THE X-RAY LARGE ARRAY

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Abstract. There is a conspicuous gap in plans for X-ray timing after the *X-ray Timing Explorer* (XTE). Timing science has played a critical role in the development of X-ray astronomy. The need now is to move into a new domain of shorter timescales and weaker modulation, one that can be reached only with very large aperture instruments. XLA is an X-ray facility with an aperture substantially greater than 1 m^2, nominally 100 m^2. Most of this area is devoted to a large array of collimated proportional counters. There is also a $\sim$ 1 m^2 coded aperture. It extends observational parameter space by several orders of magnitude in timing resolution, sensitivity to variability, and angular resolution. This will lead to a qualitatively new kind of X-ray astrophysics that can be applied to the study of a broad range of astrophysical objects. XLA is thus both an advanced timing mission and a general purpose facility whose principal uses are in areas that are not well covered in other aspects of the planned High Energy Astrophysics program.

1. Introduction

In the past two decades some of the most impressive discoveries in any branch of astrophysics have come from X-ray timing, including: X-ray bursters, X-ray binary pulsars, AGN variability, black hole candidates, quasi-periodic oscillators, and transient X-ray sources. Much remains to be learned about these phenomena using better probes at shorter timescales and lower levels of modulation depth – capabilities that often bring out processes taking place close to the central energy release sites, as in QPOs. The key instrumental improvement needed is very large area, since the timescale that can be seen in a given source scales as 1/area.

New phenomena at short timescales will involve new kinds of physics, leading to the involvement of new physics communities in X-ray astronomy. For example, strong-field gravitational phenomena can appear as central regions of compact sources are probed bringing involvement of the relativistic gravitation community. Another community that would benefit from large areas consists of numerical physicists modeling flows and bursts with radiation hydrodynamics codes. Such codes exist now and will develop over the next decade with improved computational power.

XLA is a successor to smaller missions, such as HEAO-1, EXOSAT, and *Ginga*, which discovered many new X-ray phenomena. XLA extends the scope of investigation which was accessible by these earlier missions, making possible studies of all classes of X-ray sources. Its scientific program can be described as "photon rich

Y. Kondo (ed.), Observatories in Earth Orbit and Beyond, 439–442.

TABLE I

XLA SCIENTIFIC CAPABILITIES

FAST PHTOMETRY: 300 TIMES FASTER 1 mCrab in 1 ms, 1 Crab in 1 μs	flux (Crab)	timescale (s)	modulation (fraction)
• Millisecond binary pulsars, CFS instability	~ 1	10^{-3}	10^{-4}
• QPOs (high frequency, low modulation depth)	~ 1	10^{-1} to 10^{-2}	10^{-3}
• Black hole candidates (shots)	~ 1	10^{-3}	10^{-1}
• Period fluctuations, Orbital parameters	~ 1	10^{4}	10^{-12}
• Eclipses and dips	$\sim 10^{-2}$	10^{4}	10^{-4}
• Radiative shock oscillations in AM Her stars	$\sim 10^{-3}$	1	10^{-2}
• Gravitational modulation	~ 1	10^{-2} to 10^{-3}	10^{-4}
• Neutron star vibrations	~ 1	10^{-2} to 10^{-4}	10^{-2}

TIME RESOLVED SPECTROSCOPY: 100 TIMES FASTER
30 mCrab Spectrum in 1 ms

• Rise time on X-ray bursts	$\sim$ 5 spectra per risetime
• Photon bubbles	
• QPOs, binary pulsars (1 cycle)	5 – 1000 spectra per cycle
• Rapid burster fine temporal structure	$\sim$ 100 spectra per burst
• Pair runaways	

FINE ANGULAR RESOLUTION: 1000 TIMES FINER
1 milliarcsecond on 3 mCrab source

• AGN accretion disk diameters	0.3 – 2.5 pc where $R_{core} \simeq 0.5$ pc
• Jets (e.g. SS433)	10^{8} cm (10^{-4} jet length)
• SNR fine strucure (e.g. Crab)	10^{15} cm
• RS CVn systems	$\sim 10^{-1}$ $R_{\odot}$ at 1 pc
• Cooling flow galaxy cluster cores	$< 10^{-1}$ core radius

DIFFUSE EXTENDED SOURCES: 10 TIMES FAINTER
2×10^{-9} ct s^{-1} cm^{-2} arcmin^{-2}

• Galaxy cluster halos	0.5 degree resolution

X-ray astrophysics", the result of observing $\sim$ 2000 bright X-ray sources with a very large X-ray collector, each source receiving substantial observing time. XLA in two weeks of observation would gather more photons than have been collected in the first 25 years of X-ray astronomy, and this creates a qualitatively new situation. Much of the novelty comes from reaching very short timescales. The large increase in photon throughput brings orders of magnitude of quantitative improvement in four kinds of measurements: (i) fast (microsecond) photometry, (ii) fast (millisecond) time-resolved spectroscopy, (iii) ultrafine (milliarcsecond) angular resolution, and (iv) mapping of highly extended diffuse sources, e.g., outer regions of bright clusters.

