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LOFT: a Large Observatory For x-ray Timing

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LOFT (Large area Observatory For x-ray Timing) is an innovative mission submitted in response to the Cosmic Vision "Call for a Medium-size mission opportunity for a launch in 2022" recently issued by ESA. LOFT is an ideal candidate for the next generation of (extremely) large experiments for X-ray timing dedicated to the study of the physics of compact objects and to the understanding of the behavior of matter in strong gravitational fields. Recent developments in the field of large area monolithic silicon detectors allowed us to reach an effective area ∼12 m^2 (15 m^2 goal), more than a order of magnitude larger that RXTE/PCA, in the energy range 2-30 keV (1-40 keV goal). This Large Area Detector (LAD) will have both high timing resolution (<10 μs, 5 μs goal) and good spectral capabilities (<260 eV, <180 eV goal). A Wide Field Monitor (WFM), sensitive in the ∼1-50 keV energy range, will observe simultaneously more than a quarter of the sky in order to both discover and localize transient events and study their long term evolution.

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1. Introduction

Neutron stars and stellar mass black holes are the only laboratory where the physics of extreme gravitational fields can be investigated. Effective diagnostic tools must probe the regions close to the compact source. In this respect observations at high energy are essential because X-rays are copiously produced by in-falling matter in the last moments before accretion and by the hot surface of neutron stars [1]. One of the most promising techniques which has emerged in the last decade, largely thanks to the Proportional Counter Array on-board the Rossi X-ray Timing Explorer, is the study of the signal in the time domain. For example, accreting matter can spiral around the central source down to the radius of the marginally stable orbit, reaching velocities equal to a sizable fraction of that of light and characteristic timescales of the order of milliseconds or less. The possibility to study the emission in such a short time interval and its temporal evolution reveals the details of the accretion process, but also the parameters of the central object, e.g. mass, spin.

The state of the art for high resolution timing studies is today the 15 years old RXTE satellite. The success of this mission has been due to the PCA instrument, which at launch had an effective area as large as 0.67 m^2, and to the presence of an All-Sky Monitor which has assured the possibility to trigger the observation in particular spectral states of the sources. While X-ray timing has achieved its golden age with RXTE, the future is much more uncertain. After the upcoming demise of RXTE only the Indian satellite ASTROSAT [2] will be able to perform high resolution timing studies with an area similar to that of PCA (and with a better response at higher energy). The only perspective of a significant increase in sensitivity would be the High Time Resolution Spectrometer (HTRS) on-board the International X-ray Observatory (IXO), which, if selected, could be launched not earlier than 2021 [3]. In any case, the HTRS is only one of the IXO instruments and therefore only a fraction of the observation time could be dedicated to timing. Other mission proposals (e.g. the 4-m^2 AXTAR, [4]) have not a defined path yet.

2. The LOFT mission

To fully exploit the X-ray timing as a diagnostic technique, a collecting area $>$10 m^2 is required. There is a major technological issue in building such huge collecting areas because of the high resources in terms of power consumption, weight, volume and costs, but today it is made possible thanks to recent developments in the construction of large yet high quality Silicon Drift Detectors (SDDs, [5]). The particular design we are proposing [6, 7] was initially developed for the Inner Tracking System of the ALICE experiment in the LHC at CERN, and provides a large collecting area (53 cm^2 on a single monolithic detector for the current prototype), together with good spectroscopic capabilities ($<$400 eV at room temperature, [8]) and a low energy threshold (about 1.5 keV). SDDs have a time resolution of 10 μs (5 μs goal), mainly due to the drift time, and are segmented detectors, so that the deadtime in the single element is negligible. The mass production of SDDs has been already proved: 260 such detectors, for a total area of 1.37 m^2, are working at LHC since 2008 in a high radiation environment. For the main instrument of LOFT, the Large Area Detector (LAD), we expect to use 76 cm^2 monolithic SDDs with 854 μm anodes and a drift distance of 35 mm to achieve a total 12.0 m^2 (goal 15 m^2). This design is power-limited, with the requirement of a satellite fitting of the fairing of a Vega launcher, but the design is fully

