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AGO: Adjustable Gamma-ray Optics

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Abstract

Laue lenses, optics based on Bragg's law of diffraction, are the most promising method to focus X and gamma-rays with a reasonable focal length of a few tens of meters. Laue lenses consist of several crystals properly aligned to diffract X-/gamma-ray beams and concentrate them into a focal point. However, several limitations have been found in the alignment process of the crystals to the common focus with techniques based on standard glue bonding. In particular, the alignment accuracy which has been obtained so far is of the order of a few arcminutes. In this **Techno Grant INAF 2023** we explore the possibility of applying, for the first time, an active alignment of optical components based on piezoelectric actuators. This feature opens new, unexplored possibilities, such as a continuous fine-tuning of the crystal's alignment and even the design of a Laue lens tunable at different energies depending on the source target.

Laue Lenses

Laue lenses were introduced in the 90's [1] as the only technique capable of focussing hard X and gamma rays above the energy of ~70 keV. A Laue lens is made up of many properly aligned crystals arranged in concentric rings over a spherical cup, with their diffracting planes perpendicular to the sphere (Fig. 1). The crystals are disposed to concentrate the incident radiation onto a common focal point, at half of the radius of the spherical cup for geometrical reasons.

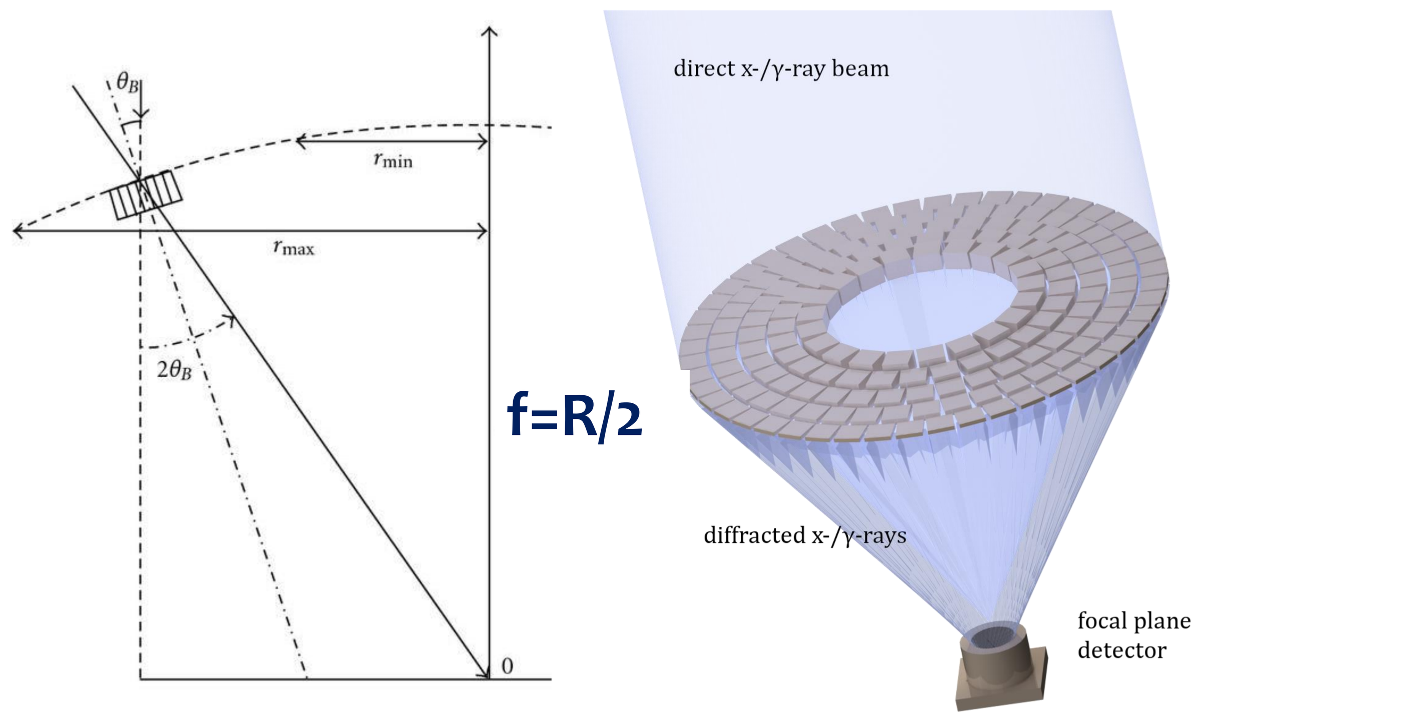

Fig. 1. Left: Principle of Laue lenses. The incoming radiation hitting a crystal is diffracted at a known angle, depending on the Bragg law and the atomic structure of the crystal being used. Right: Schematic view of a Laue lens. The crystals are positioned and oriented to focus radiation on a common focal point. Each ring of crystals diffracts a narrow energy passband. By combining multiple rings, the lens can focus the radiation into a broad energy passband.

An unexplored technique in hard X-rays

An alignment solution based on the elastic bending of a flexible material with a piezoelectric actuator to properly orient the optical elements to the desired Bragg's angle. The possibility of implementing, **for the first time, an active alignment system** (Fig. 3) for each crystal is being considered based on:

1. an elastic flexure;
2. a piezo-actuator.