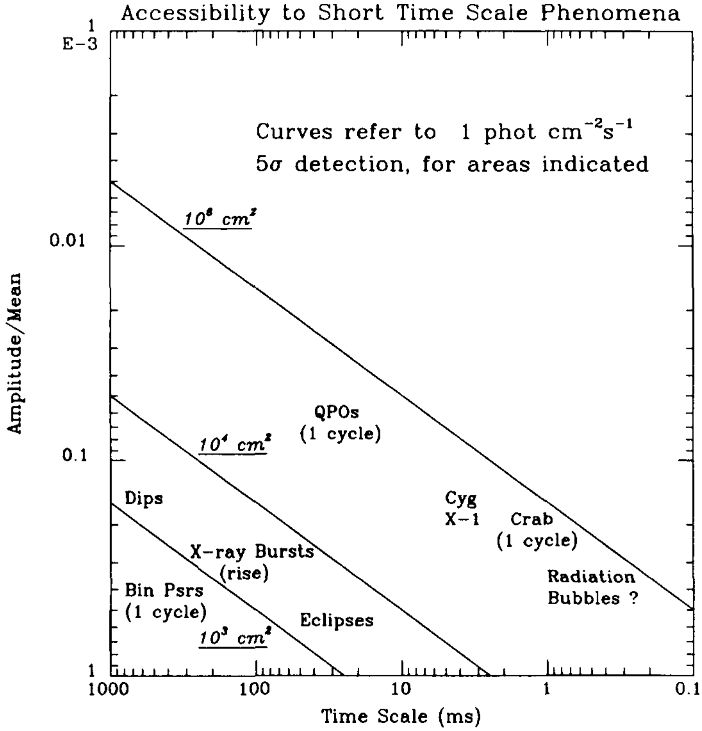

Fig. 1. Low amplitude and short timescale variability require large area instruments, such as XLA, to be detected. Currently planned X-ray timing missions are all smaller than 10^4 cm^2 in area; XLA has an area of 10^6 cm^2.

2. XLA Mission Overview

The scientific applications possible with XLA span the breadth of modern astrophysics (Table I). Fast photometric observations, with time resolution down to microseconds, can be used to search for millisecond X-ray pulsars, single cycle QPOs, shots of noise from black hole candidates, and fluctuations in X-ray pulsar periods.

Fast time resolved spectroscopic observations, with time resolutions down to millisconds, is required to resolve the risetime in X-ray bursts, the spectral variability from photon bubbles, and the energy dependent lags in QPOs. Ultrahigh angular resolution occultation observations, with resolution as fine as milliarcseconds, makes possible the determination of the diameters of X-ray emitting regions in AGN, the lengths of the jets in SS433, and fine structure in SNR. With raster scans, XLA can map extended low surface brightness objects such as galaxy cluster halos.

A pre phase A study of XLA, conducted in 1987 by NASA/MSFC yielded a strawman facility suitable for deployment on the Space Station *Freedom*. XLA contains an effective collecting area of 100 m^2 of proportional counter (PC) arrays and a large co-aligned coded aperture. The PCs have 1 square degree fields of view and are sensitive to 0.25–100 keV X-rays. Pointing stability of $\sim$ 10 arcminutes is required, which is suitable for the Space Station environment. XLA can detect the Crab in 1 μs and 3C273 in 1 ms. The coded aperture not only serves as the monitor for the field being viewed by the large array, but also provides a capability for determining the hard X-ray spectral character of the $\sim 10^4$ brightest sources in the X-ray sky including all the major source classes of X-ray astronomy.

Continuing concept studies by NRL and Stanford University have identified options and tradeoffs for XLA. These include siting options (Space Station, LEO free flyer, lunar surface), assembly options (manned EVA, robotics, self deployment), and instrumentation optimizations (minimize cost and weight per unit area; exploit replication of hardware). Tradeoff studies are currently needed

3. Summary

A large area X-ray array facilitates exploiting bright X-ray sources for a new kind of astrophysics: photon rich X-ray astronomy. Sub-millisecond work requires large areas (Figure 1).

XLA is a general purpose instrument. It has applications in diverse areas of astrophysics, particularly those involving strong gravtitational and magnetic fields and the high densities found in compact objects. Figure 1 shows a few of the phenomena that can only be discovered and studied when very large apertures are used on bright X-ray sources. Facilities with modest area such as AXAF will not fill the need for photon rich X-ray astronomy.

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