XTRA: The fast X-ray timing detector on XEUS

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Abstract. The Rossi X-ray Timing Explorer (RXTE) has demonstrated that the dynamical variation of the X-ray emission from accreting neutron stars and stellar mass black holes is a powerful probe of their strong gravitational fields. At the same time, the X-ray burst oscillations at the neutron star spin frequency have been used to set important constraints on the mass and radius of neutron stars, hence on the equation of state of their high density cores. The X-ray Evolving Universe Spectroscopy mission (XEUS), the potential follow-on mission to XMM−Newton, will have a mirror aperture more than ten times larger than the effective area of the RXTE proportional counter array (PCA). Combined with a small dedicated fast X-ray timing detector in the focal plane (XTRA: XEUS Timing for Relativistic Astrophysics), this collecting area will provide a leap in timing sensitivity by more than one order of magnitude over the PCA for bright sources, and will open a brand new window on faint X-ray sources, owing to the negligible detector background. The use of advanced Silicon drift chambers will further improve the energy resolution by a factor of ~ 6 over the PCA, so that spectroscopic diagnostics of the strong field region, such as the relativistically broadened Iron line, will become exploitable. By combining fast X-ray timing and spectroscopy, XTRA will thus provide the first real opportunity to test general relativity in the strong gravity field regime and to constrain with unprecedented accuracy the equation of state of matter at supranuclear density.

INTRODUCTION

The X-rays generated in the inner accretion flows around black holes and neutron stars carry information about regions of strongly curved spacetime. This is a regime in which there are important predictions of general relativity still to be tested, such as the existence of an innermost stable circular orbit. X-ray spectroscopy and fast timing studies can both be used to diagnose the orbital motion of the accreting matter in the immediate vicinity of the collapsed star, where the effects of strong gravity become important.

With the discovery of millisecond aperiodic X-ray time variability from accreting black hole and neutron star X-ray binaries (quasi-periodic oscillations: QPOs), and brightness burst oscillations in neutron stars, RXTE ([1]) has clearly demonstrated that fast X-ray timing has the potential to constrain the mass and radius of neutron stars and measure the motion of matter in strong gravity fields (see [2] and e.g. Lamb these proceedings). As pointed out by van der Klis, it is now time to turn these diagnostics into true tests of general relativity. For this, a follow-up to the RXTE Proportional Counter Array (PCA) should have a collecting area of at least ten times larger (more than 6 m^2) and an energy resolution at least five times better (i.e. ~ 200 eV at the Iron line).

There are two possible implementations for such an instrument. One is collimated, in which the collecting area is the same as the detector area (as in the PCA), and one in which the two are decoupled through the use of focussing optics. In the first case, beside proportional counters (e.g. Zhang, these proceedings), large area thick Silicon PIN diodes could be considered (e.g. [3, 4] and Kaaret, these proceedings), although it is unclear whether they will provide an improvement in energy resolution and whether the background could be kept as low as in PCA-like proportional counters. On the other hand, with the use of focussing optics, the immediate advantage is that the detector can be made very small with low background and good energy resolution, allowing timing and spectroscopy to be carried out simultaneously.

This paper describes the XEUS Timing for Relativistic Astrophysics (XTRA) instrument considered for the focal plane instrumentation of the XEUS mission [5]. Combining the huge collecting area (30 m^2) and broad band pass (up to ~ 30 keV) of the XEUS mirror optics with Silicon drift chambers, XTRA will fulfill the two main requirements for a follow-up to the PCA. The science case for such an instrument was presented by van der Klis in the context of XEUS [6], and will be emphasized again in many papers in these proceedings (see the contributions by Kaaret, van der Klis, Lamb, Miller, Psaltis, Strohmayer, ...). It will not be repeated here. In-

[1] On behalf of all of those who were supporting the proposal to add a fast timing detector in the XEUS focal plane (see Acknowledgments).

stead in this paper, first I will briefly summarize the current XEUS mission profile, then I will present some sensitivity estimates for XTRA and show the results of some simulations of QPOs and burst oscillations, using the expected count rates for XTRA. Finally, I will describe the detector implementation (see also [7, 8]).

