Unveiling long-term variability in XMM-Newton surveys (the EXTraS project)

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The 3XMM-DR4 catalogue, the XMM-Newton Slew Survey (XSS) and the associated XMM-Newton EPIC data, are extensive resources for exploring high energy, time-domain astrophysics. Amongst these data are potential, hitherto unidentified variable sources, ranging from short duration (~seconds) transients through to objects varying on timescales of years. Variability signatures can be key to understanding the energetics and physical processes in a diverse range of astrophysical settings. The EU/FP7-Cooperation Space framework project, `Exploring the X-ray transient and variable sky' (EXTraS), aims to exploit these XMM-Newton resources to explore, as fully as possible, the range of X-ray variability present and provide the results to the community through a public database. Here we outline one of the project's core aims, i.e. identifying and characterising long-term (days to years) variability. The 3XMM-DR4 catalogue contains ~67000 sources comprising at least 2 detections, with some objects observed up to 44 times. In conjunction with the XSS, which has now covered ~68% of the sky, often with multiple slews, there is excellent scope for identifying new variable objects that manifest themselves through changes in luminosity between XMM-Newton observations. We discuss the plans for the EXTraS long-term variability catalogue and highlight some examples of the detection of long-term variability in 3XMM-DR4/XSS data.

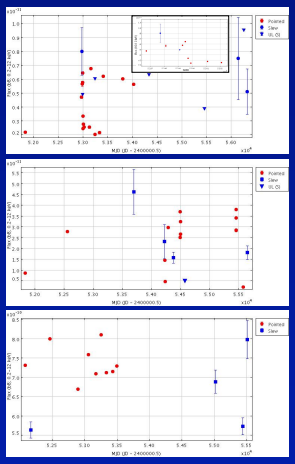


Figure 2: Three examples of long term light curves combining 3XMM-DR4 and slew survey flux data, including upper limit information. 3XMM-DR4 data is shown in red, slew data in blue. Upper limits are indicated by triangles. The inset in the first plot focuses on the near-vertical set of points around MJD 53000. All examples show very significant long term-variability.

Statistics of the XMM-Newton catalogues

	3XMM-DR4	Cleaned Slew Survey (xmms1D6) *
Number of detections	531261	20163
Number of unique sources	373728	~18400
Unique sources with > 1 detection	66728 (up to 44 repeats)	> 950 (up to 8 repeats)
Non overlapping sky coverage	1.9%	~68%

* The slew survey catalogue will be improved and augmented as part of the EXTraS project

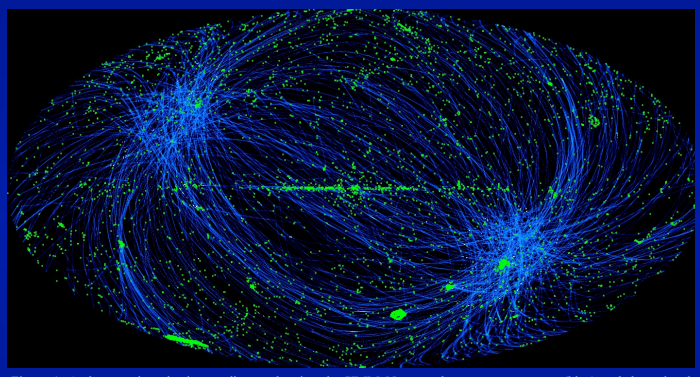


Figure 1: A sky map in galactic coordinates showing the XMM–Newton slew survey coverage (blue) and the pointed observations (green) from the 3XMM-DR4 catalogue. The slew survey has now covered ≈ 68% of the sky, typically with an exposure of between 1 and 12s, with some areas, such as the ecliptic poles having multiple overlapping slew coverage. The pointed observations cover around 1.9% of the sky but with an average exposure of ~18ks (pn) and 22.5ks (MOS).

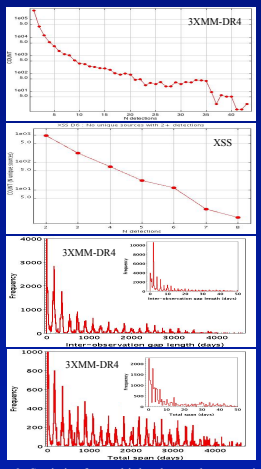


Figure 3: Statistics for multiply-observed sources in the 3XMM-DR4 and XMMSL1D6 slew survey catalogues.

Upper panel: Number of unique sources in 3XMM-DR4 comprising N detections (repeat observations). Second panel: As upper panel but for the XMMSL1D6 slew survey (XSS) data. Third panel: distribution of gap lengths (in days) between consecutive observations of the same unique source in 3XMM-DR4. Lower panel: Distribution of time spans (in days) between first and last observations of a unique source in 3XMM-DR4. Insets in the latter two plots focus on the short interval regions.

