A BALLOON BORNE LAUE LENS TELESCOPE FOR GAMMA RAY ASTRONOMY

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ABSTRACT

The future of the soft gamma–ray astronomy (>100 keV) is linked with the development of focusing instruments. Laue lenses are the best candidate instruments. We propose a balloon experiment in order to test for the first time a new concept of focusing gamma–ray telescope that makes use of Laue lenses made of Cu mosaic crystals in transmission configuration, now under development in our institutes, in conjunction with a room temperature solid state detector as focal plane. We present here the features and requirements of this balloon experiment. In a typical observing time of 10000 s per each source at 3 mbars we expect to reach enough sensitivity to demonstrate the spectral and imaging, as well as the polarimetric capabilities of the lens telescope we propose to test.

1. INTRODUCTION

Experimental hard X– and soft γ–ray (10–1000 keV) astronomy is moving from direct sky viewing telescopes to focusing telescopes. With the forthcoming focusing telescopes in this energy range, a big improvement in sensitivity is expected: a factor of 100-1000 with respect to the best non-focusing instruments of the current generation, either using coded masks or not. A significant increase in angular resolution will be also achievable from the ~10 arcmin of the mask telescopes to less than 1 arcmin. The next generation of γ–ray (> 100 keV) focusing telescopes will make use of the Bragg diffraction technique from mosaic–like crystals in a transmission configuration (Laue lenses). The astrophysical issues that are expected to be solved with the advent of these telescopes are many and of fundamental importance. A summary of the main science goals was discussed in the framework of a mission proposal, *Gamma Ray Imager* (GRI), submitted to ESA in response to the first AO of the 'Cosmic Vision 2015–2025' plan [1]. The GRI mission concept was not approved due mainly to the readiness problems of the Laue lenses technology. For the astrophysical importance of the soft γ–ray band (>100 keV) see also [2,3,4,5]. Thanks to an ASI contribution, we have obtained last year the first laboratory results of a Laue lens for soft γ–rays, developed within the Hard X-ray TELescope (HAXTEL) project, devoted to developing a technology for building a broad energy pass-band Laue lens instrument. On the basis of these results and their expected improvement in short times, we propose here to test a Laue lens aboard a balloon experiment. Indeed balloon experiments for high energy astrophysics have a long history (since 60s in Italy) and our group has a strong experience in them (several balloon launches from France, Trapani, Palestine, Fort Sumner, and long duration transatlantic flight). These balloon flights cannot compete with satellite experiments, but they are crucial to test new technologies and to qualify instrumentation to be flown successively aboard satellite missions (e.g., the LAPEX balloon experiment for the PDS instrument on the BeppoSAX mission, [6,7]).

2. RESULTS OF A LAUE LENS PROTOTYPE

A first Laue lens Prototype Model (PM) has been developed (Fig. 1). The goal of this PM was to test the lens assembling technique adopted. Details on the lens assembling steps as well as on the tests using the LARIX beam in Ferrara (Italy) have already been reported [5,8]. The difference between the measured Point Spread Function (PSF) and the simulated one (black circle) is shown in Fig. 2. The corona still visible in the difference image is the result of the cumulative error made in the mosaic Cu crystal tiles positioning.

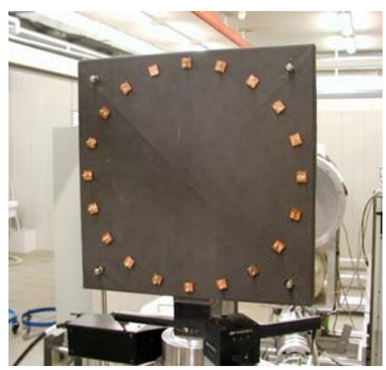

Figure 1. The first Laue lens prototype model developed at the LARIX facility in Ferrara (Italy).

Proc. '19th ESA Symposium on European Rocket and Balloon Programmes and Related Research, Bad Reichenhall, Germany, 7–11 June 2009 (ESA SP-671, September 2009)

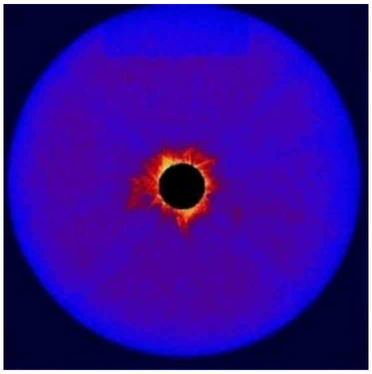

Figure 2. The measured PSF using the Laue PM compared with the ideal one (black circle) obtained with a Monte Carlo code by assuming a perfect positioning of the Cu tiles in the lens.

