A survey of long-term X-ray variability in cool stars

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X-ray variability in cool stars can be indicative of coronal magnetic field changes and reconfiguration from a variety of phenomena, including flare events (typical timescales of minutes – hours), active-region evolution (hours – days – weeks), rotational modulation (hours – days – weeks), and activity cycles (years – decades). As part of the EXTraS project (Exploring the X-ray transient and variable sky – http://www.extras-fp7.eu/), we have performed a systematic survey of 'long-term' X-ray variability using the ~decade-long public database of XMM-Newton observations. We are thus focussing here on timescales from ~a day to ~a decade, using average flux values from individual XMM-Newton observations. Though the resulting sampling is often highly non-uniform in time, the light-curves can provide valuable insights into the magnetic activity outside of shorter-term flaring episodes. We have taken a number of stellar samples and evaluated the statistical properties of the flux distributions, and compared these across, for example spectral type, and with previously-published estimates. We have also examined the potential effects of flare events on the apparent long-term variability estimates. We report here on overall variability distributions and extreme cases, focussing on serendipitously-observed stars (yielding, in some sense an unbiased sample).

Previous stellar X-ray surveys (see e.g. DeWarf+ 2010, ApJ, 722, 343; Robrade+ 2012, A&A, 543, A84; Hoffman+ 2013, ApJ, 759, 145; Sanz-Forcada+ 2013, A&A, 553, L6; review by Güdel 2004, A&ARv, 12, 71) have indicated long-term variability generally <~factor 2 – 3, with a few examples at ~5 – 10. Measured levels of variability have often been dependent on photon-energy band, with emission at higher photon energies more variable than lower energies (i.e. high-temperature material exhibiting more variability than lower-temperatures). In several cases activity cycles have been reported.

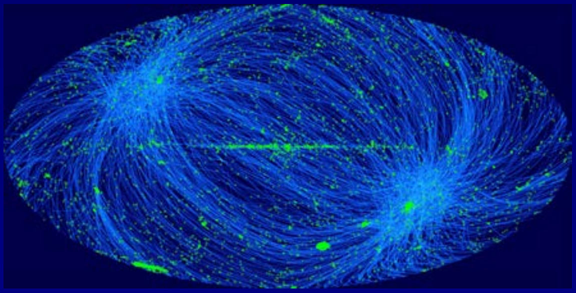

Fig.1. XMM-Newton sky coverage

A sky map in galactic coordinates, showing the pointed observations (green points; forming the basis for the 3XMM source catalogue; early-2000 – Dec 2013) and the slew-survey paths (blue; Aug 2001 – Dec 2014). The pointed observations cover ~2% of the sky, with an average exposure time ~20 ks, while the slew survey covers ~84% of the sky, with typical exposure ~1 – 12 s.

Data selection & analysis

- Used 3XMM-DR5 serendipitous source catalogue (Rosen et al, 2016, A&A, 590, A1). This provides a large, uniform sample (~566k detections comprising ~397k unique sources).
- Not used observations with non-detections (i.e. flux upper limits) or slew-survey results in the current analysis.
- Used a very simple variability indicator: **R = max_flux / min_flux**, per source, where the flux is the total-band (0.2–12 keV), average value over each XMM exposure.
- Applied quality and other filtering for each source (using information directly available in 3XMM).
- Examined as separate subsamples, '**V**' those sources flagged in 3XMM as 'time variable' (SC_VAR_FLAG = TRUE, i.e. at least 1 exposure showed significant variability), and '**NV**' those sources not thus flagged (which we will term 'not variable'). XMM catalogue and data products allow detailed examination of effects of short-term variability on long-term light-curves.
- The stellar sample presented here is from the CDS **SIMBAD** database:
  - Used B-V>0.3 + SIMBAD object type & spectral type where available to define a 'cool-star' sample.
  - SIMBAD sample is rather inhomogeneous due to its nature, but is relatively large.

Results: example distributions & statistics

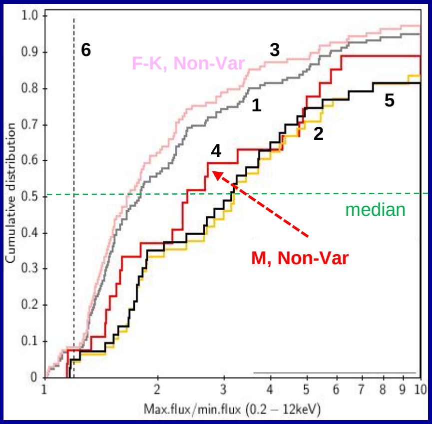

Fig.2. Cumulative distribution of max:min flux ratio, R, for SIMBAD stars/3XMM subsamples:

1 (grey). F – M stars NV
2 (yellow). F – M stars V
3 (pink). F–K stars NV
4 (red). M stars NV
5 (black). F–K stars V
[M stars V: not plotted due to v.small sample size]
6. dashed line: median value for constant source flux (from simulations)
V/NV: see 'Data selection & analysis' box

Summary of long-term variability from SIMBAD sample

- [R = max_flux / min_flux]
- ~650 F – M stars
- F, G, K stars: median ~1.7 [Fig.2, curve 3]
- M stars: median ~2.6 [Fig.2, curve 4]
- → Typical variability amplitude, factor ~2 – 3
- → M stars appear to show more variability than F–K (though possible effects of short-term variability not yet fully investigated)
- Short-term variability adds significantly, but does not appear to dominate, the measured long-term variability distributions, increasing the median R by factor <2 (Fig.2). In general, the effects of short-term variability can be separated from the longer-term.
- For a set of non-variable sources, we have determined by simulation that R_median ≈1.2 (indicated by the vertical dashed line in Fig.2).
- We see cases where apparent long-term variability *is* due to short-term flaring and cases where there *is no detectable* short-term enhancement (Fig.3).
- Potential for statistical studies of activity cycles & active-region evolution [serendipitous data likely too sparse for detection of individual cycle periods]

Results: individual [extreme] cases

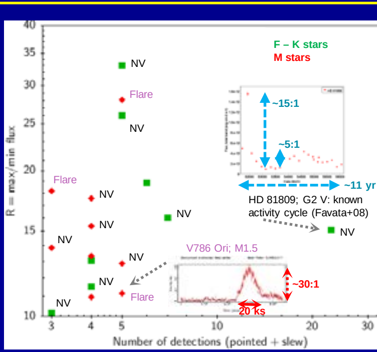

Fig.3. Max:min flux ratio, R, vs number of XMM detections for each star

- Towards the 'extremes' of the variability distributions, R >~5 – 10
- ~10 – 15% of stars have R>5
- M stars appear more variable

NV = no discernible short-term variability;
Flare = apparent long-term variability may be dominated by flare(s)