# Unveiling long-term variability in XMM-Newton surveys within the EXTraS project


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(on behalf of the EXTraS project)



The EXTraS project (Exploring the X-ray transient and variable sky) is an EU/FP7-Cooperation Space framework programme that aims to bring together a diverse set of time-domain analyses of XMM-Newton X-ray data and make them available to the public in a coherent manner. Through a combination of pointed observations and slew scans, XMM-Newton has repeatedly observed many regions of the sky, in a few cases up to ~50 times, with ~70000 sources being observed more than once. While non-uniformly spaced and often sparse, these snapshots provide scientifically valuable information on the photometric behaviour of sources on longer term (hours to ~ a decade) timescales. Here we describe the collation of XMM-Newton data for long-term variability from the 3XMM-DR5 catalogue, the latest slew survey and upper-limit information from the associated XMM-Newton products, and the analysis being performed on the ensuing light curves. We also present emerging examples of some newly identified long-term variable sources to highlight the value of this element of the EXTraS project. These longer baseline light curves can (i) unveil variable sources that appear stable in individual observations, (ii) reveal exotic and transient sources and (iii) complement short-term variability information from elsewhere in the EXTraS project by probing slower physical phenomena.


## The data and analysis

Analysis for the long-term-variability (LTV) component of the EXTraS project exploits (i) detections from the 3XMM-DR5 catalogue [1], (ii) detections from the latest bulk re-processing of the XMM-Newton slew survey (Read et al., in preparation) and (ii) upper limit information* for all unique sources comprising pointed and/or slew detections, extracted from any pointed or slew observations in which the source was not detected.

The slew data benefit from several improvements to slew processing, including better characterisation of the PSF, refined handling of high-background intervals, and better treatment of sources at the boundaries of sub-images along the slew path, as well as embracing around 800 new or previously un-analysed slew observations.

The photometric data for the LTV analysis are computed in bands 6 (soft=0.2-2.0 keV), 7 (hard=2.0-12.0keV) and 8 (0.2-12.0 keV). Photometry is provided in the form of fluxes and count rates for each instrument (pn, MOS1, MOS2 and all-EPIC), along with a hardness ratio from bands 6 and 7.

The XMM-Newton long-term light curves are often sparse and generally non-uniformly sampled. Analysis of potential long-term variability employs simple measures, including a $\chi^2$ test against constancy and finding the largest $(F_{max} - F_{min})/\sigma$ change of any pair of points in the timeseries, where $F_{max}$ and $F_{min}$ are the highest and lowest fluxes and $\sigma$ is the uncertainty on $F_{max} - F_{min}$ (see also [4]). A runs (Wald-Wolfowitz) test is also applied. The timescales for the largest flux changes, along with those for the fastest factor 2 and factor 10 rises and declines, are provided.

* from a version of the FLIX upper limit server (http://www.ledas.ac.uk/flix/flix_dr5.html), tailored for EXTraS.

## Statistics of the XMM-Newton catalogues

| | 3XMM-DR5 | Cleaned Slew Survey |
|---|---|---|
| Number of detections | 565962 | 29945 |
| Number of unique sources | 396910 | 23840 |
| Unique sources with > 1 detection | 70453 (up to 48 repeats) | 3807 (up to 14 repeats) |
| Non overlapping sky coverage | 2.1% | ~70 % |

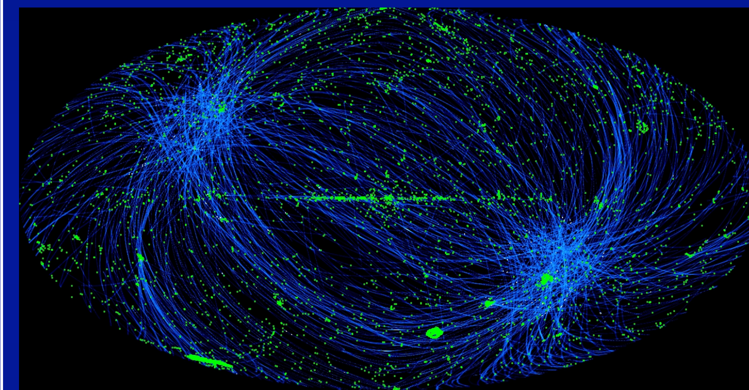

Figure 1: A sky map, in galactic coordinates, showing the XMM–Newton XMMSL1 slew survey coverage (blue) and the pointed observations (green) from the 3XMM catalogue. The slew survey has now covered ≈ 70% of the sky, typically with an exposure of between 1 and 12s, with some areas, such as the ecliptic poles having multiple overlapping slew coverage. The pointed observations cover around 2% of the sky but with an average exposure of ~18ks (pn) and 22.5ks (MOS).