XEUS IN BRIEF

XEUS: The X-ray Evolving Universe Spectroscopy mission represents a potential follow-on mission to the ESA XMM−Newton cornerstone observatory currently in orbit. The XEUS mission was considered as part of the ESA Horizon 2000 plus program within the context of the International Space Station (ISS). XEUS is the next logical step forward in X-ray astrophysics after the current set of great observatories (XMM−Newton and Chandra), have completed their operational lives. The scientific objectives of XEUS are however so demanding that the mission will clearly represent a major technological challenge compared to past astrophysics missions. Its development and ultimate success rely on the capability to achieve a key breakthrough in the size of an optic capable of entering orbit.

The primary aim of XEUS is the astrophysics of the most distant discrete objects in the Universe (see [9] for details). The specific scientific issues, which XEUS will address can be summarized as follows: 1) To measure the spectra of objects with a redshift $z > 4$ at flux levels below 10^{-18} ergs cm^{-2} s^{-1}, which is just about 1000 times fainter than XMM−Newton 2) To determine from the X-ray spectral lines the redshift and thus age of these very faint objects that may not have easily identified optical counterparts 3) To establish the cosmological evolution of matter in the early Universe through the very clear means of the study of heavy element abundances as a function of redshift, i.e. the role of element evolution as the Universe aged through galaxy formation in the associated early stellar processes.

To meet these scientific objectives, XEUS consists of two free flying satellites: a mirror spacecraft (MSC) and a detector spacecraft (DSC) separated by 50 meters and aligned in orbit by an active orbital control and alignment system [10, 11]. In the baseline mission scenario, the required large aperture mirrors (see Figure 1) cannot be deployed in a single launch, making XEUS a two step mission, in which the growing of the mirrors involves the facilities in place on the ISS. However, given the uncertainties related to the future of the ISS, alternative mission scenarios are currently being considered at ESA.

In the baseline, XEUS−1 comprising the mated mirror and detector satellites will be launched by an Ariane 5 type of launcher in a low earth orbit, with an inclination similar to the ISS. After having completed a few years of observations, MSC1 will go docking on the ISS, where the external mirror segments are waiting. Using the robotic arms on the ISS, the mirror segments will be added to MSC1 to reach the final configuration of MSC2. A second detector spacecraft will then be launched to operate at the focus of MSC2: XEUS−2 will then be born. The effective areas of XEUS−1 and XEUS−2 [12] are shown in Figure 1, and compared with the effective area of the RXTE/PCA (5 units combined). The proposed high energy extension in which the inner mirror shells are coated with supermirrors is also shown. This yields ~ 20000 cm^2 at ~ 9 keV and still ~ 1700 cm^2 at 30 keV.

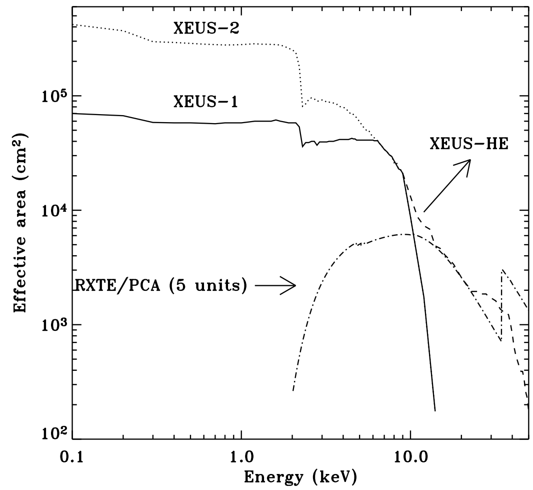

FIGURE 1. Comparison between the XEUS−1, XEUS−2 and PCA (5 units) effective areas. The proposed High Energy extension (XEUS−HE) for the mirrors is also represented (data taken from the Telescope Working Report [12]).

Although XEUS was designed to explore the most distant regions of the Universe, we now show how such an ambitious mission also has great potential for studying the brightest sources in the sky.

XTRA SENSITIVITY FOR TIMING STUDIES

For the sensitivity computations, we have assumed that the timing detector is made of 300 microns of Silicon lying above 2 mm of CdZnTe (see below). This produces a more or less flat detector response up to 80 keV. Table 1 gives the count rates expected from some sources, accounting for typical source spectra and interstellar absorption (for galactic sources, this suppresses most of the photons below ~ 1 keV). The Crab produces about 14000 counts/s in the PCA, which is just about

TABLE 1. Examples of total count rates above 0.5 keV and above 10 keV ($C_{E>10keV}$) in counts/s. The spectrum of Sco X−1 which is variable corresponds to 60000 counts/s in the RXTE/PCA (2.5–30 keV). The X-ray burst input spectrum is a blackbody of 1.5 keV yielding an Eddington luminosity at 8.5 kpc. SAXJ1808−3659 is the millisecond pulsar taken at the peak of its 1996 outburst.

