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A gamma–ray Laue lens focusing telescope aboard a balloon experiment

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Abstract. The future of the soft gamma–ray astronomy (>100 keV) is connected 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 mosaic crystals in transmission configuration, now developed in our institutes. We discuss here the features and requirements of this balloon experiment. In 10000 s of observing time per each source at 3 mbars we expect to reach the sufficient sensitivity to demonstrate the spectral and imaging capabilities of the lens we propose to test.

Key words. Laue lenses – soft gamma–ray astronomy – balloon experiments – observations – gamma–ray focusing optics

1. Introduction

Experimental hard X–/gamma–ray (10–1000 keV) astronomy is moving from direct sky-viewing telescopes to focusing telescopes. With the advent of focusing telescopes in this energy range, a big leap in sensitivity is expected, by 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 is also expected from $\sim$ 10 arcmin of the mask telescopes to less than 1 arcmin.

The next generation of gamma–ray (> 100 keV) focusing telescopes will make use of the Bragg diffraction technique from mosaic–like crystals in a transmission configuration (Laue lenses).

The expected 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 are discussed in the context of a mission proposal, *Gamma Ray Imager* (GRI), submitted to ESA in response to the first AO of the 'Cosmic Vision 2015–2025' plan (Knödlseder et al. (2007)) but not approved due to readiness problems of the Laue lenses. For the astrophysical importance of the soft gamma–ray band (>100 keV), see also Frontera et al. (2005, 2006); Knödlseder (2006); Knödlseder et al. (2007); Frontera et al. (2008).

Thanks to an ASI contribution, we have now the first laboratory results of a Laue lens for soft gamma–rays, developed within the HAXTEL project, devoted to developing a technology for building broad energy passband Laue lenses.

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 HE astrophysics have a long history (since 60s in Italy) and our group has a long experience in them (several balloon launches from France, Trapani, Palestine, Fort Sumner, long duration transatlantic flight). They cannot compete with satellite experiments, but they are crucial to test new technologies and to qualify instrumentation to be flown aboard satellite missions (e.g., PDS experiment for the *BeppoSAX* mission).

Fig. 1. A view of the apparatus for assembling the lens PM. The apparatus is located in the LARIX lab of the University of Ferrara.

2. First test results of a Laue lens prototype

A first Laue lens Prototype Model (PM) has been developed. The goal of the first PM was to test the lens assembling technique adopted. Details of the lens assembling steps have already been reported (Frontera et al. 2007; Frontera et al. 2008).

The PM was widely tested using the LARIX beam (see Fig. 1) as discussed by Frontera et al. (2008).

The difference between the measured PSF and the simulated one is shown in Fig. 2. The corona still visible in the difference image is the result of the cumulative error made in the crystal tile positioning.

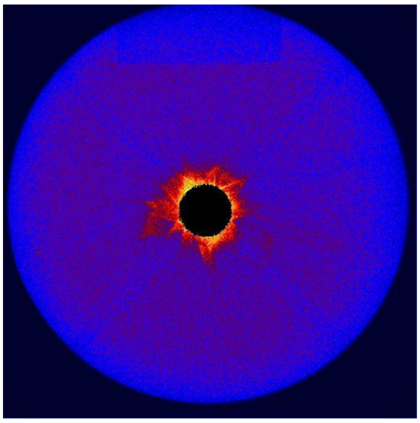

Fig. 2. Difference between the measured PSF and that obtained with a Monte Carlo code by assuming a perfect positioning of the crystal tiles in the lens.

3. Proposal of a stratospherical balloon test

The best test of a gamma–ray lens for space astronomy is that performed aboard a balloon flight experiment. We summarize here the main features of the balloon experiment we have in mind and of the expected performance (sensitivity, imaging capability) of the proposed focusing gamma–ray experiment (HAXTEL-B, Hard X–ray Telescope for Balloon).

Table 1. Laue lens features for a balloon test.

Parameter	Value
Focal length (m)	3–6
Crystal disposition in the lens	spiral
Nominal energy band (keV)	70–300 keV
Lens inner radius (cm)	6–12
Lens outer radius (cm)	25–50
Crystal material	Cu(111)
Crystal mosaic spread (')	3
Crystal tile size (mm^2)	$15 \times 15 \times 2$-3
Lens filling factor	~ 0.8
Number of lens crystal tiles	720–2600
Total weight (Kg)	25

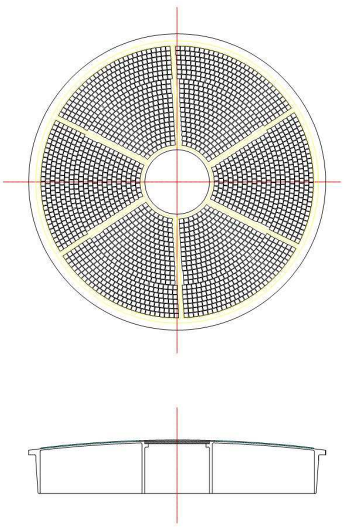

Fig. 3. Side and top view of the lens proposed for the balloon experiment.

3.1. Laue lens and focal plane detector properties

The properties of the lens we have in mind to test are summarized in Table 1. As filling factor we intend the fraction of the lens surface covered with reflecting crystals. The requested crystals have a mosaic structure (Pisa et al. 2004). 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.

Table 2. Focal plane detector for the proposed balloon borne Laue lens telescope.