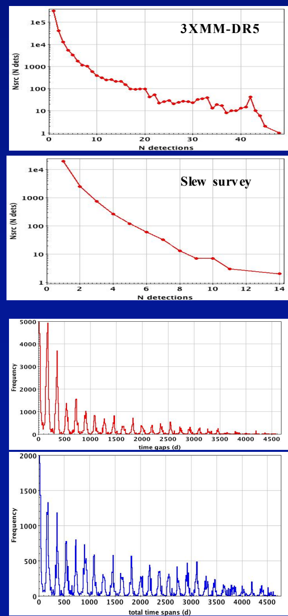


Figure 2: Statistics for multiply-observed sources in the 3XMM-DR5 catalogue and latest slew survey data.

Upper panel: Number of unique sources in 3XMM-DR5 comprising N detections (repeat observations). Second panel: As upper panel but for the slew survey data. Over 70000 sources have been observed more than once, one being observed 49 times. The third and fourth panels show the distributions of the gap lengths between consecutive observations of the same source, and of the time spans between the first and last observations of a source, respectively. The spikes arise from the observation scheduling and constraints.

The average inter-observation gap duration is 490 days. The average total span is 1167 days.

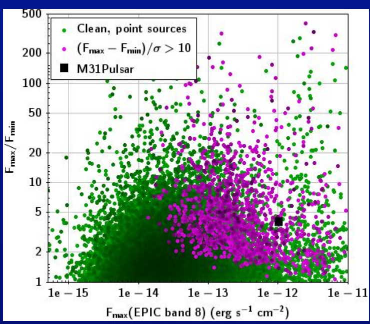


Figure 3: Ratio of the EPIC band 8 flux from the brightest and faintest detections (Fmax/Fmin) of each unique source, plotted against the brightest flux, Fmax. Green points are all point sources with 'clean' quality; magenta points are the subset where the significance of the flux change is > 10. The M31 pulsar (figure 4) is shown as a black square. The data highlight the range of flux changes amongst sources in the LTV data and facilitate selection of sources with significant long-term variability.

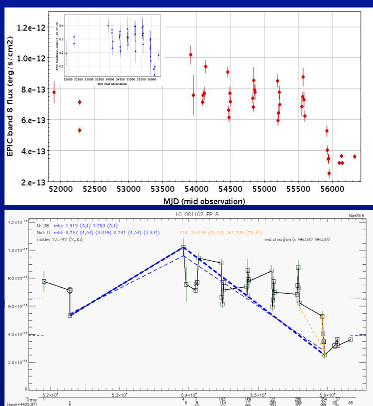


Figure 4: Upper panel shows the long-term EPIC band 8 light curve of the 1.2s pulsar discovered in M31 through the EXTraS project [2] (observed 38 times). The inset shows the hard-soft band hardness ratio. The drop in intensity at the end of the light curve is accompanied by a notable softening of the source. The lower plot shows the EPIC band 8 LTV graphic product that highlights the timescales of the largest rise and decline in the lightcurve (blue dashed lines) and the fastest factor 2 decline (orange dashed line).

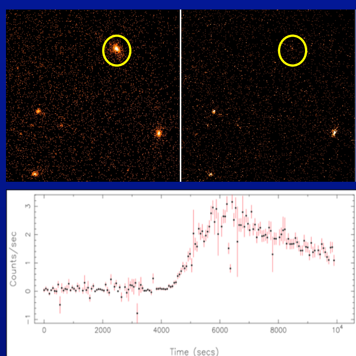


Figure 5: Upper plot displays a pair of images from two separate XMM-Newton observations of a previously unidentified X-ray source (circled) that brightens strongly in one of the observation. The lower plot shows the short-term light curve from the pn camera during the observation where it is bright, indicating it is likely to be a flare star. WISE measurements indicate a colour, W1-W2=0.23 +/- 0.03, consistent with an M3 dwarf.

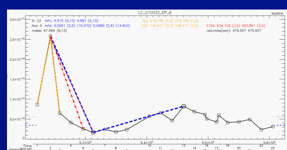

Figure 6: Long-term EPIC band 8 light curve graphic of HD81809. The early half of the data has been reported [3]. The more recent data highlight the modulation associated with the star's ~8yr solar-like cycle.

## Data availability

The composite LTV data, including the photometric measurements and the LTV characterisation, will be made public via the EXTraS project database, alongside the results from the other components of the EXTraS project. This is expected to be available by the end of 2016.


References:
[1] Rosen, S.R., et al., 2016, A&A, 590, A1.
[2] Esposito, P., et al., 2016, MNRAS, in press (http://arxiv.org/abs/1512.00467).
[3] Favata, F., et al., 2008, A&A, 490, 1121.
[4] Lin, D., Webb, N.A., Barret, D., 2012, ApJ, 756, 27.