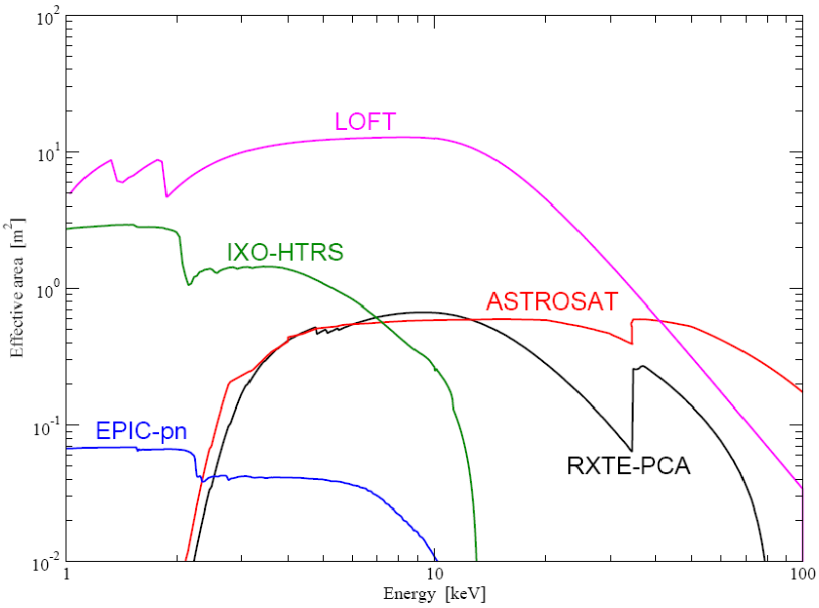


Figure 1: Comparison of the effective area of present and future missions dedicated to X-ray timing with that of LOFT. LOFT has a collecting area ∼20 times larger than RXTE.

scalable. The field of view will be limited to <43 arcmin (<30 arcmin goal) by 2 mm thick lead glass capillary plates. The main characteristic of the LAD instrument are reported in the Table 1, while the collecting area is compared with that of other present and future missions in Figure 1.

The LAD is the main instrument on-board LOFT. The payload is completed by a Wide Field Monitor (WFM) which will observe contemporaneously a large fraction of the sky accessible to the LAD. The WFM will both study the long term evolution of variable sources and trigger the observations of the LAT in case of interesting spectral states. The design of the WFM is based on the heritage of SuperAGILE [9], but, instead of microstrip detectors, it exploits the same type of SDDs as the LAD except for a finer pitch (∼300 μm). SDDs can provide a fine spatial resolution, of the order a few tens of microns depending on the drift distance [10], but only in the direction orthogonal to the drift. Therefore a WFM unit will comprise two cameras, each composed of two 20×20 cm^2 tiled detection planes coupled to two 1-dimension coded masks oriented orthogonally. The rough spatial resolution along the drift direction, of the order of a few millimeters, will be used to reduce significantly the possibility of source confusion in crowded fields. The sky coverage of the WFM can be increased adding more WFM units, and the baseline for LOFT is to use two units with a total field of view larger than 3 steradians.

A picture of the LOFT satellite, as it would appear after the deployment in orbit, is shown in Figure 2.

3. Scientific objectives

The main scientific objective of LOFT is the study of non-coherent variability and quasi-periodic phenomena, which provides a direct access to a number of information on the compact

Parameter	Requirement	Goal
	Large Area Detector	
Energy range	2-30 keV (2-50 keV expanded)	1-40 keV (1-60 keV expanded)
Effective area	12 m^2 (2-10 keV) 1.3 m^2 @30 keV	15 m^2 (2-10 keV) 2.5 m^2 @30 keV
Energy Resolution, FWHM @6 keV	<260 eV <200 eV (40% of events)	<180 eV <150 eV (40% of events)
Silicon thickness	450 μm	1000 μm
Field of View, FWHM	<60 arcmin	<30 arcmin
Time resolution	10 μs	5 μs
Dead time	<0.5% @1 Crab	<0.1% @1 Crab
Background	<10 mCrab	<5 mCrab
Maximum flux (steady, peak)	>0.3 Crab, >15 Crab	>10 Crab, >30 Crab
	Wide Field Monitor	
Energy range	2-50 keV	1-50 keV
Energy Resolution, FWHM @6 keV	<300 eV	<200 eV
Field of View	>3 steradian	>4 steradian
Angular resolution	5 arcmin	3 arcmin
Point source accuracy	1 arcmin	0.5 arcmin
Sensitivity (5σ,50 ks)	2 mCrab	1 mCrab
Sensitivity (5σ, 1 s)	0.5 Crab	0.2 Crab

Table 1: Requirements for LOFT. The expanded option refers to the possibility to acquire and send to telemetry hard X-rays for off-axis bright transients.

objects, such as the mass, the spin and the properties of the ultradense matter in neutron stars. The main scientific themes that LOFT will address include:

Ultradense matter

LOFT provides a number of tools to study the properties of ultradense matter in neutron stars. The Equation of State (EOS) can be estimated by means of the modeling of X-ray pulsations, detected in accretion-powered millisecond pulsars and/or during "type I" bursts [11]. The shape of the pulse strongly depends on the gravitational bending which affects photons in their travel from the surface of the neutron stars to the observer, making it a very sensitive probe of the ratio between the mass and the radius of the compact object. An uncertainty of the order of $\sim$5% in the radius measurement could be achieved by LOFT. An additional tool to study the EOS is the spectral modeling of photospheric radius expansion events, for which the measurement of the Eddington luminosity and of the temperature enables the estimate of the total emitting area of the central object and therefore its radius [12, 13]. The good spectral resolution of the LAD will also allow to identify the absorption features reported in some bright events [14] and to derive the gravitational redshift at the surface of the neutron star. The spectroscopy of broad iron lines and the detection of kHz Quasi Periodic Oscillations (QPOs) would provide indirect constraints to the radius of the neutron

