X-ray cycles and magnetic activity of solar-like stars
XMM-Newton meets eROSITA

J. Robrade & J.H.M.M. Schmitt
Hamburger Sternwarte, University of Hamburg, Germany, e-mail: *jrobrade@hs.uni-hamburg.de*

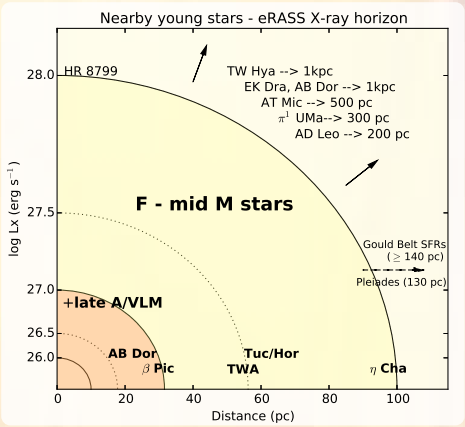
Abstract: Since the beginning of its operation XMM-Newton carries out a monitoring program to study X-ray cycles, including the nearby stellar systems α Centauri and 61 Cygni. In all studied target stars the X-ray emission varies overall smoothly on timescales of years, indicating that coronal cycles are common in weakly active solar-type stars. The derived global X-ray properties and cyclic phenomena are in line with those observed from the Sun. As an outlook and complementing ongoing pointed observation, future perspectives of stellar X-ray studies with the eROSITA all-sky survey are presented.

The eROSITA all-sky survey (eRASS)

- eROSITA/SRG (D/Ru) – launch end 2017, L2 halo orbit
- 7 co-aligned X-ray telescopes + CCDs, FOV 1.03°⌀
- HEW 15/28″, eff. area@1keV 2400/1400 cm^2 (on-axis/survey)
- 4 yr all-sky survey, 0.3 – 10.0 keV energy range
- lim. $F_X \approx 1 \times 10^{-14}$ erg cm^{-2} s^{-1} (point sources)

eROSITA and Stars

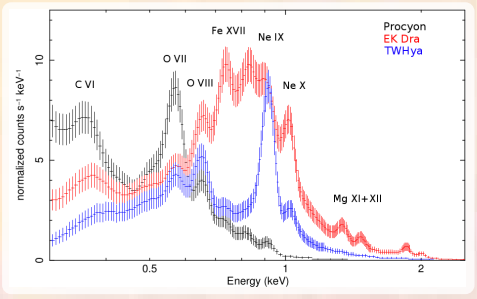
- $\sim$ 0.7 million X-ray stars (Besancon model, Guillout+ 1996)
- order of magnitude sensitivity increase to RASS
- stellar sample well classified by Gaia
- most suited to study SFRs, moving groups, active stars...



X-ray horizon of the eRASS ($L_X \gtrsim 1 \times 10^{24} \times d^2$(pc) [erg/s])

Survey the solar neighborhood

- virtually complete census of young stellar populations up to 100 pc
- X-ray survey of 'rare objects' like young BDs, VLM, Ap/Bp and HAeBe stars
- RECONS 10 pc sample: > 300 stars (4-6-20-44-248, A-F-G-K-M)



eRASS spectra of stars, 2 ks exposure
(3 – 6 cts s^{-1}, $F_X \approx 5 - 10 \times 10^{-12}$ erg cm^{-2} s^{-1})

Spectra and light curves

- **detailed study of many thousands of stars**
- 8 sky-scans (0.5 yr) with 6 scans/day (40 s each)
- variable X-ray activity, transients, flares, cycles
- medium resolution X-ray spectra
- coronal properties and HR classification

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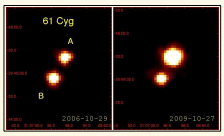
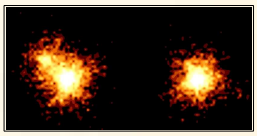


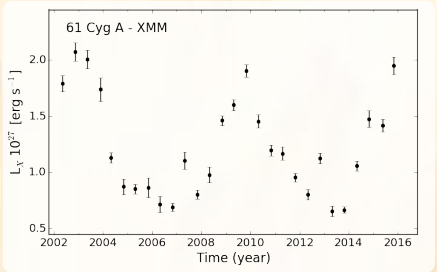
61 Cygni A/B
(XMM-Newton, 2006/2009)

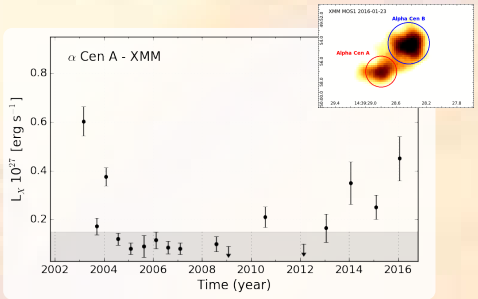


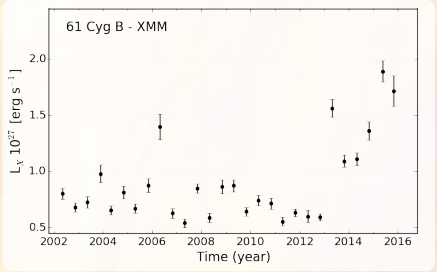
Alpha Centauri A/B
(XMM-Newton, 2003/2005)

