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A Wide Field Monitor (WFM) for the new generation X-ray missions eXTP (China) and STROBE-X (NASA).

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Abstract

We present the recent development of a Wide Field Monitor (WFM) in the X-ray range from 2 to 50 keV, with about 4 sr field of view capability. Such instrument based on European technology meets the challenge to be part of future X-ray spectral timing space missions currently under study, such as the Chinese enhanced X-ray Timing and Polarimetry mission (eXTP) and the NASA Probe mission "Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays" (STROBE-X). The WFM design is inherited from the Large Observatory For X-ray Timing (LOFT) mission concept which was proposed and selected by ESA in 2011 as an M3 mission candidate.

The WFM is a set of coded mask cameras with solid state-class energy resolution, thanks to the use of Silicon Drift Detectors (SDDs). Since SDDs provide accurate event position measurements in one direction and only coarse positional information along the other direction, pairs of two orthogonal cameras are used to obtain precise 2D source positions. The useful effective field of view of one camera pair is about 28° x 28° (90° x 90° at zero response). A set of 3 or 4 camera pairs can be implemented to provide fully sky coverage. The working principle of the WFM is the classical sky encoding by coded masks, that has been widely used in space borne instruments (e.g. INTEGRAL, RXTE/ASM, Swift/BAT). The coded mask imaging is the most effective technique to observe simultaneously steradian-wide sky regions with arc min angular resolution.

1 WFM heritage from LOFT ESA (M3 call)

The Large Observatory For X-ray Timing (LOFT) was selected by ESA as one of the four M3 space missions concepts of the Cosmic Vision programme 2015 - 2025 for a feasibility study [1], [2] and [3]. Two instruments were included in the scientific payload of LOFT: the

Large Area Detector (LAD) and the Wide Field Monitor (WFM). The WFM is a coded mask instrument, based on the principle of sky encoding by a coded mask; the mask shadow is recorded by the position sensitive detectors and can be deconvolved to recover the image of the sky. Silicon drift detectors (SDDs) are used for both the LAD and WFM instruments.

The main goal of WFM is to detect transient X-ray sources at outburst to be pointed with LAD; therefore, the field of view is designed to have a maximum overlap with the sky accessible to LAD pointing. These sources are new transients, as well as known sources undergoing spectral state changes, e.g., neutron stars and black holes.

1.1 WFM X-ray detector

The WFM detector is based on the large area SDD technology [4] which allows very small weight, low power consumption and low fabrication cost, in addition to enable excellent timing capabilities and energy resolution. One of the four SDD tiles of the WFM detector plane is shown in Fig. 1 left. The SDD detector is divided into identical parts as illustrated in Fig. 1 left. When a X-ray photon interacts with the detector, an electron cloud is generated and drifted towards the read-out anodes driven by a constant electric field sustained by a progressively decreasing negative voltage applied to a series of cathodes, down to the anodes at 0V . While drifting, the electron cloud size increases due to diffusion. The charge distribution over the collecting anodes depends on the absorption point in the detector.
We measure for each photon its deposited energy, proportional to the collected charge, the so called X-position, the center of the charge cloud (< 60 μm), the Y-position proportional to the width of the charge cloud (< 8 mm), and the time of the event. The analysis of the charge distribution over the anodes is performed on-board by the FPGA-based BEE on each event and therefore results in the determination of the amplitude, the anode position and the drift position of the event.

1.2 WFM imaging design

As commented in subsection 1.1, the SDD provides accurate position in the anodes side but only coarse positional information in the other one; when combined with a 1D coded mask in each WFM camera (Fig. 2 left), they provide "1.5D" positions of celestial sources. Pairs of two orthogonally oriented co-aligned cameras (Fig. 2 right) will give precise 2D source positions. The FoV of each camera (and camera pair) is 90° x 90° FoV, at zero response (FWZR), and the fully illuminated FoV is approximately 30° x 30°. The detector-mask distance is 202.9 mm (Fig. 1 right). The angular resolution (FWHM) for the on-axis viewing direction is the ratio of the mask pitch and the detector-mask distance, 4.24 arcmin in the fine resolution direction and 4.6° in the coarse resolution direction.

