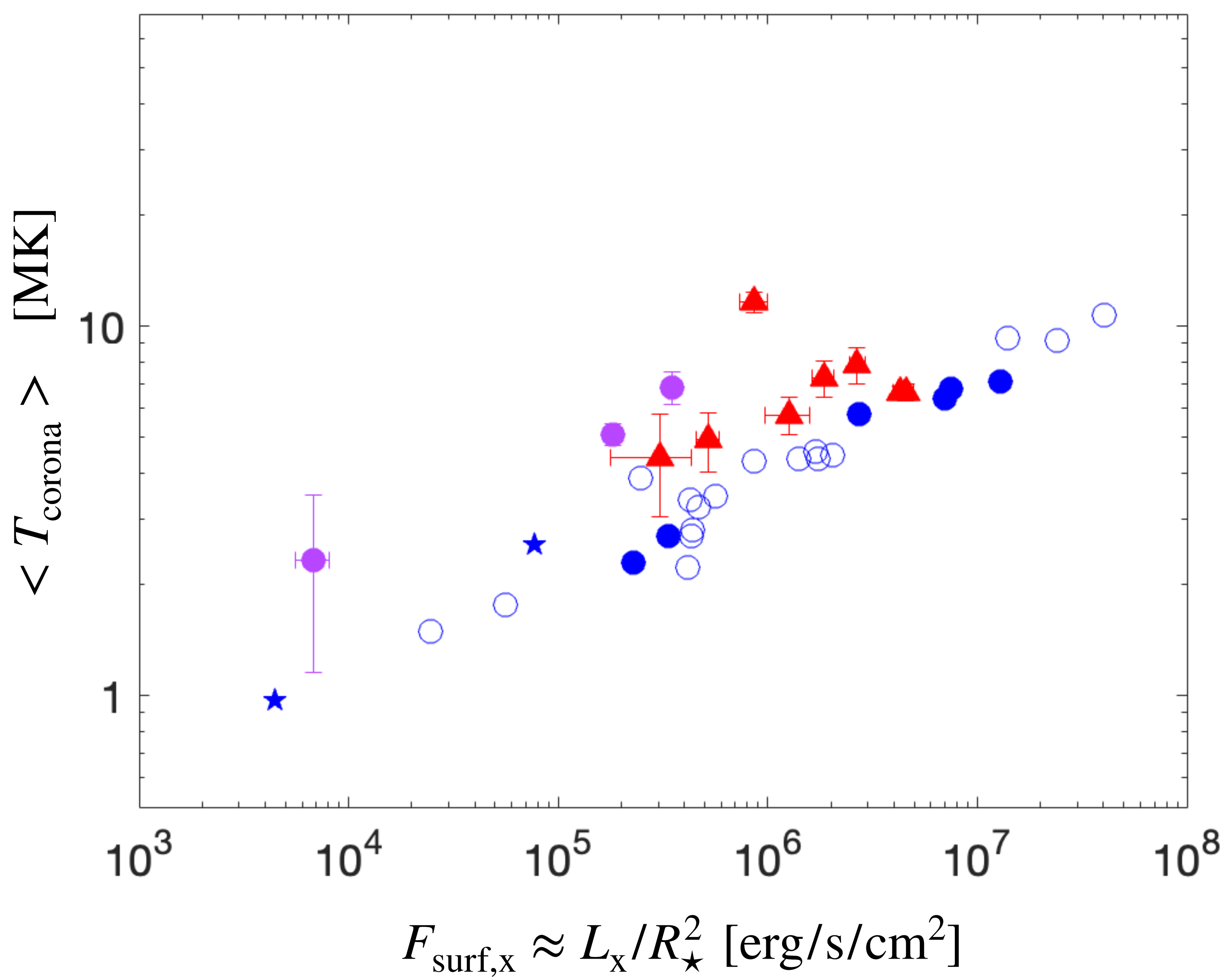
Magaudda+22: M dwarfs from eFEDS

Modirrousta-Galian+20 & Magaudda+20:
M dwarfs from XMM-Newton



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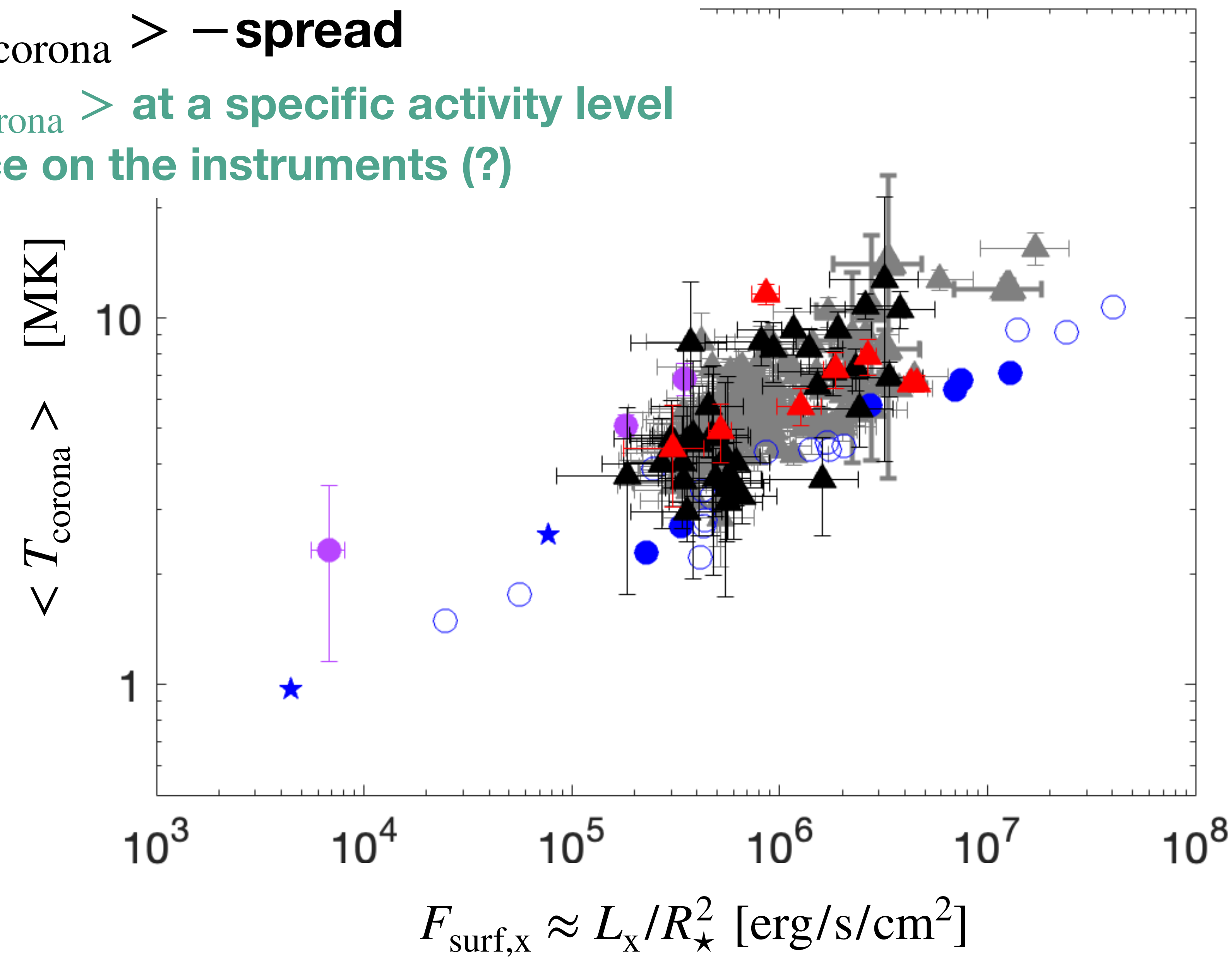
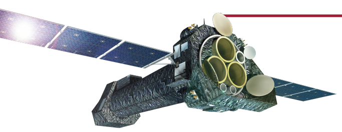
Prox Cen w/ XMM-Newton + Prox Cen w/ eROSITA

Significant $< T_{\rm corona} >$ −spread

→ range of $< T_{\rm corona} >$ at a specific activity level and/or dependence on the instruments (?)