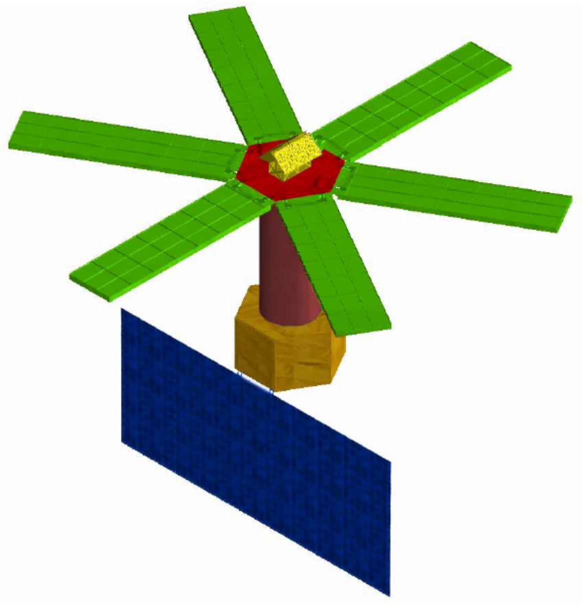


Figure 2: LOFT after the deployment in orbit. The deployment mechanism is inspired from the ESA mission SMOS. The LAD is in green, the WFM is in yellow and the solar panel array is in blue.

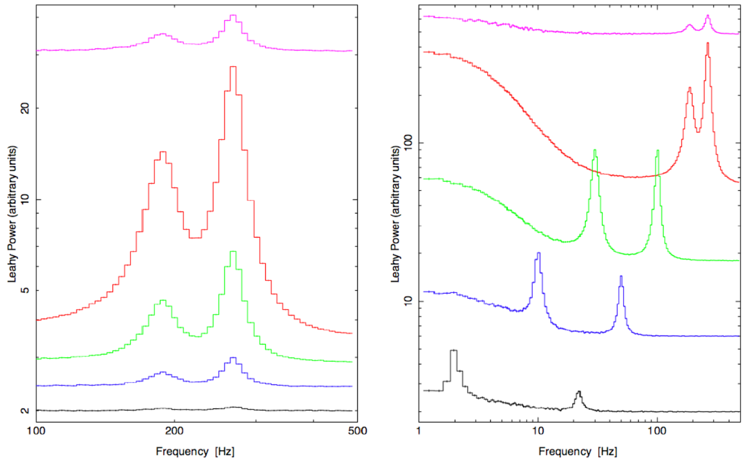
star. The large area of the LAD will also allow for deep searches of low amplitude pulsations: the spin distribution, in particular that of the fastest neutron stars, will constrain the EOS against the centrifugal break-up and the possible role of gravitational waves emission in balancing the accretion torque.

LOFT will also be an ideal observatory to confirm (and study) that global sesmic oscillations (GSOs) occur during major flares or glitches from magnetars. Even if the probability of occurrence of a giant flare during the LOFT lifetime is only ∼30%, the WFM will identify those active periods in which much more frequent but less energetic intermediate flares are expected to happen. Observations with the LAD, both by pointing the source or by collecting high energy photons which pass through the collimator for the brightest events, allow to detect a number of different, although weak, frequencies associated to different oscillation modes, thus opening the way for neutron star seismology.

Strong gravity

It is generally accepted that QPOs, detected in both accreting neutron stars and black holes, are related to the fundamental frequencies of matter motion very close to the last stable orbit. While with current data different models for interpreting the origin of QPOs are still viable, e.g. the epicyclic resonance [15] and the relativistic precession [16], LOFT could easily discriminate among them by detecting how the QPOs evolve with luminosity (see Figure 3). In particular, LOFT will be able to measure much weaker signals and to study QPOs in the time domain, i.e. to resolve the QPOs within their coherence timescale.

Bright AGNs are another opportunity to study the behavior of matter in the strong gravity regime. LOFT will study AGNs down to a flux of ∼1 mCrab: the large collecting area and the



(a) (b)

Figure 3: (**a**) Evolution of high frequency QPOs for a black hole in the epicyclic resonance model and in the relativistic precession model (**b**) [18].

wide energy band will allow for an accurate determination of the broad iron lines and to study the variability related to flares and to rotating blobs illuminated by the central supermassive black hole [17].

Additional objectives

The largest part of the sources in the X-ray sky is highly variable and this behavior reflects the physics of the source and of the processes at work. LOFT will explore the X-ray flux in the time domain from the scale below milliseconds (with the LAD) up to years (with the WFM). In particular, X-ray binaries are a primary objective for LOFT. The large area of the LAD will allow to detect the period of neutron stars (and its evolution with the accretion) with unprecedented sensitivity. The high counting statistics will allow to study instabilities in the accretion, to detect intermittent pulsation from millisecond pulsars and to follow the timing behavior of the source over a wide range of accretion rates.

The wide energy range and the large field of view of the WFM will also re-open the observational window on a particular class of Gamma Ray Bursts knows as X-ray flashes because of the softer spectrum. The arcmin positioning provided by the WFM will allow for rapid follow-ups (within a few hours) with on-ground facilities.

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