Parameter	Value
Detector material	CZT/$LaBr_3$ (opt.)
Detector thickness (mm)	5-10
Energy band (keV)	50–300
Energy resolution	5% @100 keV
Efficiency	>50% @300 keV
Sensitive area (cm^2)	10×10
Spatial resolution (mm)	2 (0.1×PSF)
Electronics dynamics	10–500 keV
N. of channels/pixels	2500
Act. shield/thickness (mm)	CsI/20
Act. shield height (mm)	100
Baffle/thickness (mm)	Pb/2
Baffle height (cm)	~ 400
Baffle aperture(FWZR)	~ 10°
Total weight (Kg)	25

As reported in the Table 1, at a distance of 3-6 m focal length, an efficient and low instrumental background position-sensitive focal plane detector is needed (Caroli et al. 2005). The features of the focal plane detector designed are summarized in Table 2. A side view of the focal plane detector along with its baffle is shown in Fig. 4. The baffle is crucial in order to minimize the detector background level.

3.2. Gondola and azimuth control 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 gondola frame, the lens plus focal plane detector holder (the tube-like structure in Fig. 5) around an horizontal axis passing through the center 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 (di Cocco et al. 2006), that is already developed and tested on ground

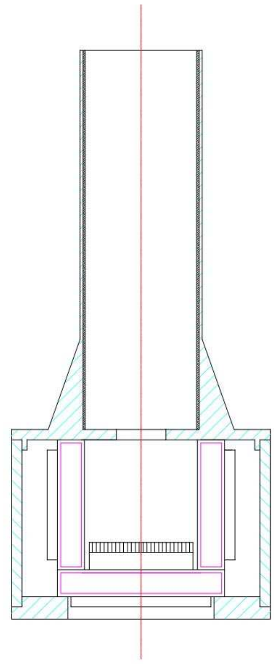

Fig. 4. Side view of the detector, along with its baffle, proposed for testing a gamma–ray Laue lens aboard a stratospheric balloon.

with very satisfactory results (see also Fig. 6), with a pointing stability of 30 arcsec and a pointing accuracy of 1 arcmin.

3.3. Power and mass budget

A preliminary estimate of the power and mass budgets of our experiment are given in Tables 3 and 4. The uncertainty in the reported values is mainly connected with the final decision about the focal distance of the lens.

3.4. 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.

In order to have a low and stable radiation environment, the flight latitude should be as lower as possible (a Trapani-like base or, better, an equatorial base).

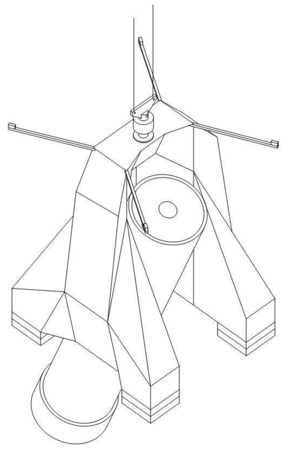

Fig. 5. Gondola for the balloon experiment devoted to test the gamma–ray lens.

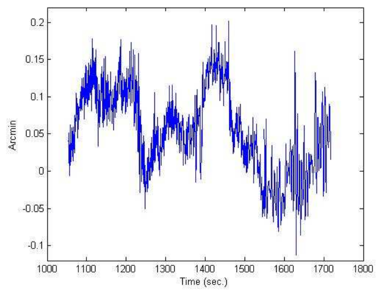

Fig. 6. Test results of the Azimuth Control System HiPEG, that is proposed for testing the gamma–ray lens aboard a stratospheric balloon.

The minimum flight duration at the float altitude should be 12 hrs.

The bit rate requirements are very soft: a continuum transmission with a bit rate of 5 kb/s. Furthermore we need to up link telecommands with very low bit rate.

4. Expected performance

Using a Monte Carlo code, we have derived the expected flux sensitivity and imaging capability of the Laue lens telescope. The on axis sensitivity, for a 10^4 s observation time at a 3σ confidence level is shown in Fig. 7 as a function of the photon energy. The expected

Table 3. Power budget of the balloon experiment HAXTEL-B

Parameter	Value (W)
Lens thermal control	150
Detector & FEE	30
DPE and TLM/IF	70
ACS motors	150
ACS Electronics	50
Star sensor	50
Total power requested	500

Table 4. Mass/size budget of the balloon experiment HAXTEL-B

Parameter	Value
Gondola weight (Kg)	160–240
Telescope (Kg)	80–120
ACS weight (Kg)	80
Payload weight (Kg)	320–440
Total weight (Kg)	700–900
Gondola size (m×m×m)	2×2×2–4 (H)
Telescope length (m)	3–6
Telescope diameter (cm)	60–120

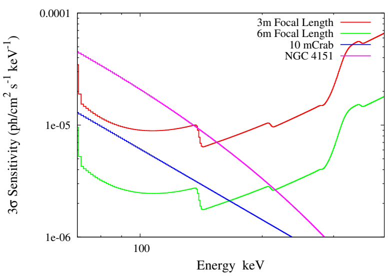

Fig. 7. Expected sensitivity of the HAXTEL-B balloon experiment. The spectrum of a well known Seyfert galaxy (NGC4151) and that of a Crab–like source a factor 100 weaker are also shown.

point spread function of the lens for an on-axis source is shown in Fig. 8.

5. Conclusions

The Laue lenses are expected to be the future of the soft gamma–ray astronomy (>100 keV).

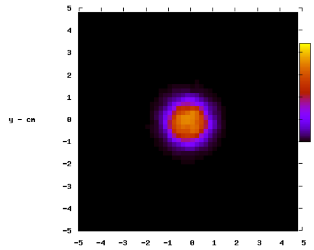

Fig. 8. Expected image from an on-axis source, for a Laue lens with 6 m focal length.

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

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