Coronal temperature and activity states



Prox Cen vs eFEDS M dwarfs **&** XMM M dwarfs

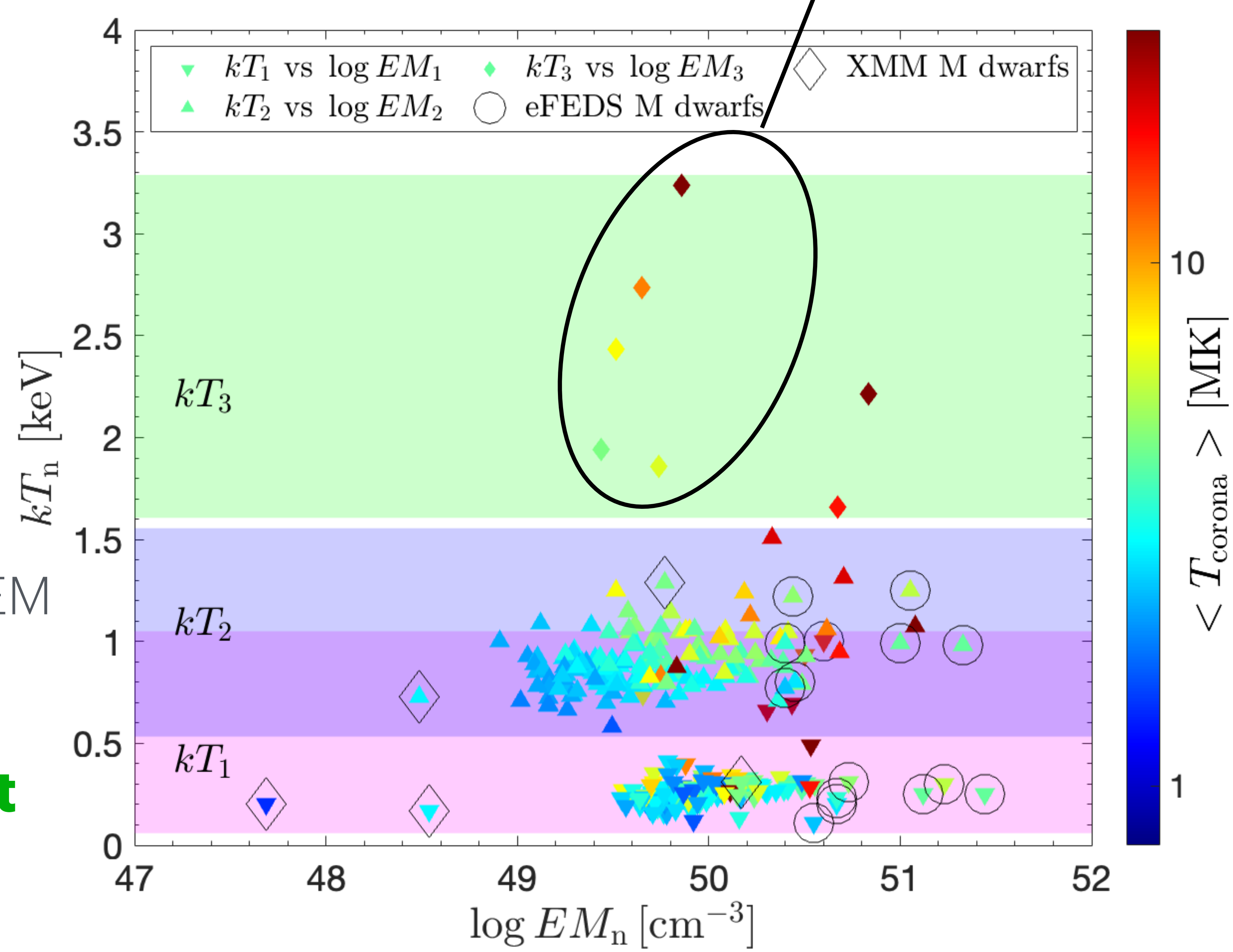
Magaudda+22 *Magaudda+20*

kT_3 vs EM_3: low statistic but it seems to be a linear relation with a steeper slope

eFEDS M dwarfs have high EM

→ $R_\star$ − dependence

or mostly dominated by flare?



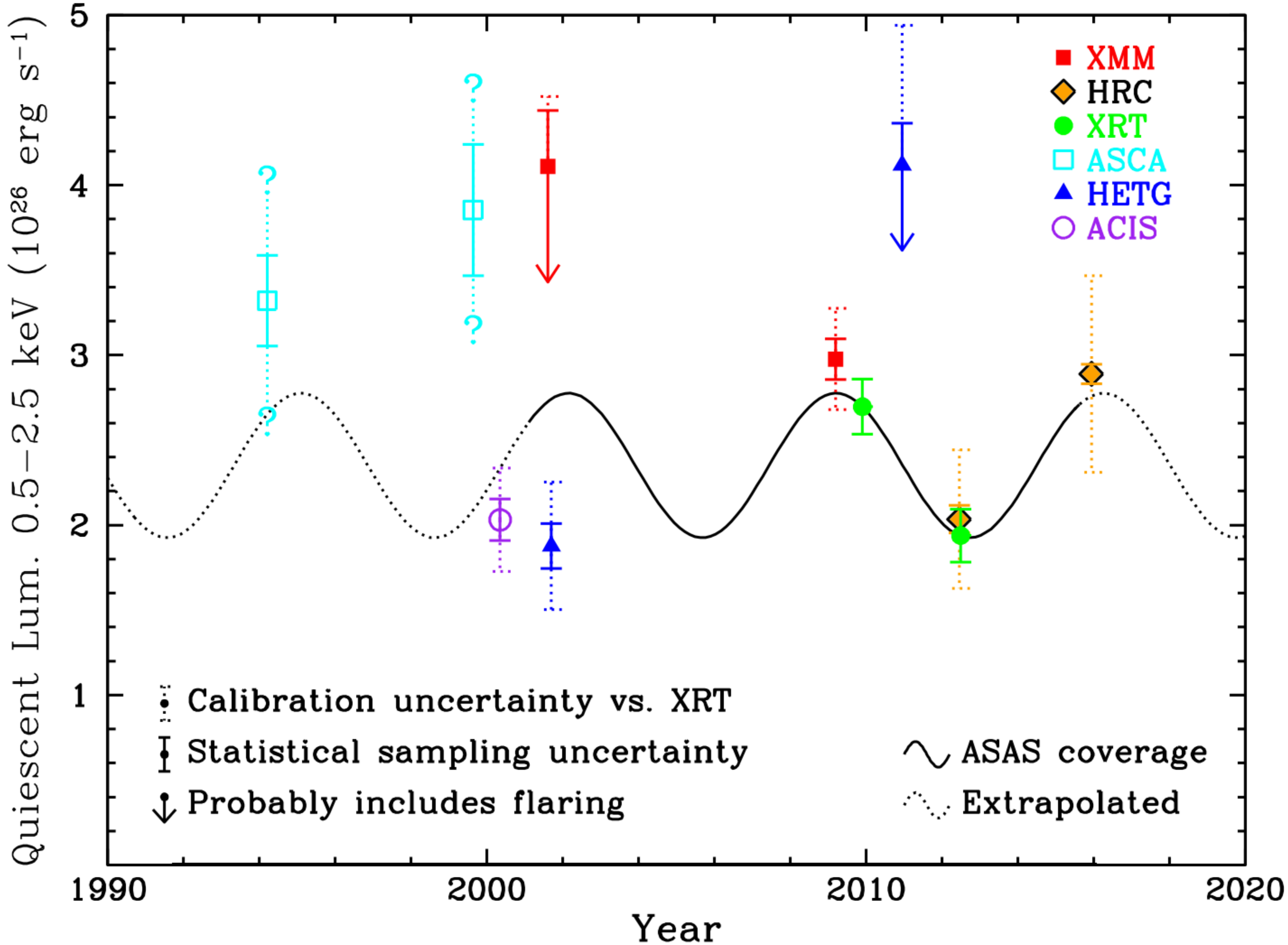
XMM M dwarfs:

- $R_\star \sim 0.3\, R_\odot$
- One is flaring and has high EM
- Two are NOT flaring and have low EM

Evidence of different activity levels

Long-term quiescent L_X study

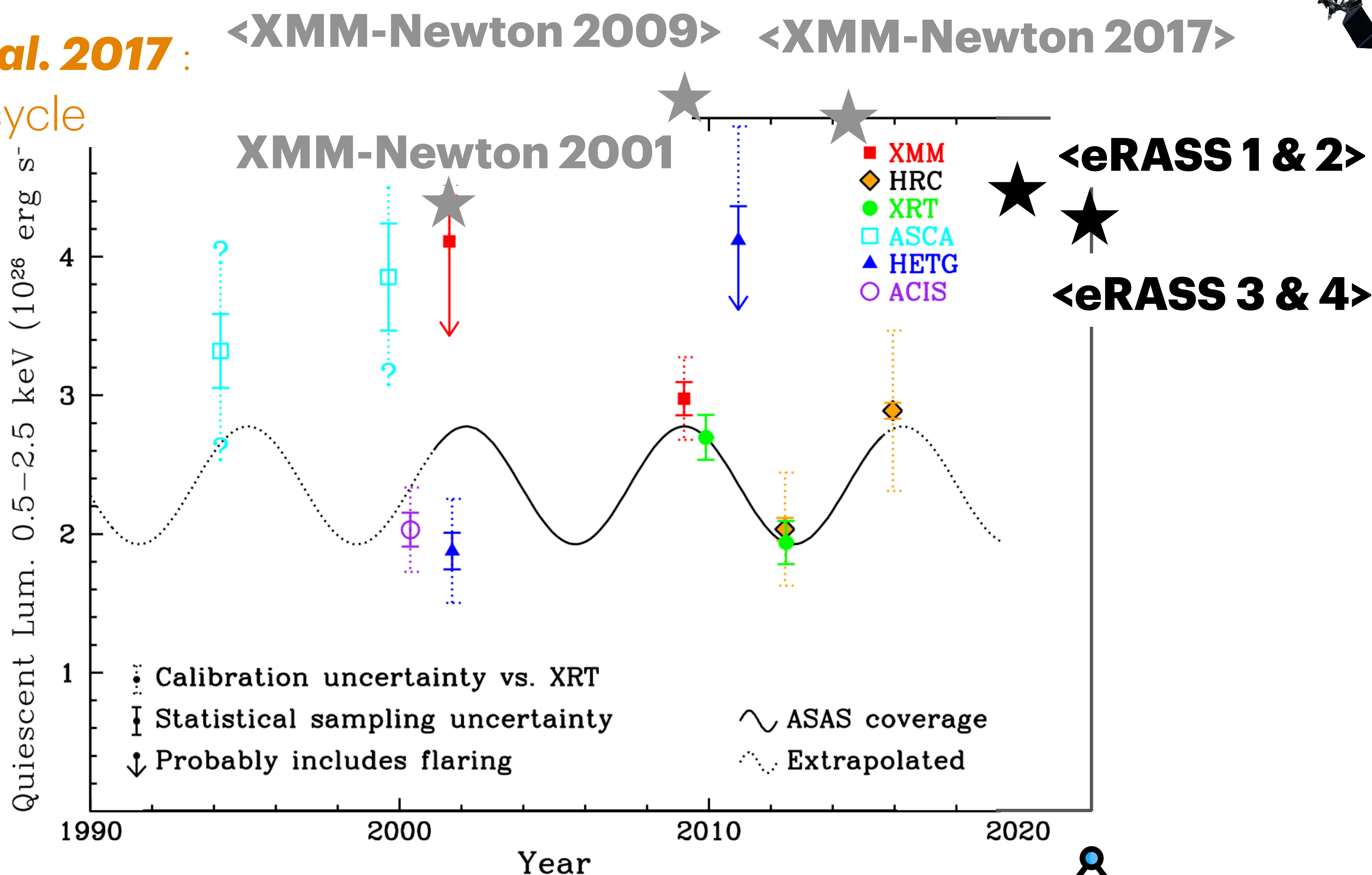
Wargelin et al. 2017 : 7-yr activity cycle



Long-term quiescent L_X study

Wargelin et al. 2017 :