3. A PROPOSAL FOR A LAUE LENS BALLOON TEST

The best way to test a γ–ray lens for a future space astronomy mission is to realise a balloon borne experiment. In the following, we summarize the main features of the balloon borne Laue telescope we plan to built (HAXTEL-B, HArd X–ray TELescope for Balloon) and the achievable performance for typical balloon observation duration.

The HAXTEL-B stratospheric experiment will be made of three main subsystems: the Laue lens, the focal plane detector, the gondola with the pointing system.

3.1 The Laue lens

The properties of the lens we have in mind to test are summarized in Table 1. The filling factor is the fraction of the lens surface covered with reflecting crystals. The requested crystals have a mosaic structure [9]. The range of values given in Table 1 can be better defined once the focal length of the lens is established. Top and side view of the lens is shown in Fig. 3. The suggested arrangement of the mosaic crystal tiles on the lens support follows an Archimedes spiral. This arrangement allows having smoother variation of the Laue lens effective area with energy (see Fig. 7).

Table 1. The HAXTEL-B Laue lens main features.

Item description	*Value*
Focal length	6 m
Crystal tiles disposition	spiral
Nominal energy band	70–300 keV
Lens inner radius (cm)	12 cm
Lens outer radius (cm)	50 cm
Crystal material	Cu(111)
Crystal mosaic spread	3’
Crystal tile size	$15\times15\times2\text{-}3$ mm^3
Lens filling factor _ 0:8	~0.8
Number of crystal tiles	2600
Total weight	**25 kg**

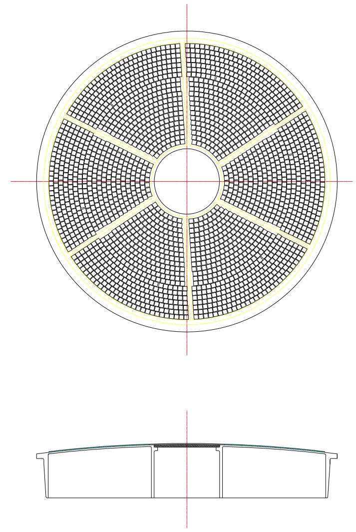

Figure 3. The HAXTEL-B Laue lens subsystem.

3.2 The focal plane detector

As reported in the Table 1, for a 6 m focal length, an efficient and low instrumental background position-sensitive focal plane detector is needed [10, 11,12]. The proposed focal plane detector is made of a mosaic of thick (5-10 mm) CZT pixels modules. The proposed geometric spatial resolution (2 mm) is well tuned to, and therefore allows a good sampling of, the HAXTEL-B Laue lens PSF characteristics (see Fig. 6). The main features of the focal plane detector designed are summarized in Table 2. A side view of the focal plane detector along with its baffle extending up to ~400 cm above the CZT detector and with its CsI well shaped active shield is shown in Fig. 4. Both baffle and active shield are crucial elements in the focal plane design in order to minimize the detector background level and therefore to increase the telescope sensitivity.

Table 2. The HAXTEL-B focal plane main features

Item description	*Value*
Detector material	CZT
Detector thickness	5-10 mm
Energy band (keV) 10–300	10-300 keV
Energy resolution (FWHM)	5% @100 keV
Efficiency >50% @300 keV	>50% @ 300 keV
Sensitive area	10×10 cm^2
Spatial resolution	2 mm
N. of channels/pixels	2500
Active shield/thickness	CsI/20 mm
Active shield height	10 cm
Baffle/thickness	Pb/2 mm
Baffle height	400 cm
Baffle aperture(FWZR)	~10º
Total weight	**25 kg**

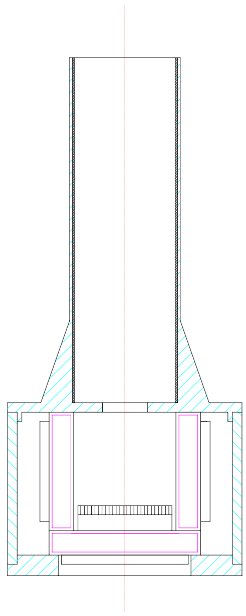

Figure 4. The HAXTEL-B focal plane detector scheme.