Source name	XEUS−1	XEUS−2	$C_{E>10keV}$
Crab	250000	800000	5000
Sco X−1	1200000	3800000	10000
X-ray burst	120000	220000	2000
SAXJ1808−3659	30000	130000	300

17 times less than for XEUS−1 and 57 times less than for XEUS−2 (larger conversion factors apply for spectra softer than the Crab spectrum; 20 is a good average).

QPO detection sensitivity

Let us now compute the sensitivity for QPO detection. The signal to noise ratio n_σ at which a QPO is detected in a photon counting experiment is approximately:

$$n_\sigma = \frac{1}{2}\frac{S^2}{B+S}r_S^2\left(\frac{T}{\Delta\nu}\right)^{1/2}$$

where S and B are the source and background count rates, respectively, r_S is the (RMS) root mean squared amplitude of the variability expressed as a fraction of S, T the integration time and $\Delta\nu$ the bandwidth of the variability. The coherence time of the signal is related to the width of the QPO as $\tau = 1/\pi\Delta\nu$.

From the above formulae, assuming B ~ 0 appropriate for XTRA, one can estimate the RMS amplitude corresponding to a 5σ QPO detection as a function of the source count rate (Figure 2). One can also do the same computations for the PCA (assuming a background of 100 counts/s) and for an EXTRA-like instrument of the type proposed to ESA in response to the call for F2/F3 mission proposals [3]. EXTRA was designed as a collimated instrument with a detector made of large area Si PIN diodes, covering a total effective area of 6.7 m^2 (see also Kaaret, these proceedings for a similar design). Estimated background rate for such an instrument in a low earth orbit gave about 2500 count/s. Figure 2 shows that i) XTRA provides better than one order of magnitude sensitivity improvement in terms of RMS for QPO detections over the PCA ii) thanks to the negligible background, XTRA will enable the timing of very faint X-ray sources (down to less than 0.1 mCrab; e.g. binaries in external galaxies), whereas the background of an EXTRA like mission is of the order of 5 mCrab.

Given the scaling of the above formula, and the increase of count rates between the PCA and XTRA, a

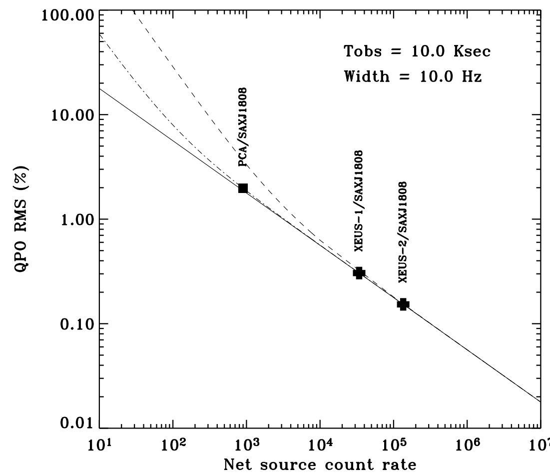

FIGURE 2. Comparison between the XTRA (solid line), RXTE/PCA (dot-dashed line) and EXTRA (dashed line) sensitivities for QPO detection (5σ in 10 ksec, signal width 10 Hz). An illustrative example is provided by the millisecond pulsar. As can be seen, a factor of ~ 10 improvement in sensitivity over the RXTE/PCA is obtained with XEUS/XTRA.

QPO detected at 5σ with the PCA will be detected at $\sim 100\sigma$ with XEUS−1. Similarly, XTRA on XEUS−1 will detect signals at the same level of significance as the PCA but for an observing time ~ 400 times shorter, and for the strongest signals over tens of milliseconds. XTRA will thus enable us to detect kilo-Hz QPOs at much lower amplitudes, especially in the domain in which the PCA loses the signal towards the highest frequencies [2]. This is a region where we might be able to see the saturation of the frequency at the innermost stable circular orbit (which gives a measure of the neutron star mass), if the orbital interpretation for the signal is correct. One might also detect QPOs at frequency above 1330 Hz which is the maximum observed today [13]. As stressed by Miller in these proceedings, detection of QPOs at frequencies as high as 1800 Hz would allow us to eliminate all standard nucleonic or hybrid quark matter equations of state, leaving only strange stars.

