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Monitoring AGNs and transient sources with the Wide Field X-ray Telescope

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Abstract. The Wide Field X-ray Telescope (WFXT) is a proposed mission concept with a high survey speed, due to the combination of large field of view (FOV), effective area and sharp PSF across the whole FOV. A mission such as WFXT will detect a large number of variable and transient X-ray sources during its operating lifetime. We present estimates of the WFXT capabilities in the time domain, allowing to study variability of thousand of AGNs with significant detail, as well as to constrain the rates and properties of hundreds of X-ray Flashes/faint GRBs, Tidal Disruption Events, ULXs, Type-I bursts etc. The planned WFXT extragalactic surveys would thus allow to trace variable and transient X-ray populations over cosmological volumes.

Key words. Galaxies: active – X-rays: bursts – Gamma-ray burst: general – supernovae: general – X-rays: binaries – novae, cataclysmic variables – Surveys – Telescopes

1. Introduction

X-ray timing studies are a very powerful tool to constrain the properties and evolution of high-energy astronomical sources. However, due to the limited sensitivity and field-of-view (FOV) of past and current X-ray instruments, such studies were mainly focused on individual and relatively nearby and/or bright sources.

The Wide Field X-ray Telescope (WFXT) is a proposed X-ray mission concept characterized by a wide field (1 square degree), a large effective area ($1m^2$ @ 1 keV) and a costant PSF across the entire FOV (Murray et al. 2010). While not designed as a monitoring mission, its capabilities and the proposed observing strategy, make it suitable to conduct timing studies for an unprecedented number of moderate and high redshift AGNs, as well as to discover and constrain rates and properties of distant, faint and rare X-ray populations such as X-ray Flashes/faint GRBs, Tidal Disruption Events, ULXs, Type-I bursts etc.

In this work we present estimates of the WFXT capabilities in the time domain for

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AGNs and other variable/transient sources, that can be detected in the 3 main extragalactic surveys planned for the mission. More specific and/or dedicated studies (e.g. galactic surveys, nearby galaxies monitoring etc.) may further increase the WFXT impact in the field.

2. Monitoring SMBH accretion with WFXT

Intense variability on all timescales, from hours to years, is a common property of all AGNs. This variability increases with energy, and is very intense in the X-ray regime, in close resemblance with the one observed in galactic accreting Black Holes (BH) (McHardy 2010). Long observations, as those required to conduct deep surveys (*Chandra* Deep Fields, Lockmann Hole), allowed to study variability also in higher redshift sources, confirming that variability is common to all AGNs over cosmological volumes, and that it reflects the details of the accretion process and the properties of the system (mass, accretion rate, obscuration) (Almaini et al. 2000; Paolillo et al. 2004). X-ray variability can thus be used as a tool to trace the accretion history of SMBH across cosmic time (Papadakis et al. 2008; Allevato et al. 2010). Such studies are currently hampered by the very random sampling and small number of sources accessible with the present generation of X-ray satellites.

The study of AGN populations is one of the primary objectives of the WFXT missions. In its first 5 years WFXT will conduct 3 extragalactic surveys that are predicted to detect $> 10^7$ AGNs(see Tozzi et al. 2009). The WFXT grasp (Effective area $\times$ Field of view) ensures that a considerable fraction will be suited for variability studies on the temporal baselines sampled by the different surveys.

In order to evaluate the WFXT monitoring capabilities for AGNs, we assumed that each field in the 3 planned surveys will be observed continuously. While this is realistic for the *Wide* and *Medium* survey due to its short exposure time per field (2 ks and 13 ks), for the *Deep* survey the long exposure times (400 ks) and the visibility constrains for a low-orbit mission will likely result in multiple observations for each sky region; however we will use this assumption as a working hypothesis noticing that longer baselines will increase the likelyhood of variability detection and that the effects of sparse sampling can be kept under control through simulations and a proper observing strategy (see e.g. Vaughan et al. 2003; Allevato et al. 2010). To simulate the intrinsic AGN variability we adopted a template X-ray Power Density Spectrum (PDS) observed in nearby AGNs (e.g. NGC 4051) displaying the characteristic power-law shape with a high-frequency break (e.g. Uttley et al. 2002). We further required at least 10 bins of equal duration in the X-ray lightcurve, and that the average signal-to-noise ratio (S/N) per bin in the satellite band, due to the intrinsic variability, is larger than a fixed threshold ($S/N = 3$ in Figure 1). Note that the requirements are more stringent than a simple variability detection, allowing to derive constrains on the underlying physical process. The expected number of variable AGNs were derived from AGN number counts (Hasinger et al. 1993; Giacconi et al. 2002; Luo et al. 2008) and the sky coverage of each survey (20000, 3000 and 100 sq.deg. for the Wide, Medium and Deep survey).

