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The WFM Instrument of the LOFT mission

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Abstract

LOFT, the Large Observatory For X-ray Timing, was selected by ESA in 2011 as one of the four M3 (medium class) missions concepts of the Cosmic Vision programme that will compete for a launch opportunity at the start of the 2020s. LOFT includes two instruments: the Large Area Detector (LAD), a ~ 10 m^2 collimated X-ray detector in the 2-50 keV range (up to 80 keV in extended mode), and the Wide Field Monitor (WFM), a coded-mask wide field X-ray monitor based on silicon radiation detectors. We, the Institute of Space Sciences (CSIC-IEEC) in Barcelona, are deeply involved in the LOFT mission, sharing the leadership of the WFM instrument with DTU Space in Denmark. We are responsible of the mechanics of the WFM, including the structural and thermal design. The WFM baseline is a set of 4 units (each unit corresponds to 2 co-aligned cameras) arranged in arch, covering a field of view at zero response of $180° \times 90°$, and one more unit pointing to the anti-sun direction. The structure of each camera lies on its own coded mask of Tungsten, 150 μm thick, a collimator and the detector plane (20 cm below the mask) providing a fine (arc minutes) angular resolution. The camera detector plane (182 cm^2) will operate at $-20°$C in order to achieve an energy resolution FWHM of less than 500 eV in the 2-50 keV energy range. The WFM has the main scope of catching good triggering sources to be pointed with the LAD. Its large field of view will permit to observe in the same energy range of the LAD about 50% of the sky at once. The WFM is designed also to catch transient/bursting events down to a few mCrab fluxes and will provide for them data with fine spectral and timing resolution (up to 10 μsec).

1 Introduction

LOFT (Large Observatory For x-ray Timing) [6, 7] is one of the four M3 missions selected in 2011 for assessment study in the framework of the Cosmic Vision program of ESA [4]. LOFT

*See http://www.isdc.unige.ch/loft/ for the full list of LOFT members

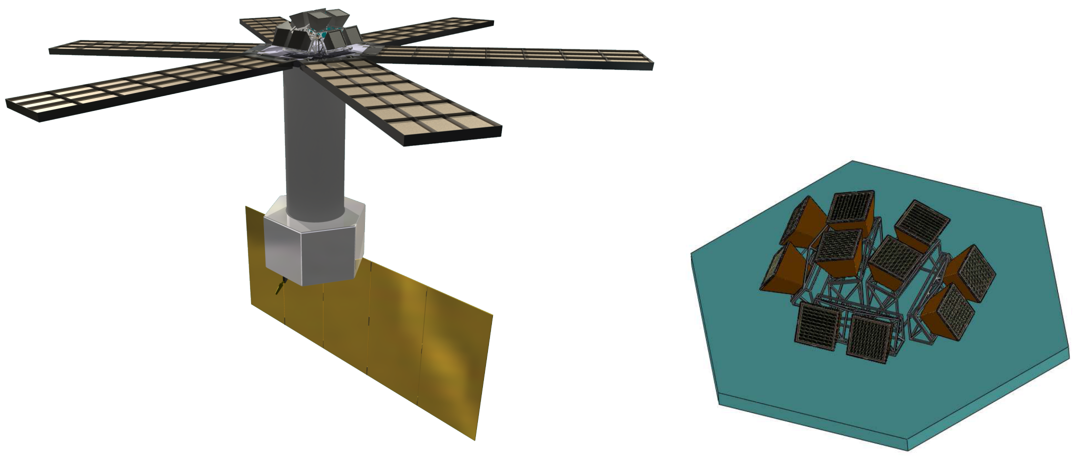

Figure 1: *Left panel:* Schematic view of the LOFT spacecraft in anti-sun direction showing the deployed Large Area Detector (LAD) panels attached to the optical bench. The Wide Field Monitor (WFM) is placed on the top of the optical bench. *Right panel:* Scheme of WFM configuration consisting of 5 units, with 10 cameras in total.

will include two instruments, as depicted in Fig. 1, both based on Silicon Drift Detectors (SDDs). The Large Area Detector (LAD) is a collimated instrument with an effective area of ~ 10 m^2, designed for X-ray timing [9]. The LAD will provide an effective area ~ 20 times larger than any previous mission, thanks to the low mass–effective area ratio attainable with SDD detectors. The spectral resolution of the LAD will be < 260 eV (@ 6 keV), with a time resolution better than 10 μs. The second instrument of LOFT is a Wide Field Monitor (WFM) [1] based on the coded mask principle, and with a detector plane of SDDs similar to the LAD detectors, but with a design optimized for good position determination. The WFM is in charge of monitoring a large fraction of the sky potentially accessible to LAD. It will discover and localize new X-ray transients and bursting events, and monitor spectral state changes of known transients, with unprecedented sensitivity, providing interesting targets for LAD's pointed observations. Through the so-called LOFT Burst Alert System (LBAS), the position and occurrence time of transient events discovered by the WFM will be transmitted to the ground in less than 30 seconds from detection. The nominal mission duration will be 4 years, mainly driven by the expected statistics of occurrence of bright black hole transients, which are prime targets for the LAD.