As stressed above, QPOs will be detected on very short timescales, and depending on the nature of the signal, possibly within their coherence times. This would by itself allow us to discriminate between the various classes of models [6], yielding in some cases constraints on the compact object mass, angular momentum and orbital radius at which the QPOs are produced (see e.g. Abramowicz & Kluzniak, Miller these proceedings). For illustrative purposes, we have first carried out a simulation of a QPO, which is a pulsar like signal of constant amplitude (6.5% RMS for a source count rate of 3000 count/s in the PCA) for which the phase is changed randomly every 200 cycles. The frequency of the signal shifts at a constant rate of 0.25 Hertz per second. This produces a QPO of width ~ 4 Hz corresponding to a quality factor Q= $\nu/\Delta\nu \sim 200$. Q values as large as 200 have already been reported for QPOs measured in power density spectra integrated over 100 seconds or more (e.g. [14] for 4U1608−52). Here we have computed power density spectra over 1 second time intervals, and produced a dynamical power density spectrum for both the PCA and XTRA, assuming a count rate of 45000 counts/s for the latter. The result is shown in Figure 3. It clearly shows that, although the frequency evolution of the QPO can be tracked in the PCA image, only XTRA can measure its frequency and width on short time scales.

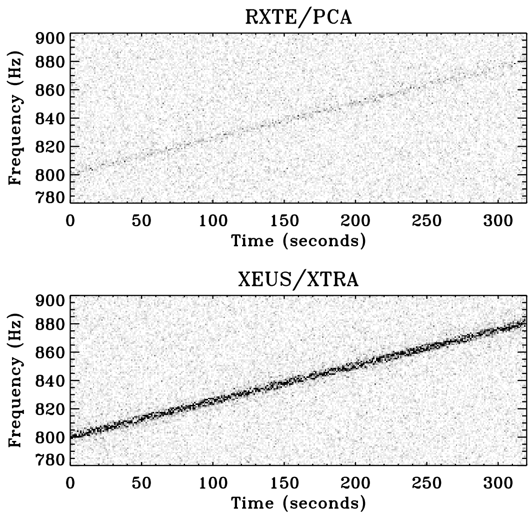

FIGURE 3. *Top:* Dynamical power density spectrum of a source producing 3000 counts/s in the RXTE/PCA and a QPO of RMS $\sim 6.5\%$. The QPO is produced by a pulsar like signal (i.e. the signal is always there) and the phase is changed randomly after 200 cycles (its width is about 4 Hz, FWHM). The power spectra are integrated over a 1 second time interval. The frequency of the QPO increases linearly with time at a rate of 0.25 Hz/s. *Bottom:* The same simulations but for XTRA with a count rate 15 times larger than the PCA one. Not only the QPO can be detected in all 1 second intervals at the expected frequency, but its width can also be inferred.

We have carried out a second set of illustrative simulations to demonstrate that under somewhat favorable conditions, one can localize the signal directly in the time domain. This time the QPO is made of a succession of wavetrains of finite lifetime (QPO at 830 Hz keeping the same frequency for 200 cycles, the RMS of the QPO is again fixed at 6.5% for a source at 3000 count/s in the PCA and there is one wavetrain per second). To explore the signal in the time domain, we slide a window of 0.4 second width over the data with a time step of 0.1 second. Then we search for a periodic signal using a standard Rayleigh test. The periodograms (2.5 Hz of resolution) so obtained are stacked together to form a time-frequency image. One expects that when the window is centered on the QPO wavetrains, the periodogram will reach a maximum at the QPO frequency, and this will appear as a strong excess in the image. A comparison between a time-frequency image obtained for PCA and XTRA count rates is shown in Figure 4. Whereas it is impossible to locate the signal in the PCA image, it stands out very clearly in the XTRA image. Once located in the time domain, one can look at the time profile of the oscillations (in the present simulation folding the data produces a nice sinusoid) and study what causes the signal to lose its coherence. One can also do waveform fitting, correlated timing and spectral analysis and so on. With sophisticated time-frequency analysis tools (singular spectrum analysis, maximum enthropy methods, ...), even under less favorable conditions (i.e. shorter coherence times, rapid frequency drifts, superposition of wavetrains, ...), with XTRA it will be possible to investigate the true nature of the signal by looking for the first time at its properties in the time domain.