1.3 Elements of the WFM camera

The mechanical design of the WFM camera is described in Fig. 3 left. The elements under our responsibility are highlighted with a red circle. A brief description of each element is

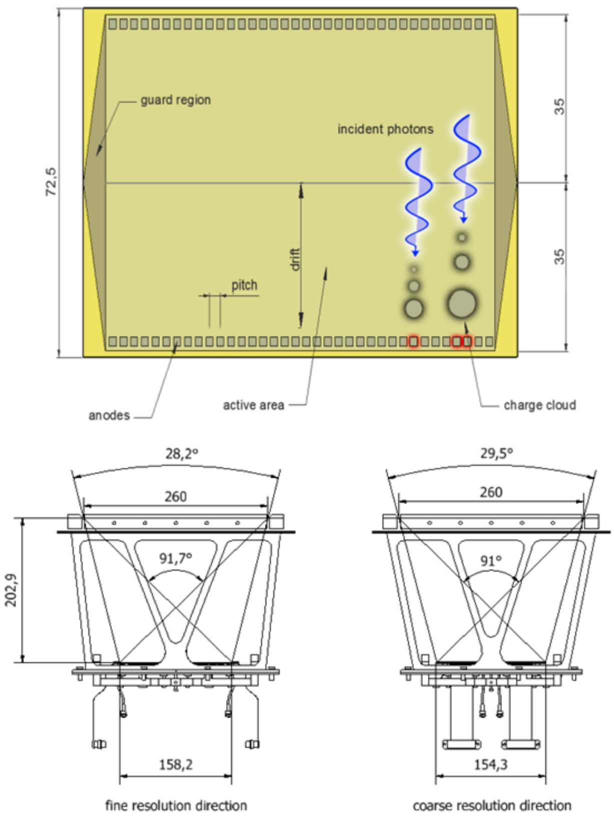


Figure 1: Left: Working principle of the SDD detector and dimensions, in mm, of the SDD tile. Right: Optical configuration of a WFM camera showing the fine and coarse resolution

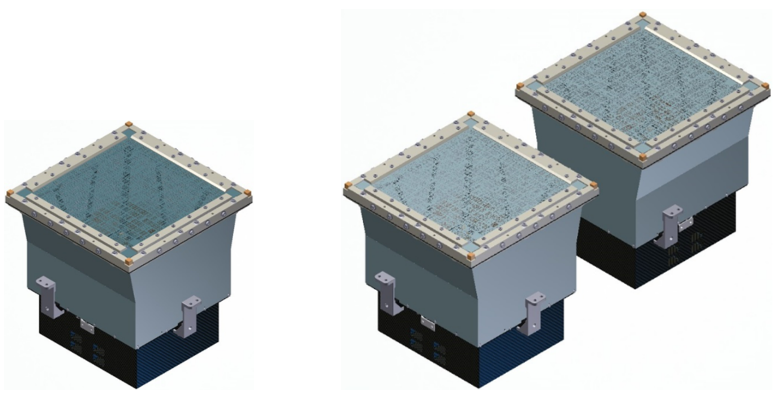


Figure 2: Left: One camera providing "1.5D" positions. Right: One camera pair results from the combination of two orthogonal cameras; it provides accurate 2D positions

given below:

- The **Coded mask** is manufactured from a 150 μm thick Tungsten foil and has a coded area of 260 mm x 260 mm (Fig. 3 centre).
- The **Collimator** is made of an open CFRP structure (Fig. 3 right) 3 mm thick. It holds the mask assembly and shields the detector plane from photons coming from outside of the field of view and cosmic rays since it is outer covered by a 150 μm thick Tungsten sheet.
- A 25 μm thick **Beryllium filter** above SDDs prevents impacts of micro-meteorites and small orbital debris particles.
- The **Detector tray** hosts the four SDD tiles and their corresponding read-out electronics.
- The **Detector Tray Support Structure** holds the detector tray and facilitates the mounting of the collimator and the Back-End Electronics (BEE) box.
- The **BEE** (including the Power Supply Unit of the camera) determines positions, energy and time of the recorded photons.