The three surveys will reach limiting (variability) sensitivities, for $S/N > 3$, of $\sim 2 \times 10^{-12}$, 1×10^{-13} and 5×10^{-15} erg/s for the Wide, Medium and Deep survey respectively in the 0.5-2 keV band. (Figure 1). As the sampled timescale increases, the flux and counts limits for a sound variability detection decrease, due to a combination of longer integration time and a larger intrinsic rms variability produced by the power-law behavior of the AGN PDS. With several thousand of counts in each source this sample largely overlaps with the one suited for spectroscopic studies (Tozzi et al. 2009), allowing a detailed characterization of these AGNs. The predicted rms range between 10% and 25%, in good agreement with the values reported for deep extragalactic surveys (see e.g. Paolillo et al. 2004). While the Wide survey covers a much larger sky area, the longer integration will favour the Medium and Deep surveys, both in terms of accessible flux range and variability timescales.

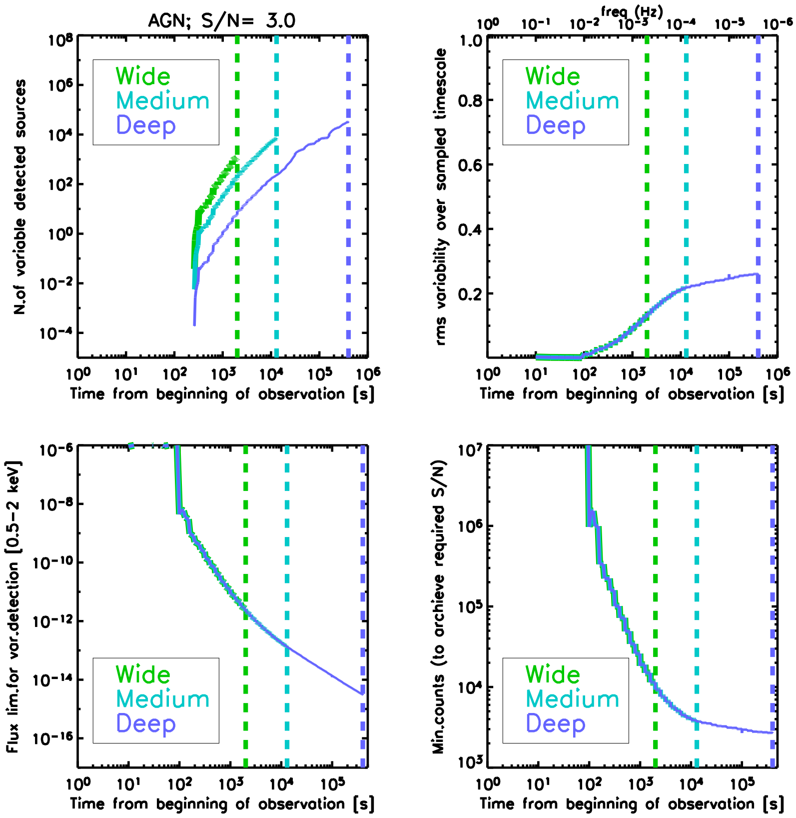

Fig. 1. AGN variability estimates for the WFXT extragalactic surveys as a function of the sampled timescale: *Bottom panels*) Flux limit for variability detection within the assumed S/N threshold (left) and corresponding total counts (right); *Top panels*) Number of sources for which variability is detected with the required S/N (left) and average rms variability detected at every timescale. The vertical dashed lines represent the duration limit of each survey, assuming continuous monitoring.

These results are summarized in Figure 2, where we present the WFXT performance in terms of the number of AGNs with variability detected at the $> 3\sigma$ level, over the whole lightcurve. In this respect the WFXT capabilities appear comparable to other planned missions with a more stringent monitoring character: for instance the design of the EXISTS mission (Grindlay 2007) would allow monitor thousand of AGNs but, due to the different energy band, spatial resolution, sensitivity and sampling pattern, would offer a complementary view of more nearby AGNs (Della Ceca et al. 2009).

3. Transient and variable sources

In this simulation we explored some of the most likely variable objects to be observed during the WFTX main surveys: Tidal Disruption Events (TDEs), Low Luminosity GRBs/X-ray flashes (LL-GRB, XRF), Super Soft Sources (SSS), Ultraluminous X-ray binaries (ULX), Type I bursts etc. Below we briefly present the different classes, referring to more detailed reviews for a detailed discussion.