7-yr activity cycle

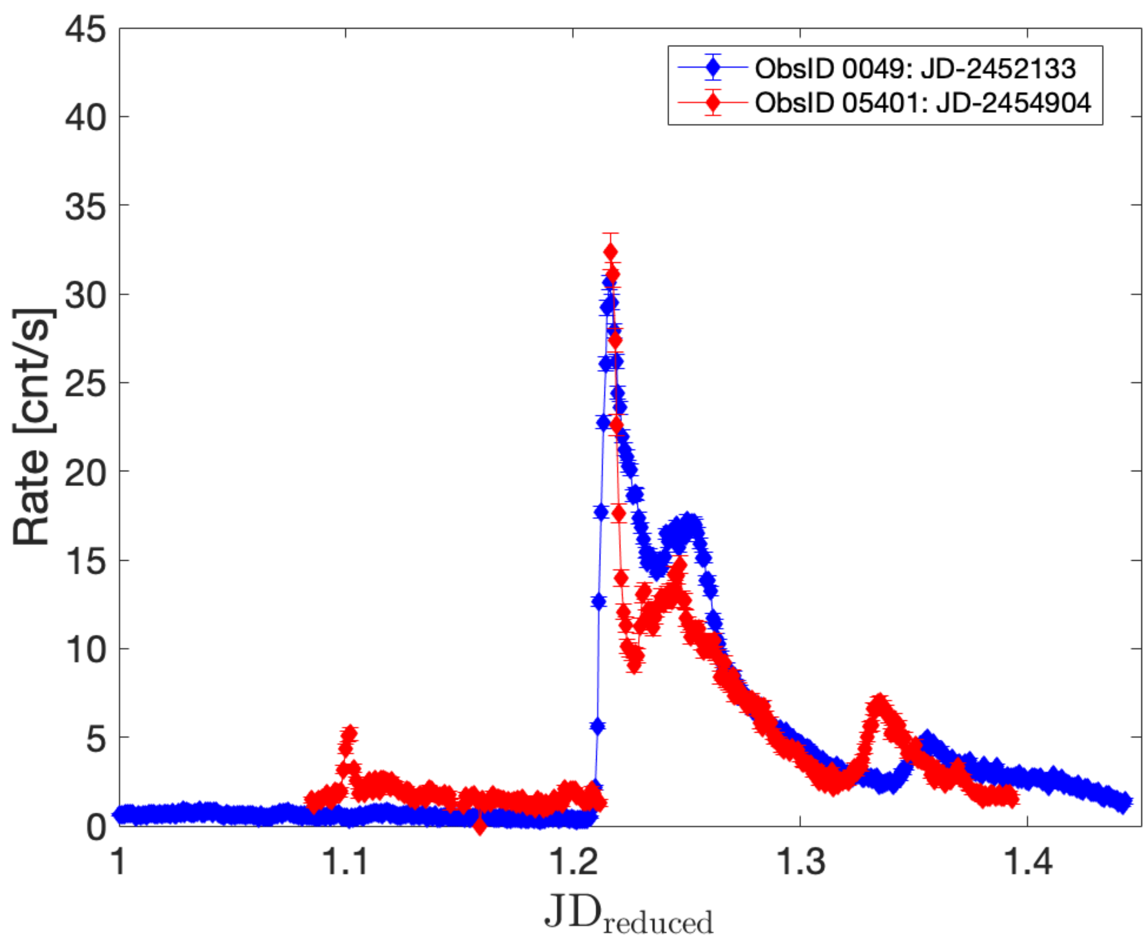


New Lomb-scargle periodogram with this dataset

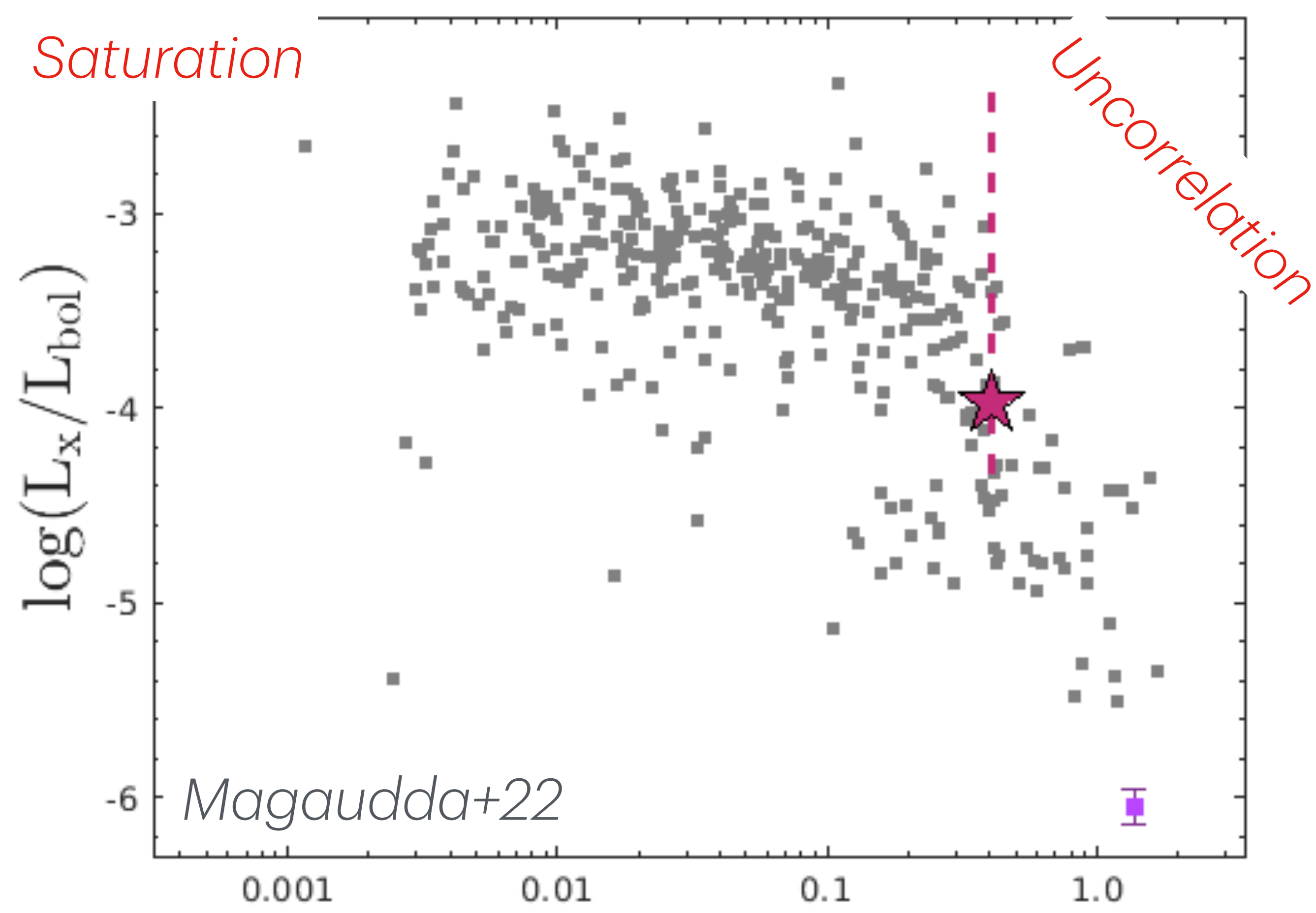
X-ray activity of Proxima Centauri

XMM-Newton: 2001 vs 2009

same flare shape after ~10 yr
→ did the active region persist for so long??