2 The WFM in the enhanced X-ray Timing and Polarimetry (eXTP) mission

The eXTP (enhanced X-ray Timing and Polarimetry) mission [5] is a major project of the Chinese Academy of Sciences (CAS) and China National Space Administration (CNSA) currently performing an extended phase A study and proposed for a launch by 2025 in a low-earth orbit. The eXTP scientific payload (Fig. 4 left) envisages a suite of instruments: Spectroscopy Focusing Array (SFA), Polarimetry Focusing Array (PFA), Large Area Detector (LAD) and Wide Field Monitor (WFM) offering unprecedented simultaneous wide-band X-ray timing and polarimetry sensitivity. A large European consortium is contributing to the eXTP study and it is expected to provide key hardware elements, including a Wide Field Monitor (WFM). Our institute is deeply involved as explained with more detail in section 4.

3 The WFM in the Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays (STROBE-X) satellite

The Spectroscopic Time-Resolving Observatory for Broadband Energy X-rays (STROBE-X) is a probe-class mission concept that will provide an unprecedented view of the X-ray sky, performing timing and spectroscopy over both a broad energy band (0.2 - 30 keV) and a wide range of timescales from microseconds to years [6]. STROBE-X includes two narrow-field instruments, i.e. X-ray Concentrator Array (XRCA) and the Large Area Detector (LAD),

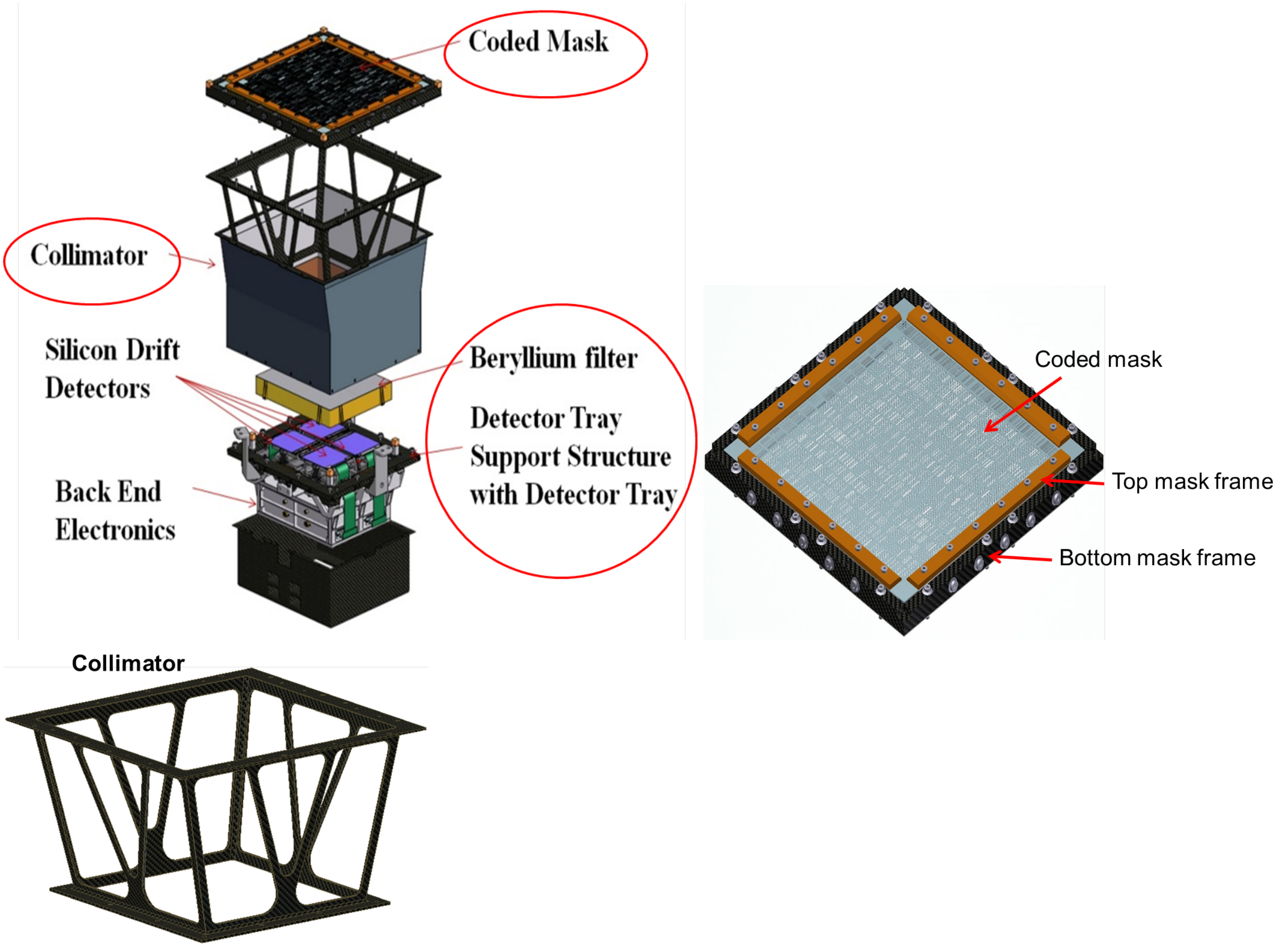
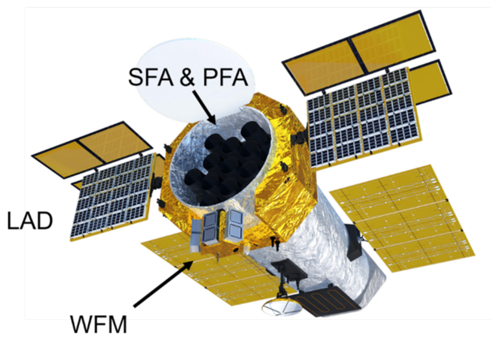