The main scientific objectives of LOFT aim to answer two fundamental questions of ESA's Cosmic Vision Theme "Matter under extreme conditions", namely, "Does matter orbiting close to the event horizon follow the predictions of general relativity?" and "What is the equation of state of matter in neutron stars?" Additional objectives address the study of a wide range of objects, where accretion (ejection) onto (from) compact objects (black holes, neutron stars, white dwarfs) takes place (pulsars, X-ray bursts, magnetars, X-ray binaries, cataclysmic variables, novae) as well as gamma-ray bursts.

2 The WFM instrument

Due to the WFM location on the satellite, its potential field of view is limited to the hemisphere centered on the pointing direction of the LAD. The overall WFM consists of 5 units as shown in Fig. 1. Four of the five units are arranged in arch in the plane defined by the solar panel of the LOFT spacecraft, and the fifth unit is tilted out of this plane, away from the Sun, by 60°. Relative to the LAD pointing direction, the viewing directions of the four units in arch are offset by ±15° and ±60° respectively.

Each unit is composed of 2 co-aligned cameras. The combined use of 2 cameras in a unit enables a fine 2D angular resolution as explained later. The structure of one single camera has two key elements: the coded mask and the detector plane based on SDDs [8].

The coded mask is composed of a 150 μm thick Tungsten foil. The mask pattern consists of open/closed elements of dimensions 250 μm × 14 mm. The detector-mask distance is baselined at ∼200 mm to achieve the required angular resolution (5 arcmin or better).

The detector plane is composed by 4 SDDs. Each tile of Si has a dimension of 77.4 mm × 72.5 mm and has 448 read-out anodes × 2 rows as it is depicted in Fig. 2. The anode pitch for the WFM is set to 145 μm in order to optimize the position resolution at low energies [5]. The active area of each WFM camera is square. This allows to arrange two identical cameras at 90° (in order to achieve fine angular resolution in two coordinates) but still having the same field of view, to compose one WFM unit. Each SDD detector has a fine (∼ 30–60 μm) position resolution in the anode direction and a coarse (∼ 5–8 mm) in the drift direction. This is reflected into the asymmetrically coded mask, providing each camera an angular resolution of 5 arcmin × ∼ 5°. The fine position resolution in the two coordinates is guaranteed by 2 orthogonal and co-aligned cameras forming each WFM unit, as previously said. The imaging capability of the WFM unit has been studied in detail in [3].

2.1 The WFM characteristics

A summary of the baseline WFM instrument characteristics as well as some important requirements are given in Table 1. WFM is described and the corresponding resources, in terms of mass, envelope size and power are quantified. Such estimates play an important role in the context of the definition of the LOFT mission as they strongly influence the spacecraft requirements and corresponding resources.

The working principle of the WFM is the classical sky encoding by coded masks, which is widely used in space borne instruments (e.g. INTEGRAL/JEM-X/IBIS/SPI, RXTE/ASM, SWIFT/BAT, and SuperAGILE). The mask shadow recorded by the position-sensitive detector can be deconvolved by using the proper procedures in order to recover the image of the sky, with an angular resolution given by the ratio between the mask element and the mask-detector distance. The mask pixel size must always be larger than the corresponding detector resolution. The coded mask imaging is the most effective technique to observe simultaneously steradian-wide sky regions with arc min angular resolution.

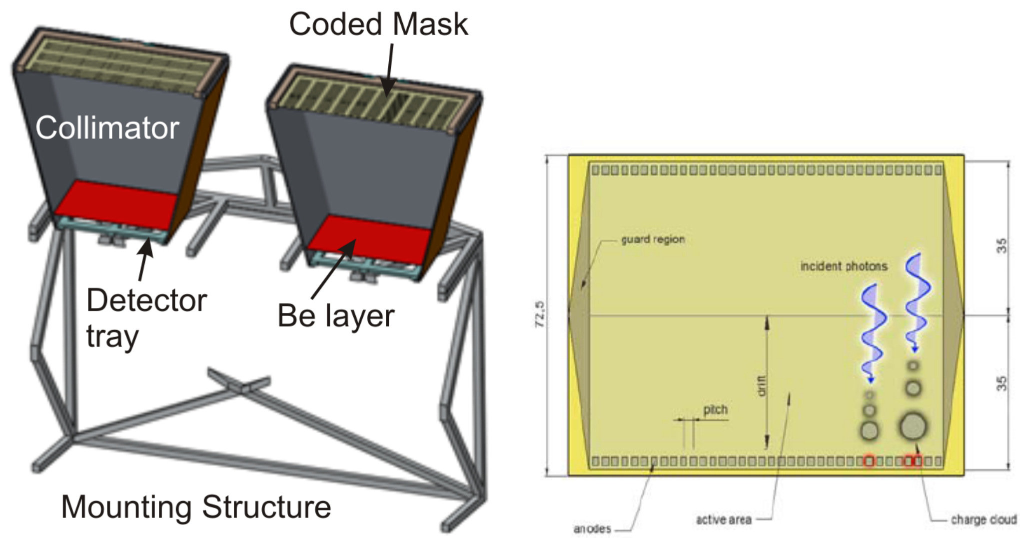

Figure 2: *Left panel:* View of half of a WFM unit. *Right panel:* The detector module with read-out anodes. The size of the charge cloud depends on the drift length and the energy of the incoming photon.

