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 are performing 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 (Hipparcos-Tycho, Simbad …) and are evaluating the statistical properties of the flux distributions, and comparing these across, for example spectral type, and with previously-published estimates. We are also examining the potential effects of flare events on the apparent long-term variability estimates. We give here a preliminary report, based on the 3XMM-DR5 source catalogue, 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.

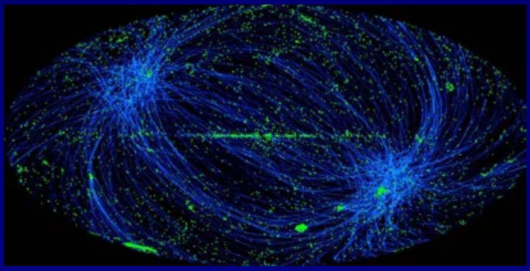

Fig.1. XMM-Newton sky coverage (to ~Dec 2013)
A sky map in galactic coordinates, showing the pointed observations (green points; forming the basis for the 3XMM source catalogue) and the slew-survey paths (blue). The pointed observations cover ~2% of the sky, with an average exposure time ~20 ks, while the slew survey covers ~70% of the sky, with typical exposure ~1 – 12 s.

Selection of stellar samples

- Tycho-2 (Hog+ 2000) & SIMBAD.
- Used B-V>0.3 + SIMBAD object type & spectral type where available to define a 'cool-star' sample from each of Tycho & SIMBAD.
- SIMBAD sample rather inhomogeneous due to its nature, but is larger and contains a much higher fraction of dM stars.

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 at this stage.
- 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):
  - Number of detections >=3 (i.e. at least 3 data points in each long-term light-curve
  - Relative error in R <=30%
  - Not 'confused' i.e. no ambiguity in assignment of detection to a source
  - Point-like, i.e. not detected as spatially extended
  - 3XMM quality flag: worst SUMFLAG value <=2 (for any detection comprising the source)
- Considered 'not target' [NT] sources as those with a minimum off-axis angle >=1.5 arcmin.
- 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.

Results: distributions & statistics

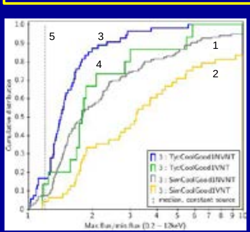

Fig.2. Cumulative distribution of max:min flux ratio, R, for several stars/3XMM subsamples:
1 (grey). SIMBAD-stars NV
2 (yellow). SIMBAD-stars V
3 (blue). Tycho NV
4 (green). Tycho V
5. dashed line: median value for constant source flux (from simulations)
V/NV: see 'Data selection & analysis' box

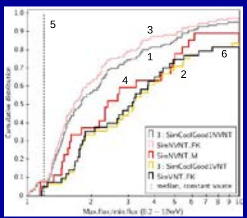

Fig.3. as Fig.2, for SIMBAD-stars/3XMM subsamples:
1, 2, 5: as Fig.2
3 (pink). F–K stars NV
4 (red). M stars NV
6 (black). F–K stars V
[M stars V: not plotted due to v.small sample size]

Summary of long-term variability

- [R = max_flux / min_flux]
- Tycho/3XMM sample (see Fig.2):
  - Median R ~1.5 – 2
- SIMBAD-stars/3XMM sample (see Figs.2, 3)
  - Median R ~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 (Figs.2, 3). 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 Figs.2, 3).
- We see cases where apparent long-term variability *is* due to short-term flaring and cases where there *is no detectable* short-term enhancement (see Fig.4).

Results: individual cases

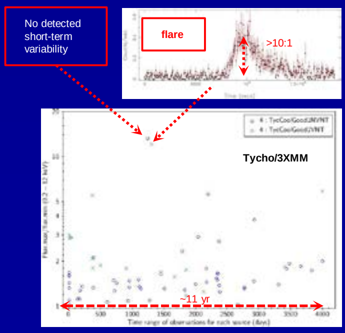

Fig.4. Max:min flux ratio, R, vs time range of observations for each star (last obs – first obs; days). 2 example high-variability (R>10) points are indicated: (i) due to a flare; (ii) where a star has no detected short-term variability.

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