M dwarf sample from eROSITA EDR1
+
Prox Cen from Chandra (*Wright+18*)

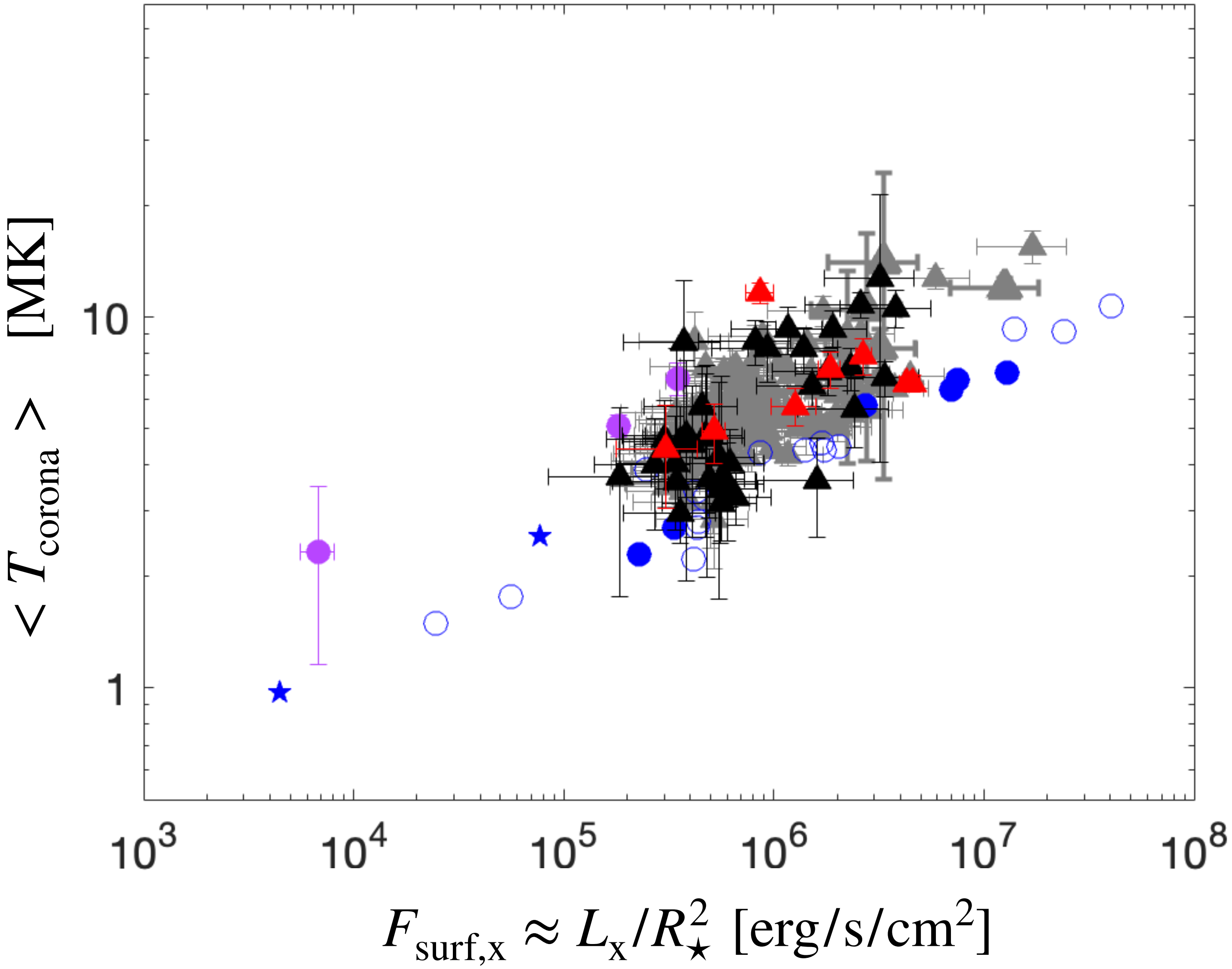


$$R_O = P_{rot}/\tau_{conv}$$

From XMM & eROSITA data:

Prox Cen X-ray emission reaches the saturated regime

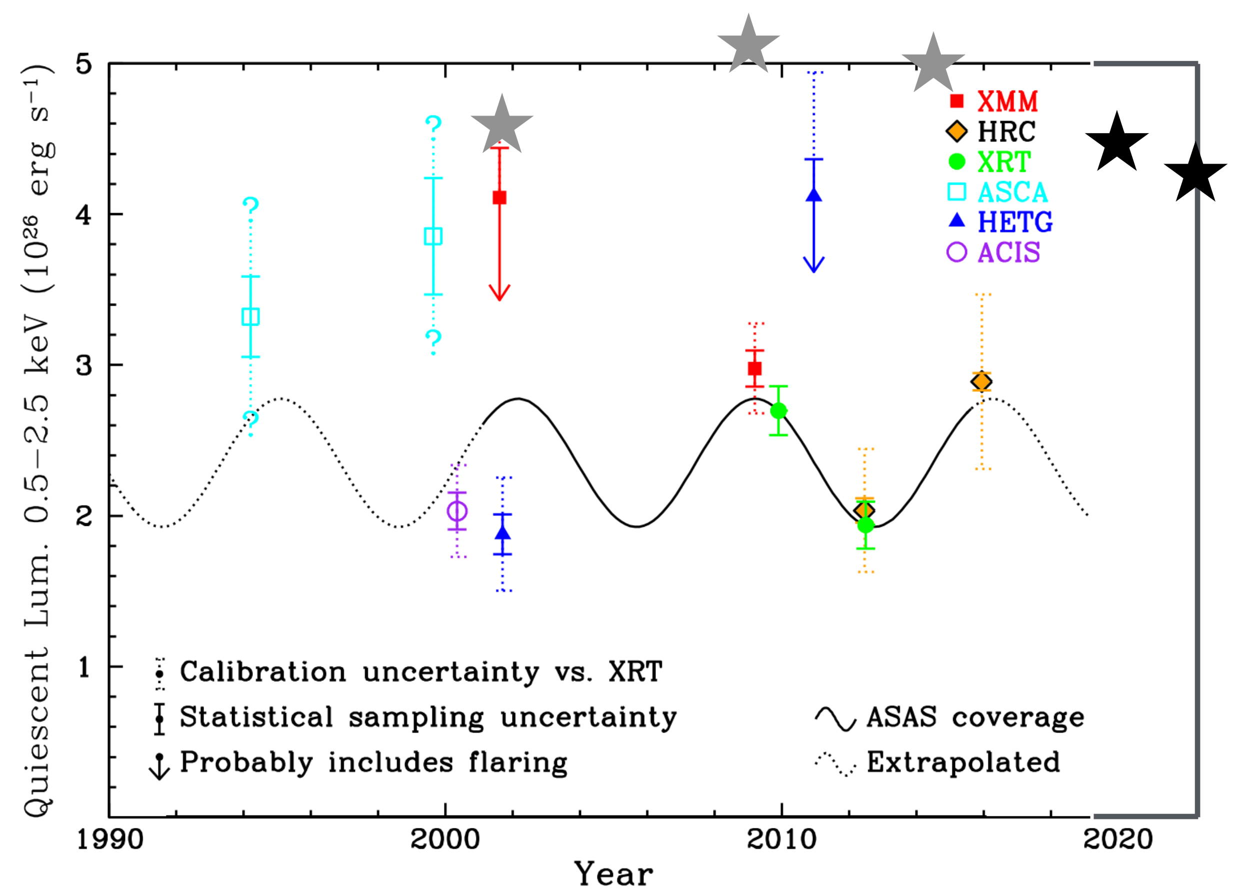
Highlights



activity state dependent

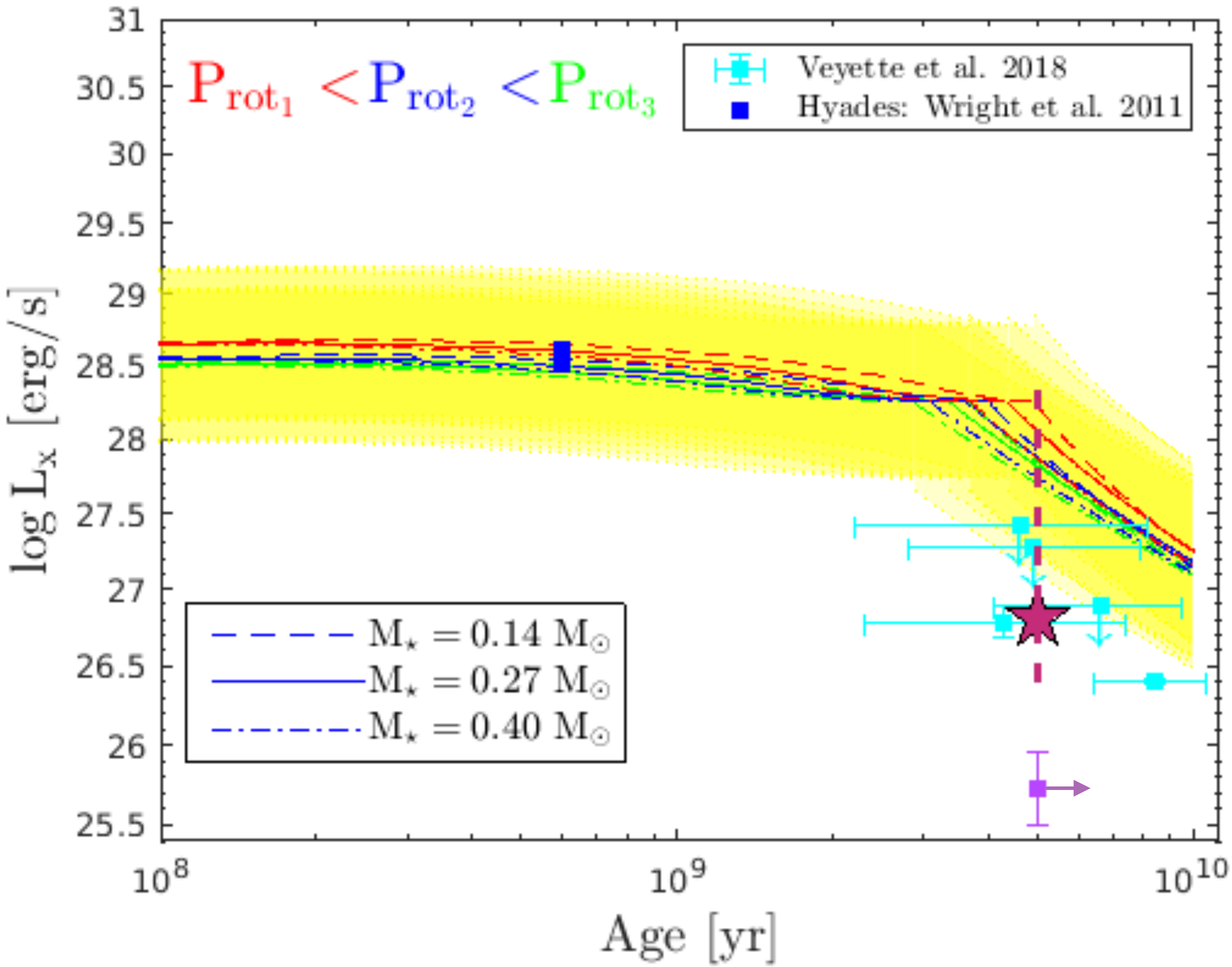
$< T_{corona} >$ – range

Testing the activity cycle of Proxima Centauri



BACKUP

The empirical activity-age relation from Magaudda+20 with Prox Cen from XMM-Newton & eROSITA data and GJ 357



Coronal temperature vs X-ray brightness

Johnstone & Güdel 2015 (JG15):
XMM-Newton & *Chandra* for FGK + 6 M dwarfs

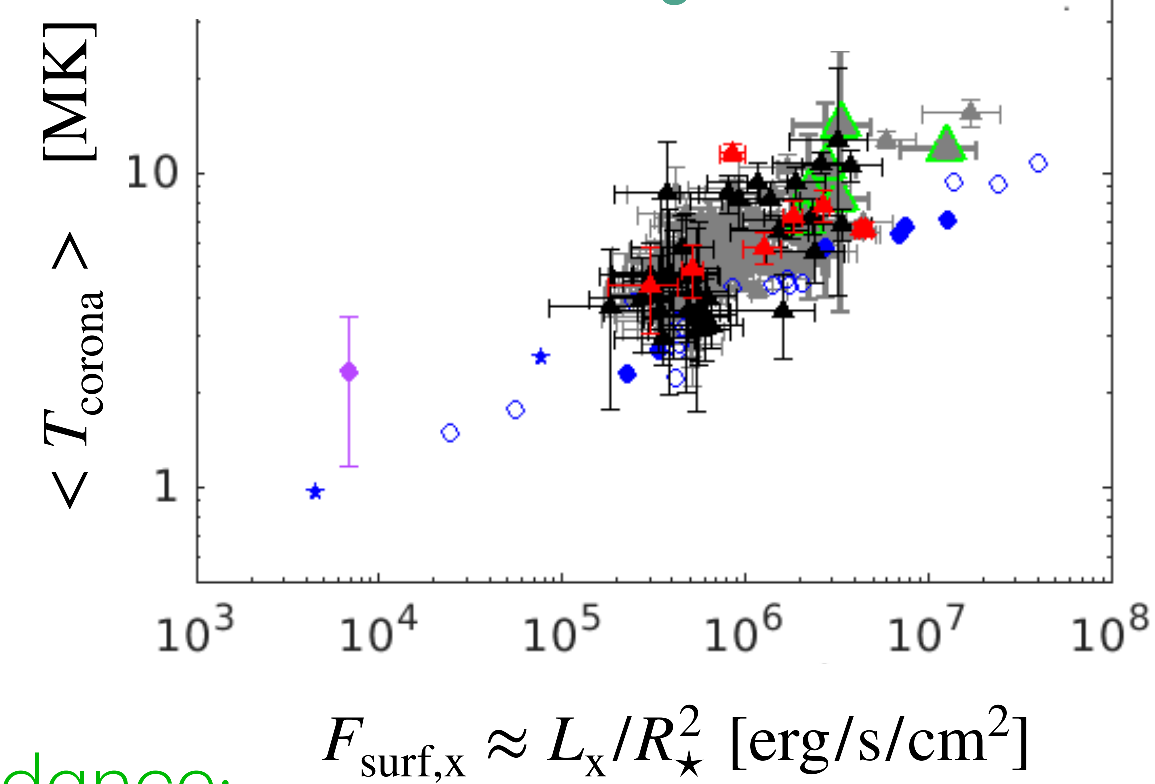
Modirrousta-Galian, Stelzer, Magaudda et al. 2020: GJ 457 from XMM-Newton