The average inter-observation gap duration is 454 days while the average total span is 1079 days.

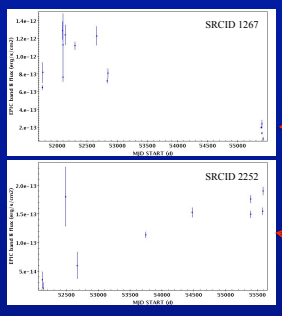
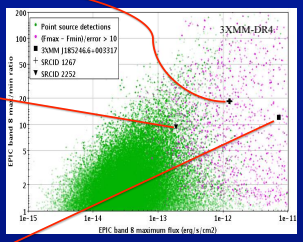


Figure 5: Long-term light curve of 3XMM-DR4 unique sources (SRCID) 1267 (upper panel) and 2252 (lower panel)



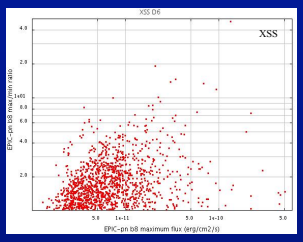
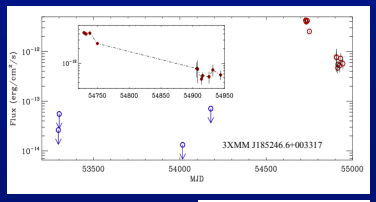


Figure 4: Finding long-term variable sources: One simple approach is illustrated above. The plot on the left shows the maximum/minimum flux ratio derived from the constituent detections of each 3XMM-DR4 unique source, plotted against the maximum EPIC band 8 flux of the source - each point represents a unique source. Green points are all 'clean', point-like sources, while magenta points are the subset where the normalised flux difference, i.e. (maximum-minimum)/σ, is > 10 (σ is the error on the flux difference). The data enable us to recognise objects with significant long-term variability. The black square is for 3XMMJ185246.6+003317 (see fig. 6). Two other example sources that display prominent variability amongst their photometric data (see fig. 5) are highlighted by the black cross and black triangle. The examples in figs. 2, 5 and 6 illustrate the potential of the EXTraS project in discovering new, interesting objects and studying the long-term behaviour of known sources.

The right panel shows the same distribution of maximum/minimum flux v maximum EPIC band 8 flux but for the current XMM-Newton slew survey (XSS) data. Given the large sky area covered by the slew survey, the majority of even singly-observed 3XMM-DR4 detections will have at least upper limit information from the slew data. Ultimately, these data will be combined as a goal of the EXTraS long-term variability project.



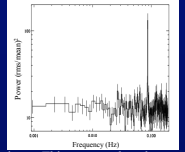


Figure 6: Discovered via its long-term variability (above, where red points are 3XMM-DR4 detections and blue points are upper limits) (L. Heil, priv. comms.), the power spectrum (right panel) of 3XMMJ 185246.6+003317 shows a strong ~11s pulsation within the separate XMM-Newton observations. This source has been proposed as a rare, transient, low-field ($B \leq 4 \times 10^{13}$ G) magnetar ([1][2])

The EXTraS long-term variability work aims to:

1. Enhance the processing of XMM-Newton slew data, e.g. trialing the use of a slew-specific PSF, exploiting improved attitude reconstructions, using the latest XMM-Newton SAS software and optimising the rejection of high background intervals.
2. Create a catalogue of detections, combining the XMM-Newton 3XMM-DR4 and updated slew survey catalogues.
3. Add upper limits from any XMM-Newton pointed or slew survey fields where a combined-catalogue source position is covered but not detected. A version of the existing FLIX upper limit server (http://www.ledas.ac.uk/flix/flix.html) will be developed to facilitate the use of slew data.
4. Identify and apply optimum methodologies to search for variability amongst the detections and upper limits of each multiply-observed unique source.
5. Explore and exploit approaches to characterise the amplitude and duration of the variability, where present. Characterising long-term variability in XMM-Newton data is complicated by the generally highly non-uniform sampling that is dictated by the observing strategy of the observation proposal for repeatedly targeted fields or the often broadly random sampling of fortuitously overlapping mosaics.
6. Publicly release the results through the EXTraS project database.

References:
[1] 3XMM J185246.6+003317: Another low magnetic field magnetar. Rea et al., 2014, ApJL, 781 L17.
[2] Discovery of the transient magnetar 3XMM J185246.6+003317 near supernova remnant Kesteven 79 with XMM-Newton. Zhou, P. et al., 2014, ApJL, 781, L16