A search for large amplitude X-ray variables with the XMM-Newton Serendipitous Survey

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Abstract

I report on our ongoing programme to search for X-ray sources with long-term, large amplitude X-ray variability. The method is to compare the fluxes of X-ray sources from the XMM-Newton Serendipitous Survey with those from previous ROSAT pointed observations and the ROSAT All-sky Survey. Here I decribe the method and present some of the preliminary results, part of which has been presented in Yuan et al. (2004, 2006).

Key words: X-ray sources, X-ray flares, variability

1. Introduction

The X-ray sky is an active one. The X-ray emission produced from celestial objects is often variable, some with large amplitudes. There is a rich variety of highly variable X-ray sources, from accreting black hole binaries to active galactic nuclei (AGN). Apart from studying the details of the physical processes in the known types of X-ray variables, monitoring the X-ray sky may also lead to discoveries of new phenomena of X-ray variability. For example, Of particular interest is a new type of non-recurrent X-ray flares from non-active galaxies, which showed variability by a factor of hundreds, or even up to thousands (e.g. Komossa et al. 2004). These events were interpreted in terms of tidal disruptions of stars by the central massive black holes in galaxies (e.g. Rees 1988). In fact, all kinds of high-amplitude variability are of interest in astrophysics, as they are often traces of extremely violent physical conditions or processes, such as, cataclysmic processes of evolution, extreme accretion events, and violent acceleration of high-energy particles.

Generally, observations of the variability of X-ray sources are pursued mainly in two approaches. One is sky monitoring/scanning with dedicated wide-angle/all-sky monitors. It has the advantage of large sky coverage but is usually of low sensitivity and spatial resolution, and can thus observe only relatively bright objects. On the other hand, long observations pointed at pre-selected targets with conventional X-ray observatories can pick up weak sources, but the observational efficiency is low. What is virtually left unexplored lies in between these two regimes—the long-term temporal properties of the bulk of X-ray sources, most of which are extragalactic and faint. To fill this gap, systematic surveys for X-ray variability are needed in large sky regions with high sensitivities and good spatial resolution. The XMM-Newton X-ray Observatory presents such an opportunity, with its a large field of view (FOV), good imaging capability, and high throughput. These virtues enable it to detect significant numbers of X-ray sources in the XMM-Newton Serendipitous Survey (Watson et al. 2001). For the typical exposure time of 20 ksec, its EPIC (European Photon Imaging Cameras) will detect about 50–100 sources over the whole FOV of ~ 0.2 sq. deg. Each year XMM-Newton observations cover $\sim$100 sq. deg. of the sky (detecting $\sim 50{,}000$ sources); a considerable fraction among them was previously observed with ROSAT pointings (PSPC or HRI). These observations thus form an ideal database with which to study the long-term variability of X-ray sources.

Here I describe and report the progress of our on-going programme to search for the long-term variability of X-ray sources along this line. The method is to make use of the data obtained in the fast-growing sky regions covered by both the XMM-Newton Serendipitous Survey and the previous ROSAT pointed observations, and to compare the fluxes of sources measured by the two instruments.

2. Search for X-ray variable sources with XMM-Newton

Our aim is to detect long-term X-ray variability for sources falling within the field of views of both the XMM-Newton and previous ROSAT observations, by comparing the source fluxes at the two epochs. The search was designed to be carried out automatically on a field-by-field basis. The ROSAT catalogues used in the cross-correlation include the 2nd ROSAT PSPC catalogue

(ROSAT team 2000b) the HRI catalogue (ROSAT team 2000a), and the ROSAT All-sky Survey (RASS) (Voges et al. 1999). Though the RASS data are not deep, they are still useful in detecting those which were bright during the RASS but dim during XMM observations. For the matching of XMM and ROSAT sources, we use the results of the catalogue cross-correlation products provided by the XMM-Newton data processing pipeline ('XMM pipeline' hereafter) generated by the XMMSSC. To enable comparisons of the fluxes the restricted energy band in the overlapping 0.2–2.4keV is used. We used the following procedure in the search:

- Retrieve information of all XMM observations and select those with acceptable data quality.
- For a given XMM observation, it is determined whether the field has ever been observed by previous ROSAT (PSPC or HRI) pointed observations.
- The information on the XMM sources are extracted from files generated by the XMM pipeline and the 0.2-2.4keV fluxes are calculated. Their ROSAT counterparts (including the RASS sources) are searched from the cross-correlation catalogues of the XMM pipeline. For sources detected by both XMM and ROSAT, the variability factors are calculated as flux ratios.
- For sources detected in only one of the two missions, the lower limits on the variability factors are obtained by from the flux limits. For ROSAT, the flux limits are estimated from the X-ray images, exposure maps, and background maps at the source positions. For XMM, the sensitivity maps provided by the XMM pipeline are used.
- The X-ray images of the sources are created.
- Select candidates of variable sources for given thresholds.
- Visually inspect each candidate to screen out spurious sources or variables.

Due to various imperfectness of EPIC observations and the X-ray CCDs, the results thus produced contain a large number of spurious cases, which are mainly caused by the detection of spurious sources (mainly from XMM). Thus visual inspection of the X-ray images is carried out to screen out spurious candidates. This problem is expected to become largely resolved with the improvement of the source detection algorithm in the XMM-Newton processing pipeline. The final results are lists of screened candidates of variable sources with estimated variability factors and the X-ray images. As demonstration we show in Fig. 1 the X-ray images of the same piece of sky region as observed by ROSAT (left panel) and XMM (right panel), in which a variable X-ray source was detected with this programme.

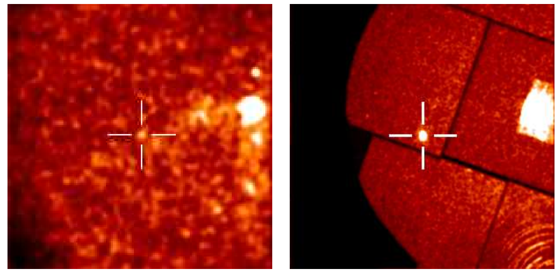

Fig. 1. Example images (10'×10') of the same piece of sky region as observed by ROSAT PSPC (left panel) and XMM-Newton EPIC MOS (right panel), respectively. It can be seen that a serendipitous source (marked by crosses) brightened dramatically from one observation to the other (comparing the source brightness with the background fluctuations). (From Yuan et al. 2006).

3. Preliminary results

The search can be done in a mostly automatic manner. So far we have performed the search over the adequate fields observed by XMM-Newton in its first-year operation. Among the $\sim$ 470 XMM pointings, 386 ($\sim$66 sqr.deg.) were overlapped (or at least partially) with ROSAT pointed observations. As the first step, we are concerned only with objects showing large variability amplitude (e.g. by factors >10). So far, only objects brighter in XMM observations than in ROSAT observations were considered. There are ten candidates were found to have the XMM-to-ROSAT flux ratios larger than 10, and up to $\sim$30.

Among the ten candidates of highly variable X-ray sources found, two are previously known objects; they are the cataclysmic variable OY Car and the micro-quasars GRS 1758-258, which both were observed as targets. The micro-quasars GRS 1758-258 was caught in outburst states during the XMM observations, which has been presented in detail in Ramsay et al. (2001). There are two sources found to be bright, nearby stars (V=8.6mag and 4mag, respectively), which underwent X-ray flares. Interestingly, there are two sources appearing to be associated with faint stars ($\sim$14mag), one with very red colour. There is one source whose counterpart is not clear because of its relatively large distance to the closest optical object (12arcsec)—probably a star in the Galactic halo; alternatively, it may originate from a background galaxy (Fig. 2). There are two sources with no optical counterparts found down to the DSS limit. One is close to the Galactic centre region (Fig. 3) and may also be associated with a radio source. It is possibly an X-ray binary. Follow-up identification and study of these sources are underway.