TDE: are believed to occur when a star is disrupted in the proximity of a quiescent SMBH, fueling the BH and revealing itself through the UV and X-ray emission due to the gravitational energy release of the accreted material. TDE

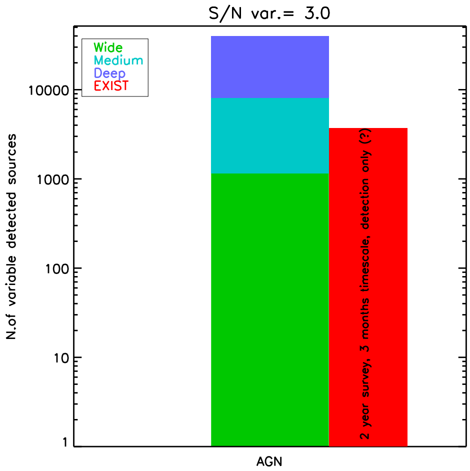

Fig. 2. Number of AGNs for which WFXT is expected to detect variability with $S/N > 3$, in each of the 3 planned extragalactic surveys. For comparison we show an estimate of the number of AGNs predicted for EXIST, assuming the same mission lifetime, and with > 10 observations, as extrapolated from Della Ceca et al. (2009).

are one of the few means to detect quiescent SMBH in distant galaxies. So far however only a handful of events have been serendipitously observed (e.g. Gezari et al. 2009). WFXT will make the detection of such events very likely, since their emission is expected to peak in the FUV/soft X-ray bands.

LL-GRBs/XRF: X-ray bursts have been detected in coincidence with SN explosions and/or GRBs. The fenomenology of such events is still poorly understood and both precursor type and rates are very debated in the literature, due to the small number of serendipitous detections observed so far. Here we took into consideration two possible types of X-ray transients associated with SN events: XRF and LL-GRBs. The first class has its template in XRF 080109 observed by the Swift satellite without an associated GRB, and its origin can be due to the breakout of either the SN shock (Soderberg et al. 2008) or a mildly relativistic jet (Mazzali et al. 2008). On the other end LL-GRB, such as GRB 060218 (Campana et al. 2006), could represent the X-ray counterpart of many associated GRB-SNe. The number of future detections (see Table 1) depends on both the intrinsic SN rates (Cappellaro et al. 1999) and the opening angle of the associated jet (Guetta & Della Valle 2007).

SSS: Supersoft sources are X-ray emitters detected at energies below 1 keV, with X-ray luminosities of $10^{36\div 38}$ erg s^{-1}, and characterized by blackbody-like spectra with temperatures of 15−80 keV (Kahabka & van den Heuvel 2006). Believed to be mostly hydrogen-burning white dwarfs, they are found both in early and late-type galaxies. SSS have complex irregular time variability over hours to years.

ULX: Ultraluminous X-ray binaries are varible accreting systems whth luminosities $> 10^{39}$ erg/s, i.e. larger than the Eddington luminosity for a neutron star or $5M_{\odot}$ BH, which can produce X-ray flares on timescales of hours. They tend to be associated to star forming regions, and proposed as candidates for intermediate ($> 100M_{\odot}$) mass BHs (Fabbiano 2006).

Type I bursts: these are accreting neutron stars (NS) in low-mass X-ray binaries (LMXB) displaying rapid (tens to hundreds of seconds) bursts with X-ray intensity many times brighter than the persistent level. The burst X-ray spectrum is generally consistent with a blackbody with color temperature of 2-3 keV, reaching X-ray luminosities up to 10^{38} erg s^{-1}. These events are caused by unstable nuclear burning on the surface of the NS (Galloway 2008). The X-ray bursts are often recurrent on timescales from 30 min to a few hours.

Other: many more types of rare and/or faint variable and transient sources are not discussed here in detail. For instance a breakout X-ray flash is predicted in SNIa events, while flares due to tidal compression (TCE) in stars accreted by a SMBH could mark the onset of the disruption process, triggering prompt followups. We included these in our simulations in order to cover the plausible parameter space, and highlight the WFXT capabilities as a function of the properties of transient event.

We simulated the WFXT performance for variable and transient sources, other than AGNs, assuming a simplyfied burst model where a source of luminosity L_X^{quiesc} in the pre-burst phase, undergoes a burst of constant luminosity L_X^{burst} for a duration equal to the