Magaudda et al 2022: M dwarfs from eFEDS

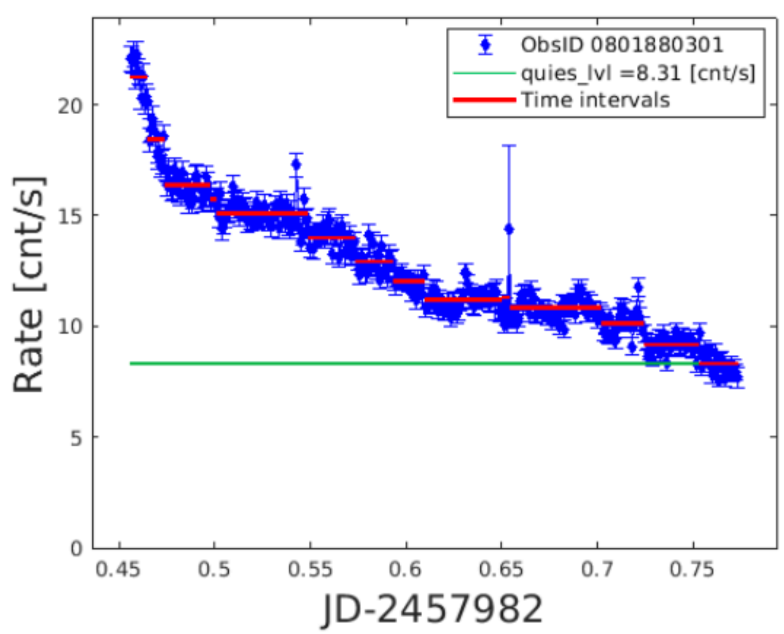
Prox Cen w/ XMM-Newton + Prox Cen w/ eROSITA

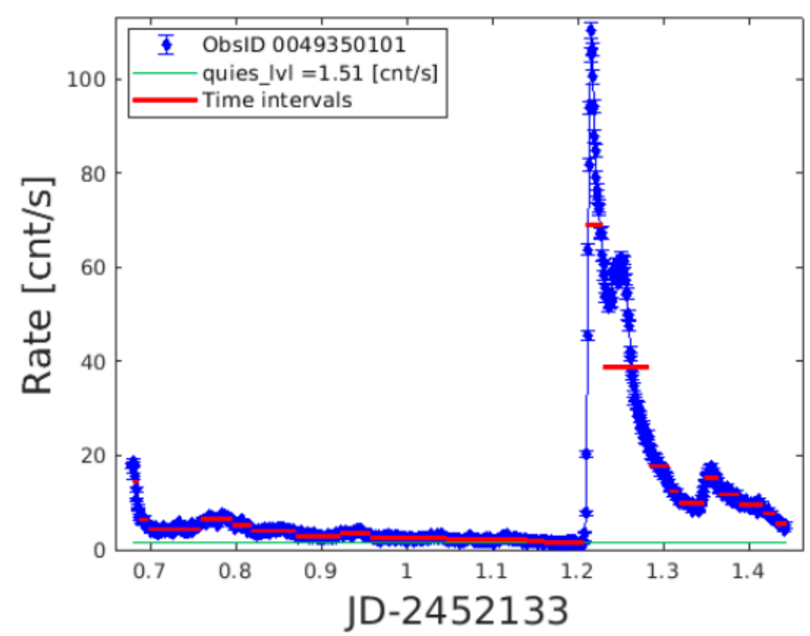
Significant $< T_{\mathrm{corona}} > -$spread

→ coronal heating mechanism



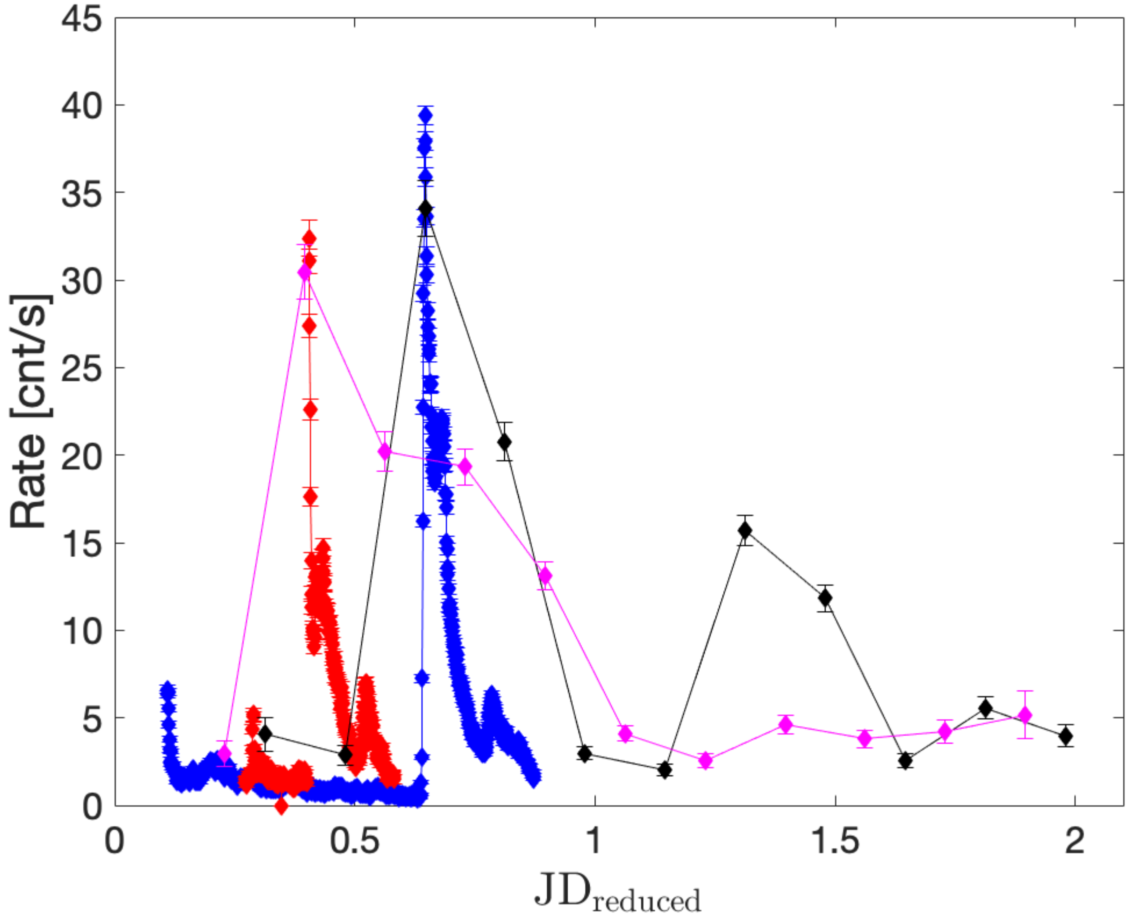
Spectral analysis w/ free global abundance: which cases?