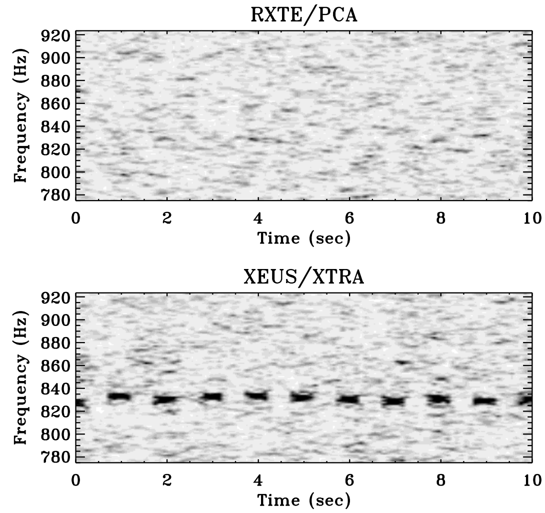

FIGURE 4. Time-frequency image made by stacking Rayleigh periodograms computed on 0.4 second every 0.1 second. The QPO is a succession of finite lifetime wavetrains of ~ 0.25 second duration (200 cycles at 830 Hz). The QPO RMS is 6.5%. There is only one wavetrain per second. The source count rate is 3000 counts/s in the RXTE/PCA (*top*) and 45000 counts/s in the XEUS/XTRA (*bottom*). The bold regions in the XTRA image coincide with the appearance of the QPO wavetrain. The signal is hardly visible in the PCA image

In general, when plotting the QPO RMS as a function of energy, it is found that it increases, to reach a saturation around 10−20 keV (e.g. Figure 5 from [14]). One limitation of the use of focussing optics is their energy band pass which drops off quickly after 10 keV (see Figure 1). In the case of XEUS however, the use of advanced super mirrors extends the energy response up to 30 keV. In fact, the effective area of the XEUS mirrors is comparable or even larger than the PCA (5 units) up to 30 keV. In the current detector implementation for XTRA, the use of CdZnTe below the Silicon would match the high energy response of the mirrors. One can compute the limiting RMS (using equation above), as a function of energy for a given source energy spectrum. This is shown in Figure 5 and compared with the observed data points for the neutron star X-ray binary 4U1608−52 [14]. This figure shows that thanks to the high energy extension of the mirrors, XTRA will be more sensitive than the PCA over the whole energy range QPOs were detected.

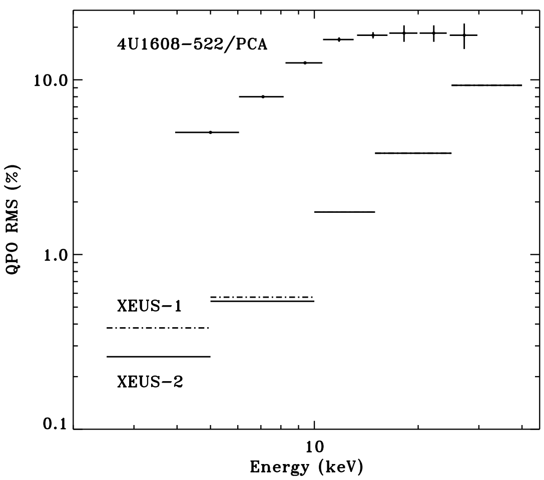

FIGURE 5. Sensitivity for QPO detection (RMS %) as a function of energy (5σ, 10 kseconds). The estimates are compared to the RXTE/PCA data from the neutron star low-mass X-ray binary 4U1608−52 (data taken from [14]).

Coherent signal detection sensitivity

For a coherent signal ($T < 1/\Delta\nu$), the familiar exponential detection regime applies, with false-alarm probability $\sim \exp[-S^2 r_S^2 T/2(B+S)]$. One can compute the RMS for the detection of a coherent signal at a given false alarm probability (Figure 6). The figure shows that XTRA would be able to detect pulsations at the 0.01% RMS level in Sco X−1. Why so far no classical low-mass X-ray binaries, such as Sco X−1, have shown pulsations in their persistent emission remains very puzzling. Several competing explanations have been put forward, as for example that they may be rotating at sub-millisecond periods or may contain compact neutron stars [6]. Thanks to its improved sensitivity for periodic signals XTRA will enable us to test these hypothesis, which have their own constraints on the equation of state of dense matter.

