The rotation-activity-age relation of M dwarfs in the era of Kepler and K2

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Why is the rotation-activity-age relation of M dwarfs interesting?

**PROBLEM:** Spin-down phase for G stars tied to the Sun, for M stars longer + unknown.

Constrain spin-down models with observations of rotation and age.
APPROACH: calibrate separately the rotation – activity relation and the activity – age relation.
Sample selection:

Based on "SUPERBLINK"

159 stars within 10pc of the Sun (volume-limited !)

~ 9000 STARS

134 stars within K2-mission FOV campaigns C0 ... C4

J < 10 mag

V – J > 2.7 mag

μ > 40 mas/yr

"The UV and X-ray activity of the M dwarfs within 10 pc of the Sun"
Stelzer et al. 2013, MNRAS

"A path towards understanding the rotation-activity relation of M dwarfs with K2 mission, X-ray and UV data"
Stelzer et al. 2016, MNRAS
Age (long-term) evolution of X-ray activity

Stelzer et al. (2013)

GALEX UV + ROSAT X-ray study for:
* “10pc sample” (field star ages)
* M dwarfs in TWA (10Myr)

→

* high-energy emission drops by 3 dex from 10Myr to Gyrs
* age decay faster at shorter \( \lambda \)
Age (long-term) evolution of X-ray activity

**GALEX UV + ROSAT X-ray study for:**
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$\beta_{\text{X}} \sim -1.1$
$\beta_{\text{FUV}} \sim -0.9$
$\beta_{\text{NUV}} \sim -0.7$

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Stelzer et al. (2013)
See also Shkolnik & Barman (2014)
Age (long-term) evolution of X-ray activity

How to constrain the evolution of X-ray and UV luminosity at ages > few 100 Myrs?

Approach: Use White Dwarfs in resolved binaries with M dwarfs as a chronometer

Stelzer et al. (2013)
See also Shkolnik & Barman (2014)
M stars

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Stelzer et al. (2013)
See also Shkolnik & Barman (2014)

* First evidence of decay of \( L_X \) with age for old M stars.

* Some outliers with strong X-ray emission

Stelzer et al., in prep.
X-ray spectrum for 4 M stars with known age → X-ray temperature $T_x$

* First $T_x – F_x$ relation for M stars with individual ages.

* Trend of decrease with age of both parameters.

→ input to models of planet atmosphere evolution

Stelzer et al., in prep.
APPROACH: calibrate separately the rotation – activity relation and the activity – age relation.
Sample for rotation – activity study:

**M dwarfs from Lepine & Gaidos (see 10pc-sample)** → nearby stars, 3-month K2 lightcurves

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

**ACTIVITY:**

(a) photospheric activity

→ e.g. Flares in K2 lightcurves

(b) coronal activity

→ X-ray emission from ROSAT (All-Sky Survey), XMM-Newton archive, XMM + Chandra follow-up

→ Rotation period from Kepler and K2 - Missions
K2 lightcurve analysis

Bottom panels: original detrended lightcurve  (by A. Vanderburg)

Top panels: rotational signal removed and flares flagged
**K2 lightcurve analysis**

Diagnostics of magnetic activity:

* amplitude of rotation cycle
* flares
* residual variability (\(S_{\text{flat}}\))
Photometric activity drastically changing at $P_{\text{rot}} \sim 10$ d

Stelzer+16.
Updated Figs.
S.Rätz
There is unresolved variability in lightcurves of fast rotators, e.g. nano-flares, many small/rapidly changing spots (signatures of energy build-up)
Rotation-activity relation for M dwarfs from the literature

Problems:
* spectroscopic rotation measurement: $v \sin i$
  (only upper limit on $P_{\text{rot}}$)
* inhomogeneous X-ray data
  (many young stars from open clusters)

Pizzolato et al. (2003)
Rotation-activity relation for M dwarfs with K2-mission data

26 detections in ROSAT, XMM archives

* X-ray saturation level decreases for later SpT

* X-ray saturation turn-off corresponds to transition period seen for photometric activity.

Stelzer et al. (2016)
Rotation-activity relation for M dwarfs with K2-mission data

26 detections in ROSAT, XMM archives

RASS upper limit

- info in correlated regime limited by X-ray data

Stelzer et al. (2016)
Rotation-activity relation for M dwarfs with K2-mission data

26 detections in ROSAT, XMM archives

Chandra follow-up

XMM-Newton follow-up

* A steep decay?

* Fully convective stars are the X-ray faintest?

Magaudda et al, in prep.
Rotation-activity relation for M dwarfs with K2-mission data

- 26 detections in ROSAT, XMM archives
- Fully convective boundary
- Chandra follow-up
- XMM-Newton follow-up

* A large scatter of $L_x$ at given long $P_{rot}$

Magaudda et al, in prep.

Wright+18: Ground-based $P_{rot}$ (MEarth) + Chandra follow-up
Rotation-activity relation for M dwarfs with K2-mission data

A steep decay
or
A large scatter of $L_x$ at given long $P_{rot}$?

Magaudda et al, in prep.

fully convective boundary

26 detections in ROSAT, XMM archives

Chandra follow-up

XMM-Newton follow-up
Rotation-activity relation for M dwarfs with K2-mission data

![Graph showing rotation-activity relation for M dwarfs]

- 26 detections in ROSAT, XMM archives
- Chandra follow-up
- XMM-Newton follow-up

Wright+18: Ground-based $P_{\text{rot}}$ (MEarth) + Chandra follow-up

A steep decay
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Magaudda et al, in prep.
Rotation-activity study with the main Kepler mission

- 16 XMM-Newton observations in Kepler field (Pizzocaro et al., A&A subm.)
- 102 main-sequence stars SpT AFGKM joint with Kepler/XMM
- typ. XMM exposure: 50 ksec (typ. P_{\text{rot}} \sim 1…50 \, \text{d})

NEXXUS sample

Kepler sample

X-ray selected Kepler sample is biased towards active stars
Rotation-activity study with the main Kepler mission

M dwarfs: Kepler sample (*Pizzocaro et al.*), K2 + ROSAT sample (*Stelzer+16*), Earth-based sample (*Wright+16,+18*)

FGKM dwarfs: Kepler sample, Earth-based sample (*Wright+11*)

SUMMARY:

- **Rotation**
- **Angular momentum evolution** (magnetic braking)
- **Age**

- A `mode-change` in photometric activity indicators at \( P_{\text{crit}} \approx 10 \text{ d} \)
- Non-saturated regime:
  - Decay law to be quantified
  - Large spread in X-ray emission at given \( P_{\text{rot}} \) or \( R_0 \)

- First constraints on X-ray luminosity and temperature of M dwarfs as function of age

**Activity**
(X-rays, UV, opt.lines)
Major problem:

Samples accessible to multi-wavelength observations

But:

More data is coming!  \(\rightarrow\) K2 Short Cadence, TESS, PLATO, eROSITA X-rays