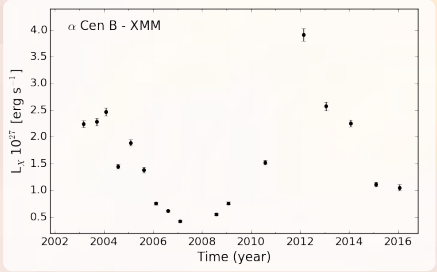
Coronal activity cycles in nearby G and K dwarfs

X-ray observations of the binaries 61 Cyg A/B and α Cen A/B show significant long-term variability in all component stars; full activity cycles are covered in 61 Cyg A and α Cen B. The observed X-ray cycles differ in amplitude and period, yet spectral changes of the coronal X-ray emission over the cycles are solar-like in all studied targets.









61 Cyg A/B (K5V + K7V)

- monitored since May 2002, well resolved
- chromospheric cycles of 7.3 yr (A), 11.7 yr (B)
  (Baliunas et al. (1995), Hall et al. (2007)
- **61 Cyg A**
  - smooth and persistent coronal activity cycle
  - cycle quite stable over $\sim$ 40 years (X-ray + Ca II HK)
  - X-rays and Ca II HK in phase
- **61 Cyg B**
  - more irregular chromospheric cycle, long-term variable
  - coronal cycle indistinct/non-sinusoidal

α Cen A/B (G2V + K1V)

- monitored since April 2003, mod./poorly resolved
- X-ray detected activity cycles (+ FUV/UV data)
- *Chandra* HRC-I joined in 2005 (Ayres 2009, 2014)
- **α Cen A**
  - strong decline of L_X in about two years
  - extended minimum over 10 years, very inactive phase
  - clear re-detection by XMM in 2016 (at 4″ sep.)
  - no maximum covered, likely period $\gtrsim$ 15 yr
- **α Cen B**
  - cyclic activity, period $\sim 8 - 9$ yr, MWL: 8.8 yr (de Warf et al., 2010)
  - activity maximum in 2012, brightest X-ray observation within 30 years ($L_X \approx 4 \times 10^{27}$ erg s^{-1})
  - coronal cycle similar to solar one

Global stellar+coronal properties

- stellar systems are old (6 ±1 Gyr) and all components rotate slowly ($P_{rot} \approx 30 - 40$ d)
- weakly to moderately active stars, $\log L_X/L_{bol} \lesssim -5.5$
- coronae dominated by cool plasma at $T_X \approx 1.0 - 2.5$ MK
- presence of 6 – 8 MK plasma around activity maxima

Par.	α Cen A	α Cen B	61 Cyg A	61 Cyg B	Sun
sp. type	G2V	K1V	K5V	K7V	G2V
P_{act} (yr)	$\sim$15?	8-9	7	$\gtrsim$12?	11
$\log L_{Xmax}$	26.8	27.6	27.3	27.2	27.8
$\log L_{Xmin}$	$\approx$26	26.6	26.8	26.7	26.7
$\log L_X/L_{bol}$	−7.0	−6.2	−5.6	−5.5	−6.1
Ampl.	$\sim$10?	6-9	3	3?	12

Stellar X-ray cycle properties, 0.2 – 2.0 keV, quasi-quiescent state from EPIC, $\log L_X$ in [erg s^{-1}]. Solar data: Judge et al. (2003), scaled to 0.2 – 2.0 keV; Ayes (2014) gives $\log L_X \sim 26.3 - 27.3$.

Characteristics of cyclic coronae

- phenomenology independent of spectral type or activity level
- strong changes of emission measure over X-ray cycle
- variability is 'solar-like' in all studied cases:
  - variability more dominant in respectively hotter plasma
  - similar coronal structures with variable filling factors
  - coronal cycle properties are energy band dependent

	61 Cyg A			α Cen B		
kT (keV)	EM_{max}	EM_{min}	EM_{ratio}	EM_{max}	EM_{min}	EM_{ratio}
$\sim$ 0.1	64%	78%	1.6	67%	83%	3.8
$\sim$ 0.3	28%	20%	2.8	31%	17%	8.6
$\sim$ 0.7	8%	1%	10.	2%	-	$\gtrsim$ 15

Typical coronal emission measure distribution at max. and min. activity, $EM_{max/min}$ are the relative contributions, EM_{ratio} of absolute values.

Corresponding publications: Robrade et al. (2005), Hempelmann et al. (2006), Robrade et al. (2012).