Figure 3: Left: Exploded view of the WFM camera elements. Centre: Coded mask assembly. Right: Collimator structure

and a Wide Field Monitor (WFM) as shown in Fig. 4 right. Our institute has taken part in the update of the WFM design led by the NASA Instrument Design Lab. STROBE-X mission concept will be presented to the 2020 Decadal Survey.

4 Spanish contribution to the WFM - eXTP

The WFM of eXTP mission [7] comprises six identical cameras grouped in three camera pairs as shown in Fig. 4 left. The WFM has an unprecedented combination of simultaneous FoV, i.e. covering 180° x 90° of the accessible sky to the LAD and the other pointed instruments, and imaging capability. It achieves the required 1 arcmin source localization accuracy in 2D. The eXTP mission is currently performing an extended phase A study which will finish in December 2018. The Institute of Space Sciences (ICE, CSIC & IEEC) plays an important



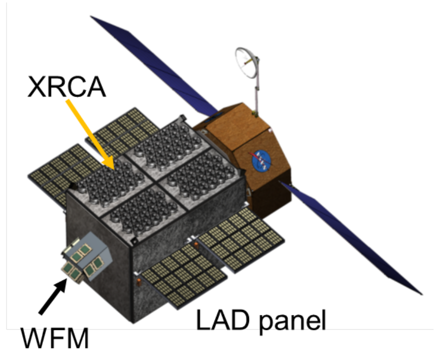


Figure 4: Artist's impression of: Left: e-XTP spacecraft with its science payload. Right: STROBE-X satellite with its scientific instruments

role in the coordination of the WFM instrument at PI level. We are also responsible of the mechanical design, manufacturing and test of the coded mask, collimator, Beryllium filter and detector tray of the WFM camera. In addition, we are also in charge of thermal control of the WFM instrument.