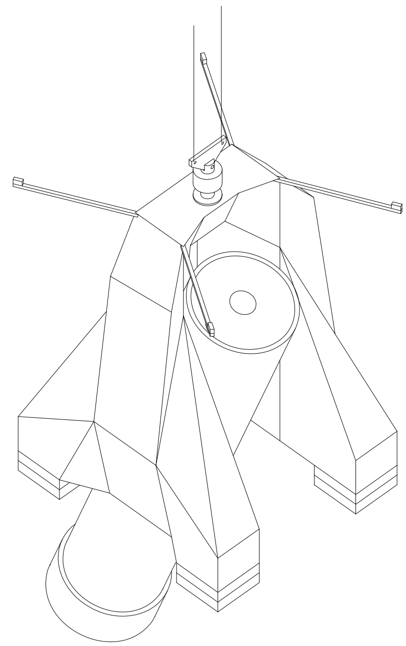

Figure 5. A possible flight configuration for the HAXTEL-B balloon borne payload.

3.3 The gondola and the pointing system

The designed HAXTEL-B gondola is shown in Fig. 5. The telescope is mounted in a platform in an elevation–azimuth configuration. Apart from a small angle around the zenith direction, the lens can be pointed everywhere in the sky. The lens elevation can be changed by rotating, with respect to the gondola frame, the lens plus focal plane detector holder (the tube-like structure in Fig. 5) around a horizontal axis passing through the centre of mass. The elevation angle can be known with a precision of 10 arcsec and an accuracy of 1 arcmin. Instead, the telescope azimuth can be changed by means of an Azimuth Control System (ACS). The ACS now foreseen is HiPEG [13], that is already developed and tested on ground with very satisfactory results, with a pointing stability of 30” and a pointing accuracy of 1’.

4. HAXTEL-B FLIGHT REQUIREMENTS

The balloon experiment has specific requirements for its success. The float altitude has to correspond to a residual atmospheric pressure of 4 mbar or less (i.e. above 35 km). In order to have a low and stable radiation environment, the flight latitude should be as low as possible (a Trapani-like base or, better, an equatorial base).

The minimum flight duration at the float altitude should be longer than 12 hours. The bit rate requirements are very light: a continuum transmission with a bit rate of ~5 kb/s, this being compatible with flexible telemetry system based on telecommunication satellite network [14]. Furthermore we need to up link telecommands with a very low bit rate.

4.1 Power and mass budget

The power and mass evaluated budgets for the HAXTEL-B experiment are given in Tables 3 and 4. The values are reported with a 20% contingency for a flight configuration using a focal length of 6 meters.

Table 3. The HAXTEL-B required power budget

Item description	*Value*
Lens thermal control	150 W
Detector and FEE	30 W
DPE and TLM/IF	70 W
Attitude system motors	150 W
Attitude system Electronics	50 W
Star sensor/Sun sensor	50 W
Total power requested	**500 W**

Table 4. Main Size and Mass budget for the HAXTEL-B experiment in flight configuration

Item description	*Value*
Gondola size	2×2×4 m^3
Laue telescope length	6 m
Laue telescope diameter	1.2 m
Gondola weight	240 kg
Laue telescope weight	120 kg
Attitude system weight	80 kg
Payload weight	440 kg
Flight configuration weight	**900 kg**

5. EXPECTED PERFORMANCE

The evaluation of the HAXTEL-B telescope sensitivity has been obtained using the expected PSF of the lens for an on-axis source (Fig. 6) and the background count rate evaluated scaling from other balloon experiments, as well as the effective area of the proposed Laue lens (Fig. 7). The on axis sensitivity, assuming a focal plane detection efficiency very close to 100%, for a 10000 s observation time at 3σ confidence level is shown in Fig. 8 as a function of the photon energy and compared to the expected fluxes from two typical hard X-ray targets for balloon observations

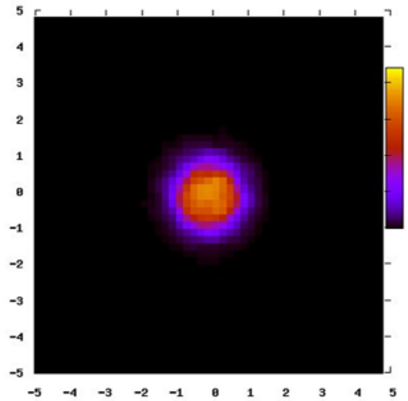

Figure 6. The expected HAXTEL-B Laue lens image of an on-axis source (PSF) for the proposed 6 m focal length configuration; both scales are in cm.