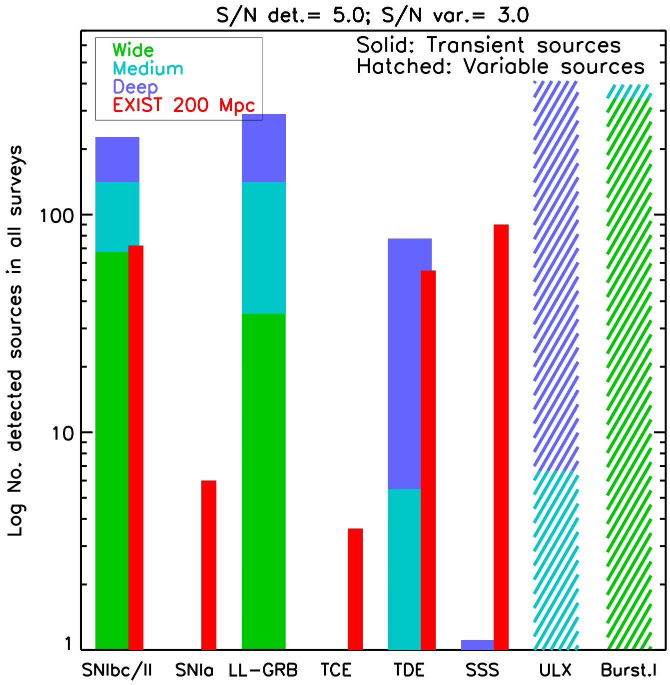

Fig. 3. Number of transient/variable sources expected in the WFXT extragalactic surveys. Recurring bursters are reported as hatched bars. For comparison we show the expected numbers within 200 Mpc from the EXIST mission over a comparable mission lifetime (Soderberg et al. 2009).

characteristic timescale of the actual X-ray lightcurve. We computed the number of expected detections, requiring that a source is detected with $S/N > 5$ and that its variable nature is ascertained with significance $S/N > 3$ with respect to the pre-burst phase, i.e. the burst starts during the observation. This simplified scheme allowed us to derive detection rates without the need of a specific knowledge of the characteristic of each source; obviously a more sophisticated approach is desirable and shall be implemented for each source separately in the future. The number of objects is calculated integrating over the cosmological volume accessible by WFXT for each source, given the parameters and constrains discussed above, and assuming an average volume density for the whole population[1].

Figure 3 shows the number of detections in all surveys for the different classes discussed above: in particular hundred of LL-GRBs, XRF, TDE are expected over cosmological distances, mainly from the Deep survey. Recurrent bursters (ULX, Type I bursts) on the other hand will be mainly observable in the nearby Universe. For comparison we also show the predictions for the EXIST mission within 200 Mpc, as reported in Soderberg et al. (2009), even though it must be kept in mind that this mission will be using different energy bands and sampling patterns. In Table 1 we report the input parameters and the numbers derived from our simulations. It must be stressed

[1] We did not explicitly include any evolutionary term, which is appropriate for most sources that will be observable only in the local Universe.

Table 1. Number of transients expected in the WFXT extragalactic surveys, along with the physical parameters used in the simulations and the calculated distance limits.

Type	N.sources	L_X^{burst} (10^{40} erg/s)	$L_X^{quiescent}$ (10^{40} erg/s)	timescale (s)	Rate ($\mathrm{Mpc^{-3}\ yr^{-1}}$)	Dist.limit (Mpc, z)
SNIbc/II	226	10^3	1.0	500	10^{-3}	2.8×10^3, **0.50**
SNIa	2.1×10^{-5}	10^2	0.0	0.01	10^{-2}	3.8, **0.0009**
LL-GRB	290	10^4	0.0	10^4	3×10^{-5}	3.8×10^4, **4.2**
TCE	0.0062	10^2	0.0	10	10^{-4}	120, **0.028**
TDE	77.6	10^2	0.0	5×10^5	5×10^{-5}	1.8×10^4, **2.3**
SSS	1.1	10^{-4}	0.0	5×10^5	30	18, **0.004**
ULX	411	1	0.5	10^5	0.1	920, **0.19**
Type I bursts	395	10^{-2}	0.0	100	30	3.8, **0.0009**

however that the properties of most sources considered here may span a wide range and/or be affected by large uncertainties. The values presented in this work are mainly intended to highlight the mission capabilities as a function of the observational parametrs. An online version of the *WFXT transient simulator* is available at `http://wfxt.na.infn.it/`, allowing the interested user to test additional type of source and/or parameter combinations.

4. Conclusions

While not a monitoring missions WFXT, with its large effective area, wide FOV and stable PSF, promises to offer a new view of the variable high-energy Universe. WFXT will allow to study thousand of variable AGNs, and hundred of other transient and variable sources. The study of such populations has been mostly limited to the local Universe so far, while WFXT will be able to sample cosmologically relevant volumes, thus constraining their rates, evolution and the underlying physical processes. WFXT would thus complement other wide-field facilities, such as Pann-STARR and LSST, that allow to monitor the whole sky with unprecedent speed. Finally, recent studies suggest that the X-ray band could be the optimal energy range to use in order to identify triggers and/or counterparts for next generation Gravitational Wave and Neutrino experiments (see, e.g. Guetta & Eichler 2010); WFXT thus would prove extremely valuable in validating and characterizing the astronomical events detected by these facilities.

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