The only extragalactic source identified so far, which

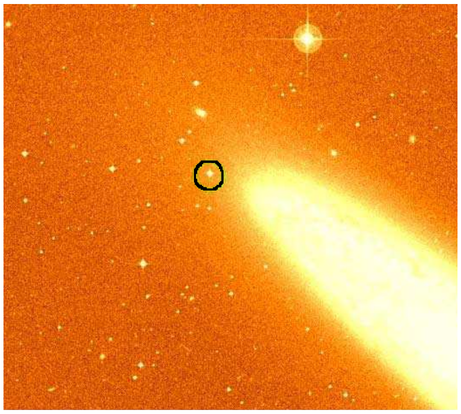

Fig. 2. Example of one variable X-ray source (the centre of the circle), which may be associated with a faint halo star (12" away) or from a source in the background galaxy (from Yuan et al. 2006).

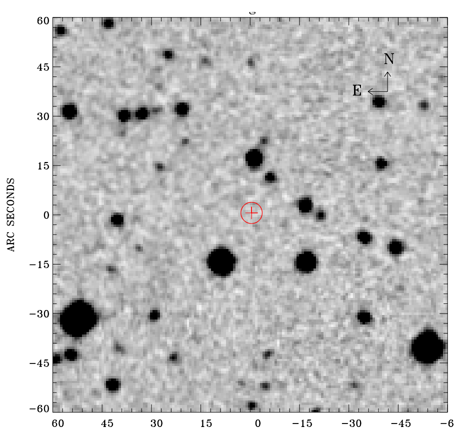

Fig. 3. Another example variable X-ray source, which is located in a region close to the Galactic centre. It has no optical counterpart down to the DSS plate limit (from Yuan et al. 2006).

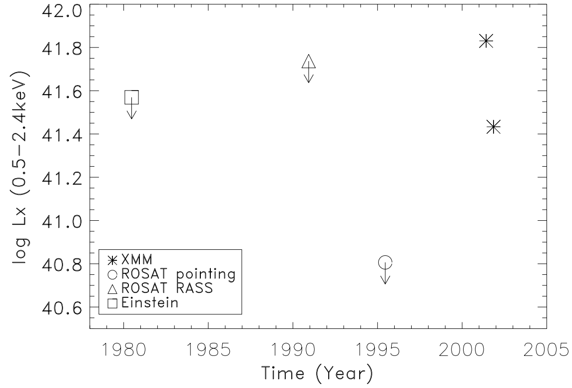

Fig. 4. Long-term light curve of 0.5–2.4 keV X-ray luminosity of the galaxy NGC7589. The arrows denote upper limits (from Yuan et al. 2004).

varied by a factor of more than 10, is from the nucleus of the galaxy NGC7589. Fig. 4 shows the X-ray light curve of NGC7589 in 0.5–2.4 keV, which is in the overlapping energy band of various X-ray missions. Its X-ray luminosity shows a dramatic increase by a factor of >10, occurring sometime between the ROSAT pointing and the XMM observation in orbit 272, on a timescale less than $\sim$5 years. Given the poor sampling, the flux seen by XMM may not represent the flux at the 'highest state', which means that the peak luminosity could be even higher. Therefore the actual variability amplitude must be $>$10. The flux decreased by a factor of 2.5 between the two XMM observations over a period of 5 months, whereas the overall 0.4–10 keV spectral shape appeared to remain unchanged. The 0.4–10 keV XMM spectrum can be approximated by a power-law with photon index of 1.7–1.8, though it seems to flatten above 5 keV, suggesting a possible complex model, such as partial covering or disc reflection. At its low light state, NGC7589 is typical of low luminosity AGN (Yuan et al. 2004).