Reale et al 2003 flare loop system

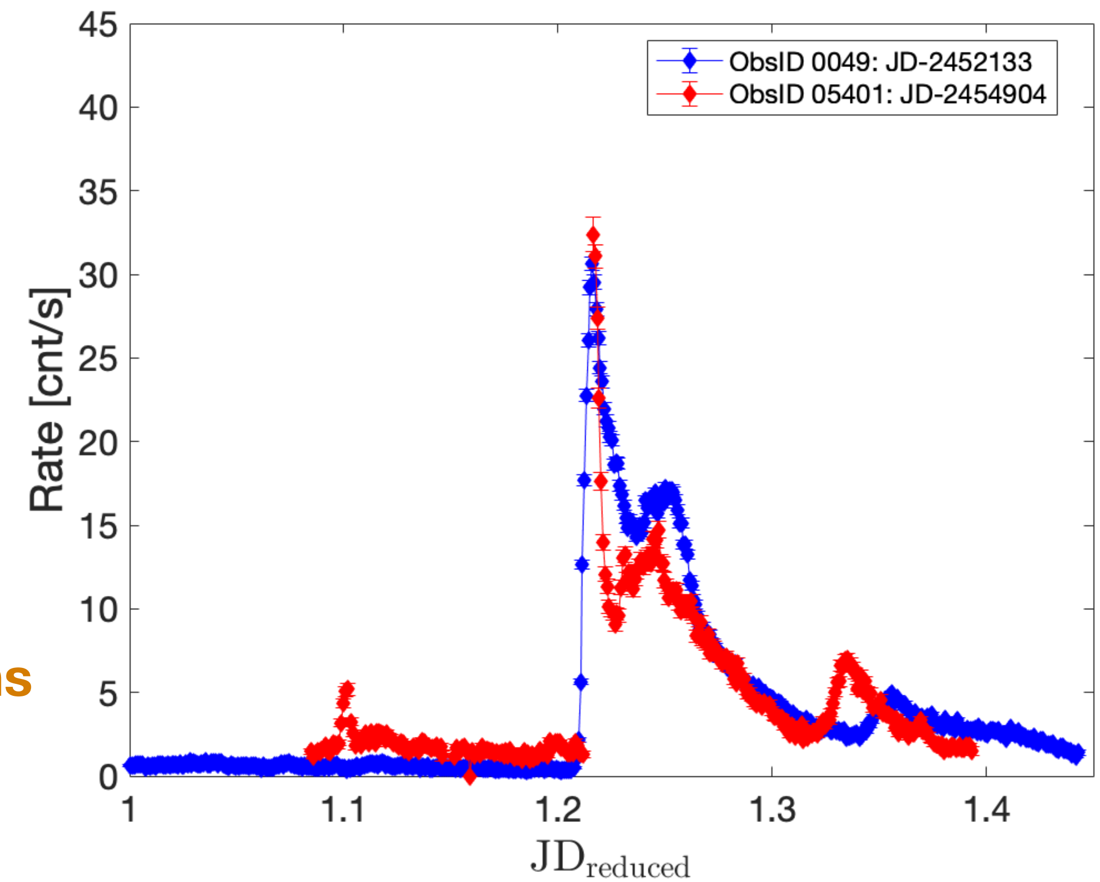
eROSITA vs XMM-Newton



rescaling and shifting in time
→ eROSITA seems to detect mostly brighter flares

XMM-Newton: 2001 vs 2009

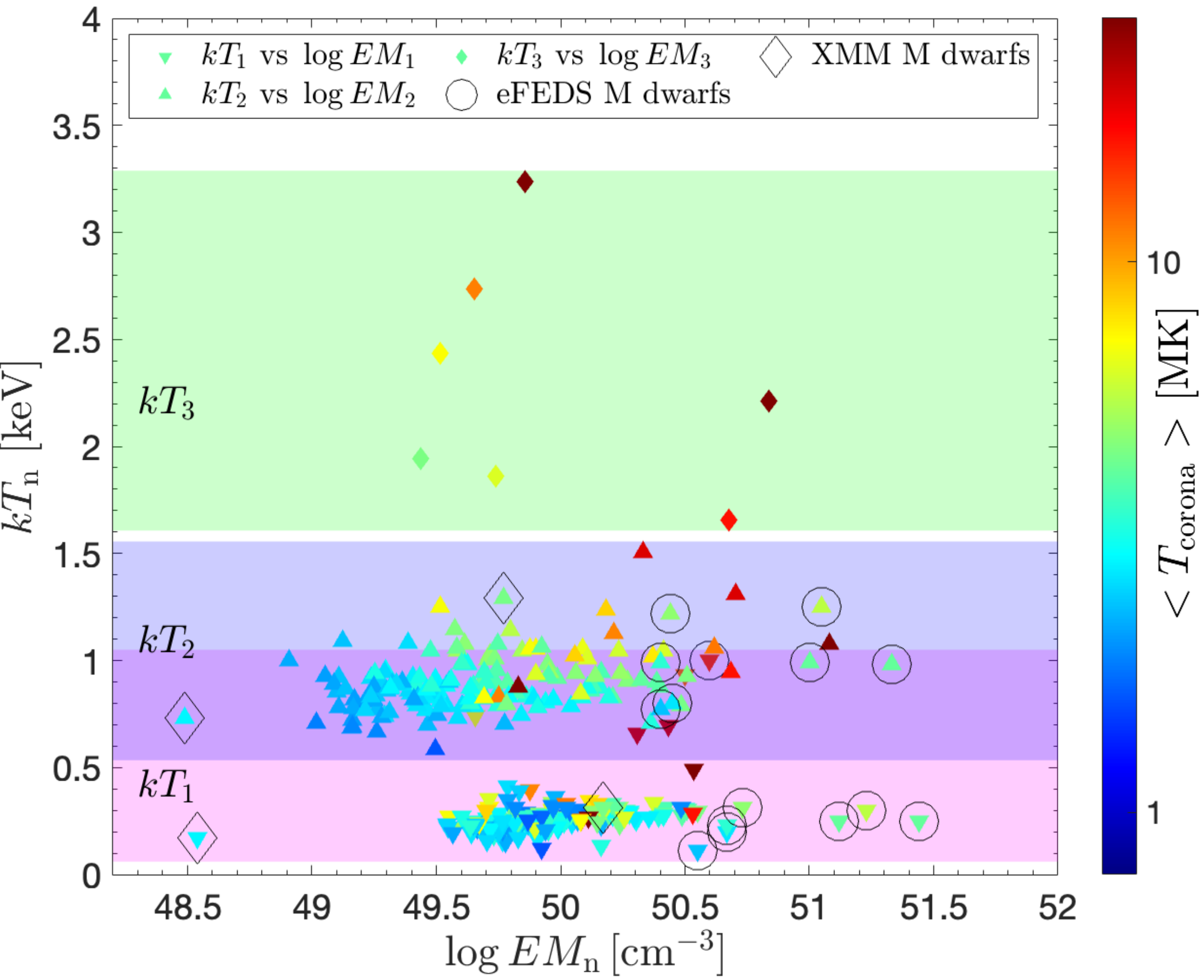
same flare shape after ~10 yr
→ did the active region persist for so long??



$P_{rot} = 89.8\,\mathrm{d}$ and Time_gap = 7.58 yr = 33.25 rotations

→ **Face-on in 2001 as well as in 2009**

Coronal temperature and activity states



Total obs. From XMM-Newton

Total obs. From eRASSs

Combined effect of instrumentation and activity states