In addition, it has been recently suggested that the neutron star spin frequencies inferred from burst oscillations have an upper limit of ~750 Hz [15]. If this is because of angular momentum removed by gravitational radiation, then searches for periodic gravitational waves emitted by these systems require highly accurate measurements of their spin periods. XTRA could naturally achieve this task.

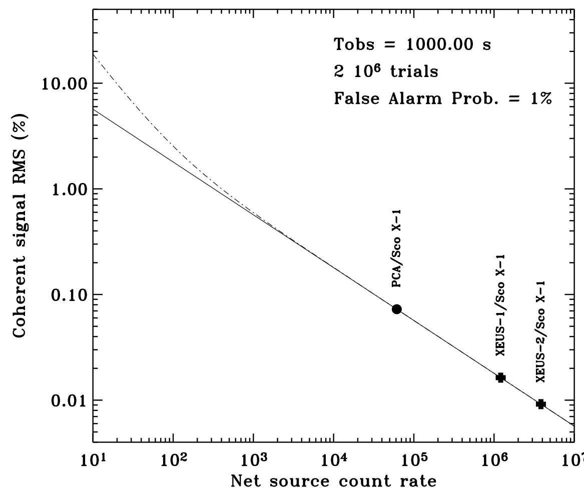

FIGURE 6. Comparison between the XEUS (solid line), RXTE/PCA (dot-dashed line) sensitivities for coherent signal detection (1 ksec). The detection level corresponds to a false alarm probability of 1% for 2×10^6 trials. So far, no pulsations have been detected from Sco X−1. The XEUS−1/XTRA sensitivity is 10 times better than the current RXTE/PCA sensitivity, and failure to detect pulsations at this level would demand major revision of our current ideas about low-mass X-ray binaries.

Concerning burst oscillations, XTRA with its optimum band pass for X-ray bursts, will allow the oscillations to be detected within one cycle (see Figure 7). These oscillations are probably caused by rotational modulation of a hot spot on the stellar surface. The emission from the hot spot is affected by Doppler boosting, relativistic aberration and gravitational light bending (whose magnitude increases with the neutron star compactness, see Figure 7). By fitting the waveform, it will be possible to investigate the spacetime around the neutron star, and simultaneously constrain its mass and radius, and hence determine the equation of state of its high density core (see Strohmayer, these proceedings, but see also Poutanen for an example of what can be done by studying the energy dependence of pulse profiles of accreting millisecond pulsars).

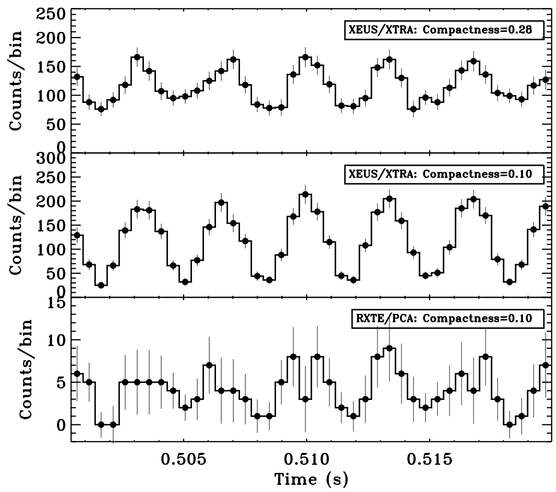

FIGURE 7. Simulated light curve of a burst oscillation at 300 Hz as seen by the RXTE/PCA and XEUS/XTRA. The burst produces 15000 counts/s in the PCA, and 400000 count/s in XTRA. The simulations take into account gravitational light bending in a Schwarzschild spacetime following the method described in [16] (one spot and a cosine emission diagram). For XTRA, the light curve is computed for two neutron star compactnesses (M/R=0.1 and 0.28). With XTRA the oscillations are directly visible in the light curve even at the highest compactness, whereas they are invisible in the PCA data. With XTRA, which will also be sensitive to the harmonic content of the signal, beside the stellar compactness, both the hot spot and viewing geometries could be constrained.

DETECTOR IMPLEMENTATION

To meet the scientific objectives of XTRA, its detector must be capable of handling up to 3 Mcts/s (XEUS−1) and 10 Mcts/s (XEUS−2) (equivalent to a 10 Crab source, see Table 1) with a timing resolution of $\sim 10\mu$s and a deadtime as low as possible, with the requirement that the latter must be measured accurately. In addition, the detector energy range should match closely the high energy response of the mirrors.