NGC7589 is a giant, low-surface brightness galaxy (Fig. 5). The galaxy was spectroscopically observed in the Sloan Digital Sky Survey (SDSS; York et al. 2000) on Sep. 29th, 2000, about 8 months prior to the high state caught by XMM. The contribution of stellar light from the host galaxy was subtracted from the observed spectrum by modeling stellar absorption lines employing a range of galaxy spectral template. A broad Hα line (see Fig. 6), which is blueshifted, is evident and had a width of FWHM$\approx$3428 km s^{-1}, compared to the narrow lines of FWHM $\approx$228 km s^{-1}. This broad emission line indicates the presence of an AGN in this galaxy. No broad Hβ line can be detected.

We performed spectral classification for NGC7589 using the emission-line ratios. On the diagnostic diagrams

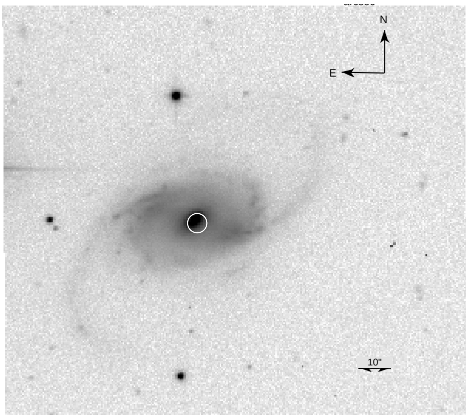

Fig. 5. Optical counterpart, NGC7589, of one of the highly variable sources discovered. A circle represents the position and its 3σ error of the X-ray source. A 10 arcsec angular distance corresponds to 5.65 kpc (from Yuan et al. 2004).

of Veilleux & Osterbrock (1987), the line ratios locate the object in the Seyfert locus but very close to the borderline with the LINERs. This also holds if we use the classical definition of LINERs (Heckman et al. 1980) which only makes use of Oxygen emission-line ratios. Therefore, NGC7589 can be regarded as one of the type of the Seyfert-LINER transition galaxy, either Seyfert 1.9 or LINER I. This property makes the large amplitude X-ray variability, which is rare in LINERs, somewhat intriguing. Part of this work has been published in Yuan et al. (2004).

So far, no object was found to show variability as large as those candidate systems of tidal disruption of stars by black holes, which are expected to vary by a factor of hundreds or more.

4. Summary

We have initiated a programme of systematic search for long-term highly variable X-ray sources in the sky regions covered by the serendipitous surveys of both XMM-Newton and ROSAT, as well as the RASS. So far, we have searched over data from the first-year XMM observations (470 fields, 386 overlapping with previous ROSAT pointings) and obtained some preliminary results. Ten X-ray sources have been found which have varied by a factor of more than 10 on timescales of years. Identification of the previously unknown ones among them is underway. No object was found to show variability by a factor above a hundred; such amount of amplitude is required to be considered as candidates of flares from inactive galactic nuclei as discovered recently (Komossa 2002).

We are now working toward enlarging the highly variable source sample by extending the search to more XMM observations. Identification of the other candidates found in the optical and other wavebands is also underway. and to identify the obtained candidates.

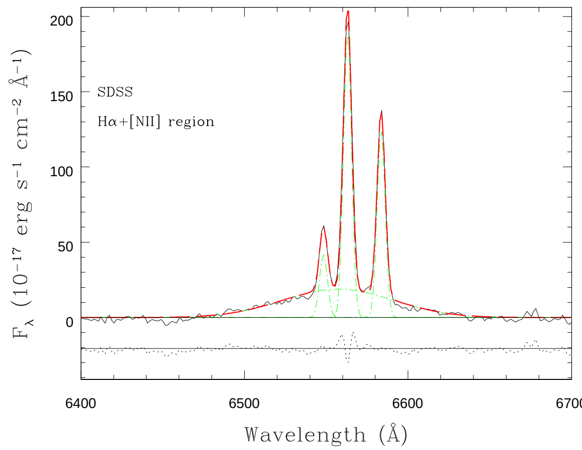

Fig. 6. The Hα+[NII] line region of the SDSS spectrum of NGC7589 after subtracting the host galaxy starlight. A broad Hα line component is evident, which is blueshifted with respect to the narrow lines.

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