3 The WFM Spanish contribution

We are deeply involved in the LOFT mission, sharing the leadership of the WFM instrument with DTU Space in Denmark. We are responsible of the mechanics of such instrument, including its structural and thermal design. Another Spanish institution, INTA, will play an important role in developing the AIV plan of the WFM instrument. A brief description of the mechanical elements of the WFM follows.

3.1 Coded mask, collimator, beryllium (Be) layer, detector tray, mounting structure and thermal analysis

The coded mask is made of tungsten (W), with a size of 260 mm $\times$ 260 mm which is $\sim$ 1.7 times larger than the detector. The thickness of the mask is 150 μm to ensure opaqueness and coding in the primary energy range up to 30 keV. The size of the mask elements (slits) is 250 μm $\times$ 14 mm, thus ensuring the position resolution of the detector to oversample the mask pixels by a factor of at least two. The open mask fraction is selected to be 25%, as a good compromise to get event rate reduction from X-ray bright sources and from the cosmic diffuse X-ray background (CXB) (thus reducing telemetry requirements), and to improve the signal to noise ratio for weak sources. A thermal blanket made of SiO_2 + Kapton +VDA will be placed in front of the mask in order to reduce as much as possible the temperature variations of the mask.

The collimator that supports the coded mask is made of 2 mm thick Carbon-Fiber-Reinforced Polymer (CFRP). It is covered by a layer of 150 μm thick tungsten shield which

Table 1: Summary of the WFM characteristics

Detector type	Si Drift
Mass	79 kg
Peak power	109 W
Detector operating temperature	< -20 °C
Total detector effective area	1820 cm^2
Mask pixel size	250 μm $\times$ 14 mm
Field of view	180° $\times$ 90° FWZR plus
	90° $\times$ 90° towards anti-Sun hemisphere
Item	**Requirement**
Angular resolution	< 5 arcmin
Sensitivity (in LAD pointing direction, 5σ)	1 Crab (1 s)
	5 mCrab (50 ks)
Energy range	2–50 keV (50–80 keV, extended)
Energy resolution [FWHM]	< 500 eV @ 6 keV

prevents X-rays coming from outside the field of view to reach the detector. In addition, thin layers of Cu and/or Mo may also be introduced and used for energy calibration of the detector in space, thus avoiding the use of on board radioactive sources [2]. The collimator also shields the detectors against optical and UV light; the interfaces between the collimator and the detection plane and the mask will need to be light-tight. From the mechanical perspective, the collimator acts as support structure for the coded mask and detector tray.

Due to the large viewing angle of the WFM camera, the impacts of micro-meteorites and small particles of orbital debris will pose a risk for the Si detectors. To mitigate this, a beryllium layer of 25 μm will be placed ~ 8 mm above the detector plane. In combination with the thermal blanket in front of the coded mask, this Be filter will reduce the risk of impact of particles of size ~ 100 μm to about 1.6×10^{-2} per year per camera.

A detector tray made of titanium (Ti) will allocate the 4 SDDs and their corresponding front-end electronics (FEE) boards. In addition, it includes an alignment mechanism capable of performing a fine and independent alignment of each pair of SDD/FEE with 4 degrees of freedom (correction in height, in tilt, and in twist direction).

Each unit will be placed independently on the optical bench by means of a light and rigid mounting structure. The independent assembly will give flexibility in the distribution on the optical bench without affecting the image capability.

A geometrical Thermal Mathematical Model (TMM) of 42 nodes per unit has been developed. The ESATAN-TMS software has been used to perform the thermal analysis.

4 Conclusions

LOFT is one of the four M3 candidate missions selected by ESA, in the framework of the Cosmic Vision Programme. Thanks to its huge effective area at energies around 8 keV (20 times larger than the best previous instruments), combined with a good spectral resolution, the LAD instrument will give access to the physics of matter at the most extreme conditions and in the strongest gravitational fields. The WFM instrument will play an essential role, not only as a monitor providing good triggering sources to be pointed with the LAD, but also performing its own observatory science, including the capability to detect and locate almost in real time transient phenomena, e.g., gamma-ray bursts. An important involvement of Spain in the development of the LOFT payload will guarantee the prompt access to its data to get exceptional scientific results, in case LOFT is finally approved as the M3 mission to be flown in 2022 or 2024.

Acknowledgments

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