Silicon Drift Detector

Among the fast X-ray detectors currently available, Silicon Drift Detectors (SDDs) are the most promising [17, 18]. The SDD is a completely depleted volume of Silicon in which an arrangement of increasingly negative biased rings drive the electrons generated by the impact of ionising radiation towards a small readout node in the center of the device. The time needed for the electrons to drift is much less than 1 μs. The main advantage of SDDs over conventional PIN diodes is the small

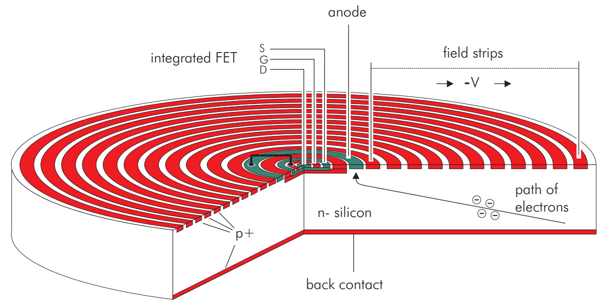

FIGURE 8. Schematic cross section of a cylindrical Silicon Drift Detector (SDD). Electrons are guided by an electric field towards the small collecting anode located at the center of the device. The first transistor of the amplifying electronics is integrated on the detector ship (drawing kindly provided by P. Lechner).

physical size and consequently the small capacitance of the anode, which translates to a capability to handle high count rates simultaneously with good energy resolution. To take full advantage of the small capacitance, the first transistor of the amplifying electronics is integrated on the detector chip (see Figure 8). The stray capacitance of the interconnection between the detector and amplifier is thus minimized, and furthermore the system becomes practically insensitive to mechanical vibrations and electronic pickup.

A spectrum of a 5 mm^2 SDD, with a customized amplifying electronics, is shown in Figure 9 to illustrate that energy resolution as good as 130 eV can be achieved, even at room temperature. Energy resolution of better than $\sim$ 200 eV can be maintained for count rates up to 10^5 cts/s (e.g. [18]).

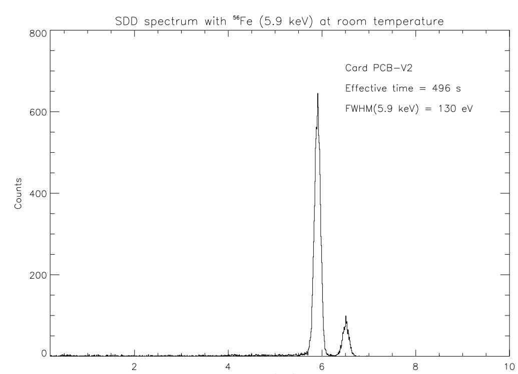

FIGURE 9. Count spectrum of a 5mm^2 Silicon Drift Detector as measured at room temperature at CESR. The energy resolution reached is comparable to CCD resolution. Such a resolution would allow spectroscopy to be combined with timing.

With such an energy resolution (comparable to what CCDs are currently providing), spectroscopy and timing can be used as independent tools to probe the strong gravity regions around compact objects. A particular emphasis should be put on the relativistically broadened Fe Kα lines, recently detected by XMM−Newton and Chandra (e.g. [19]). The line profile which is affected by several physical processes (Doppler shifts, beaming, gravitational redshifts) gives complementary information about the same region, as explored with millisecond timing. The lines are relatively broad (1 keV or more) so that the 200 eV energy resolution of XTRA is sufficient. This again offers independent opportunities to constrain the compact object mass and spin, as well as the radius at which the line is produced. Similarly, as pointed out by Strohmayer (these proceedings) lines in X-ray bursts [20] might be detectable, even with a 200 eV spectral resolution. Measurement of a gravitational redshift yields a direct estimate of the compactness of the neutron star, and yet another constraint on the equation of state of dense matter (see Strohmayer, these proceedings).

Finally with a rather conservative low energy threshold $\sim$ 1 keV, XTRA will be very sensitive to very soft sources (e.g. quiescent neutron star transients, supersoft sources, millisecond puslars, isolated neutron stars ...), in an energy domain never explored before (2.5 keV is the current energy threshold of the RXTE/PCA).