During the LOFT feasibility study, a finite element method (FEM) analysis of the mask design was performed to validate its operation during launch and orbit conditions. In addition, two pieces of $\frac{1}{4}$ of coded mask were built as shown in Fig. 5 left. The samples dimension was 100 mm x 100 mm x 0.1 mm and the pattern consisted on random slits of 14 mm x 0.250 mm with a separation of 2.4 mm between slits. The samples were manufactured by means of the chemical etching technique. Other techniques such as micro-milling and electrodischarge wire cutting were tested but finally both discarded because on one hand Tungsten is a highly abrasive material and this fact increased the fabrication cost and on the other, it was also difficult to achieve slits dimensions and chamfer requirements. A dimension control, i.e. slits position, dimensions, parallelism and chamfer, was performed for ten specific slits in both mask pieces by means of a vision machine. The general result of the dimension control showed that chemical etching is a valid technique, but there is still room to improve the procedure in order to fulfill slit requirements. Currently, we are working on more detailed mechanical and thermal analysis. On the mechanical side, we are performing a non lineal analysis in the temperature operation range in order to check displacements of the mask. And, on the thermal side, we have updated the WFM camera thermal model (Fig. 5 right) to the new ESATAN-TMS software version in order to improve the simulations.

Acknowledgments

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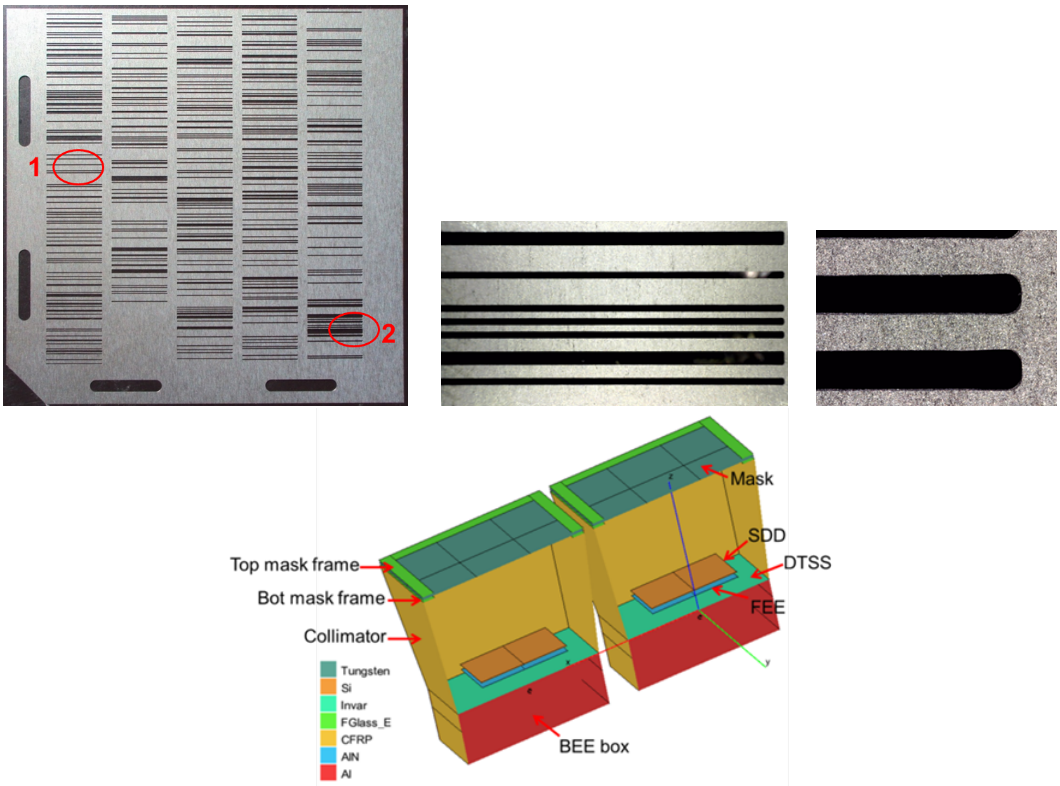

Figure 5: Left: View of the manufacturing of $\frac{1}{4}$ size of the coded mask. Centre: Zoom 1 shows a group of slits in a column. Zoom 2 illustrates the detail of the slit chamfer. Right: WFM camera thermal model

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