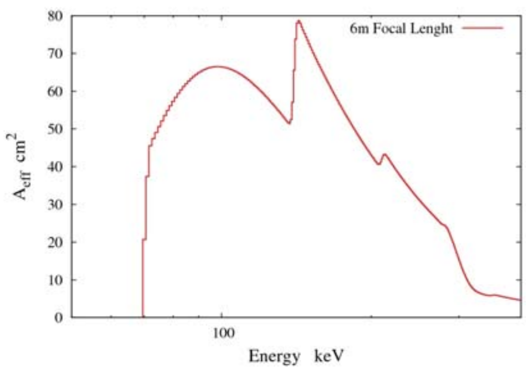

Figure 7. The HAXTEL-B Laue lens effective area as a function of energy

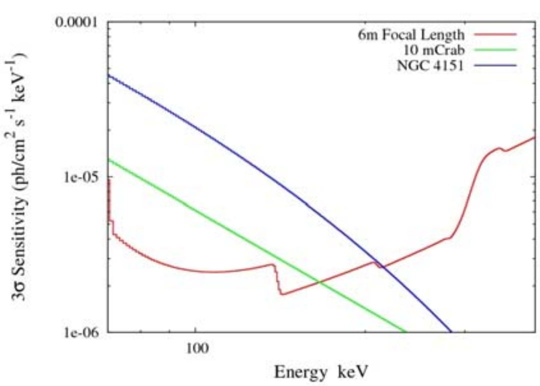

Figure 8. The HAXTEL-B expected sensitivity (at 3σ level, and assuming ΔE=E/2) for a 10000 s observation.

5.1 Polarimetric performance

The high level segmentation of the proposed HAXTEL-B focal plane detector together with the coincidence operation logic, that will be implemented in its data handling electronics, allow to perform contemporary to the spectroscopic imaging and timing observations also polarimetric measurements using the detection of Compton scattered events [15]. Table 5 reports the achievable Minimum Detectable Polarisation (MDP) [16] in a 10000 s long observation of a 100 mCrab source with a power law spectrum having a photon index of -2. The expected MDP values are in good agreement with recent results on the Crab polarisation level at high energy obtained with INTEGRAL instruments [17, 18] and therefore guarantee the possibility to verify also this important feature during an HAXTEL-B flight.

Table 5. The HAXTEL-B telescope achievable Minimum Detectable Polarization DP for a 10000 s observation on a 100 mCrab source.

CZT thickness	*100-200 keV*	*150-250 keV*	*250-350 keV*
5 mm	16%	14%	14%
10 mm	13%	11%	9%

6. CONCLUSIONS

The Laue lenses represent a very challenging technology to fulfil the requirements of the next missions generation for hard X- and soft γ– rays astronomy (>100 keV).

After big efforts, eventually we have a technology for building a Laue lens made by mosaic crystals. Also the technology for producing these crystals, after a long training, is now becoming mature (Frontera et al. 2008). We propose to test a broad band Laue lens (70–300 keV) aboard a stratospheric balloon. Our group have all the experience needed to perform this experiment. In order to achieve the expected results, the balloon launch should be performed from a low latitude balloon base. The ASI operated Trapani (Sicily) base or a lower latitude balloon base matches our requirements.

HAXTEL-B shall be seen as the pathfinder of a new generation of hard X- and soft gamma-ray satellite missions. The realisation of the HAXTEL-B telescope, in a perspective of 4-5 years, will be of strategic importance to assess the readiness of the Laue lens and related technologies for a future satellite mission in the framework of an ESA call or others opportunities.

7. ACKNOWLEDGMENTS

We wish to thank Ken Andersen and Pierre Courtois from ILL (Grenoble), for providing the Cu mosaic crystals for the Laue lens prototype realisation.

We acknowledge the Italian Space Agency (ASI) for its financial support to the successful Laue lens prototype development.

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