The XTRA detector

For timing studies, deadtime is always a critical issue. Deadtime will include contributions from the signal rise time, the charge sensitive amplifier, and the shaping amplifier. The first two of these can be very short, and the limiting contribution is that of the amplifier, where a trade-off between speed and energy resolution is necessary. Shaping time constants as short as 50 nanoseconds (ns) have been found to be usable [17]. The challenging requirement for XTRA is to achieve an accurately measured deadtime of $\sim$ 500 ns per event. Using currently available devices and pipelining techniques, the analog-digital conversion stage is not a limiting factor at these speeds.

A 500 ns deadtime per event corresponds to a 5% deadtime for a source producing 10^5 cps/s. To handle 10^6 cps/s with a reasonable deadtime, one must therefore distribute the focal beam over $\sim$ 10 detectors or more. The best and easiest solution could thus be a detector made of an ensemble of about $\sim$ 10 separate SDDs on a single wafer. Such SDD arrays already exist, as shown in Figure 10. *This detector should therefore be operated out of focus*. For XEUS−1, the out of focus distance is of the order of 10 cm. This could be accomplished either by a mechanical construction, or by changing the distance between the mirror and detector satellites. Although this will require a careful study, both solutions appear to be feasible within the current XEUS mission design. The requirements in terms of real estate on the detector spacecraft are not constraining, in particular because no complicated cooling systems will be necessary.

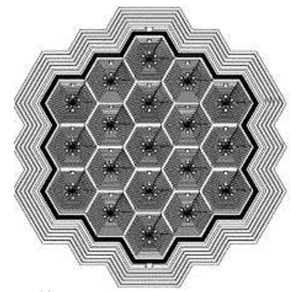

FIGURE 10. SDD array made of 19 hexagon cells of 5 mm^2 [18]. The overall size of the detector is just about 1 cm^2.

As mentioned above, a high energy extension (above 10 keV) is proposed for the mirrors [12]. SDDs are currently produced with thicknesses of 300 microns, which is adequate to cover the energy range below 10 keV. Although there are on-going efforts to make thicker devices, the best match of the high energy response of the mirrors will require the SDD array to be associated with a higher density detector located underneath. Among the potential high energy semi-conductor detectors, CdZnTe [21] stands today as a very promising solution. Such a detector would both ensure the overlap in energy range with the SDD array, and provide a flat energy response up to $\sim$ 80 keV and 10 microsecond timing resolution [21]. Count rates should not exceed a few thousands counts/s in the CdZnTe detector.

The goal for XTRA is to send to the ground the time and energy information of every photon. For most sources, data compression will make this possible (within a 2 Mbits/s data rate) without compromising either time or energy resolution. For the very brightest sources, this can still be done with a restricted number of energy channels. However, within the timeframe of XEUS, on-board memory and telemetry rate should not be considered as real issues.

The detector will be exposed to high radiation doses during operations and one must therefore consider its radiation hardness. The main limitation in the maximum acceptable dose arises from the JFET connected to the collecting anode on the back of the device [22]. High energy photons absorbed in the transistor region increase the amount of oxyde charge and interface traps, thus reducing the charge carrier lifetimes, and thus contributing to increase the leakage current. Laboratory measurements indicate however that a 300 micron thick SDD survives a radiation dose of $\sim 10^{13}$ incoming high energy photons (E$>$ 12 keV) [22]. This is equivalent to a continuous exposition of 3 years at 10^5 photons/s. Concerning particles, the XMM−Newton EPIC pn cameras, which have similar detector technology is performing extremely well in space [23]. So, the device selected can be clearly considered as radiation hard.

To get ready when XEUS gets approved in the ESA science program, we have proposed to the French Space Agency an R&T program, aimed at characterizing the performance of the detector for XTRA and starting to work on deadtime issues and on-board data processing. The proposal was approved in 2002 (before CNES experienced internal problems). Hopefully funding should arrive in 2004. This hardware program will be carried out in close collaboration with MPE/MPI, University of Tübingen and the ROENTEC company which has a great expertise on high count rate electronics for Silicon drift detectors.

CONCLUSIONS

The XEUS Timing for Relativistic Astrophysics instrument, by combining the huge aperture of the XEUS mirrors with a silicon drift detector array in the focal plane meets the two most important science requirements for a follow-up to the RXTE/PCA. It will have a collecting area more than ten times larger than the one of the PCA, and a much improved energy resolution. Through fast X-ray timing and spectroscopy, XTRA will thus provide the first opportunity to test general relativity in the strong gravity field regime and constrain with unprecedented accuracy the equation of state of dense matter.

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