Piezoelectric actuators are available for delicate adjustment in space [3]. This feature opens new possibilities, such as a continuous fine-tuning of the crystal's alignment and the design of a Laue lens tunable at different energies, depending on the energies of interest from a given hard X-/soft gamma-ray source as well.

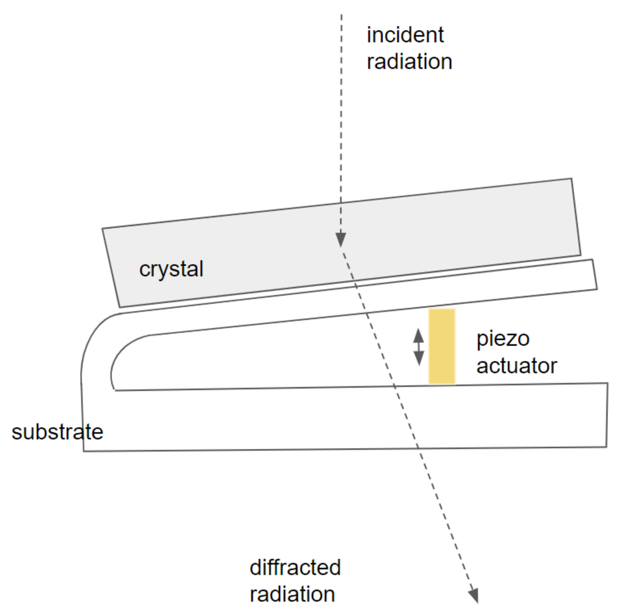

Fig. 3. In substitution of the adhesive film, the proposed innovation makes use of a flexure for each optical element and of a piezoelectric actuator to tilt the crystal of the correct quantity in order to properly orient the crystal.

References

[1] N. Lund. Exp. Astron., 2, 259 (1992). doi: 10.1007/BF00690085.

[2] L. Ferro et al. "Recent developments in Laue lens manufacturing and their impact on imaging performance," J. Astron. Telesc. Instrum. Syst. 10(1) 014002 (2024).

[3] Le Letty, R.; Barillot et al. "Piezoelectric actuators for active optics". In Proceedings of the International Conference on Space Optics—ICSO 2004, Toulouse, France (2004).

Current techniques for Laue lens realization

Several limitations have been found in the alignment process of the crystals to the common focus with techniques based on standard glue bonding [2]. When a crystal is bonded to a substrate, the inclination is typically achieved through a layer of adhesive (Fig. 2). This adhesive, being asymmetric, generates differential shrinkage that unpredictably tilts the crystal by a finite amount.

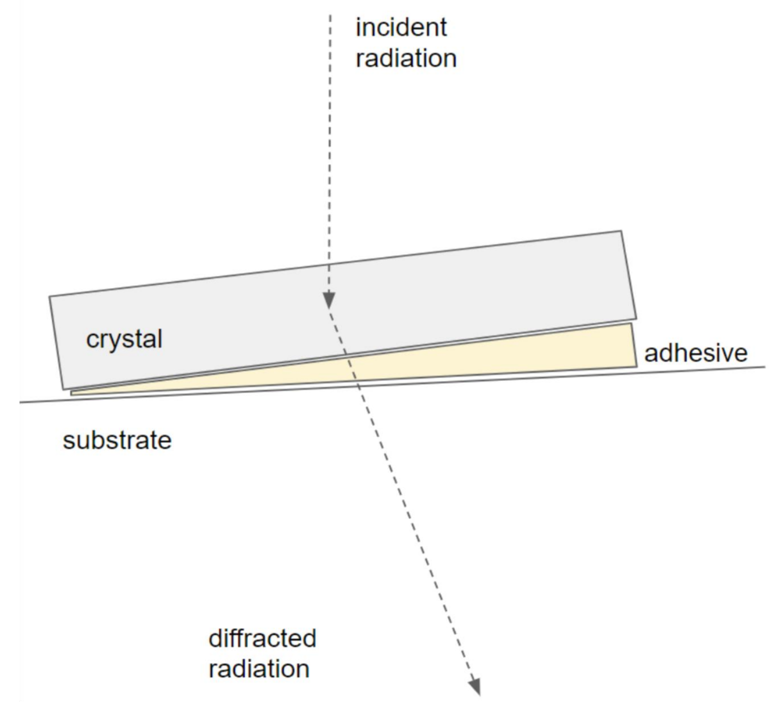

Fig. 2. A film of adhesive bonds the crystals to a common substrate. However, the uneven distribution of the adhesive introduces differential stress during the polymerization process, which affects the alignment of the crystals.

Sub-arcsec accuracy and adjustability

The lamella-flexure-substrate system is monolithic, made from a single material (titanium or aluminum), with its design (e.g., flexure joint thickness) optimized via elastic simulations. Each lamella is oriented by a piezoelectric actuator beneath it. These actuators provide linear displacements of tens of microns with nanometer precision, enabling sub-arcsecond resolution in the Bragg diffraction angle.

Since radiation passes through both the lamella and actuator, minimizing size is crucial to avoid excessive absorption. The small cross-section of commercial actuators (e.g., 3 ⨉ 3 mm²) results in an acceptable loss area of about 3%.

A demonstrator prototype with 9 crystals will be realized (Fig. 4). No power is required in static configuration. Low power is needed during corrections, generating no heat when at rest. A simple circuit for powering the system is outed on the substrate, with negligible radiation absorption.

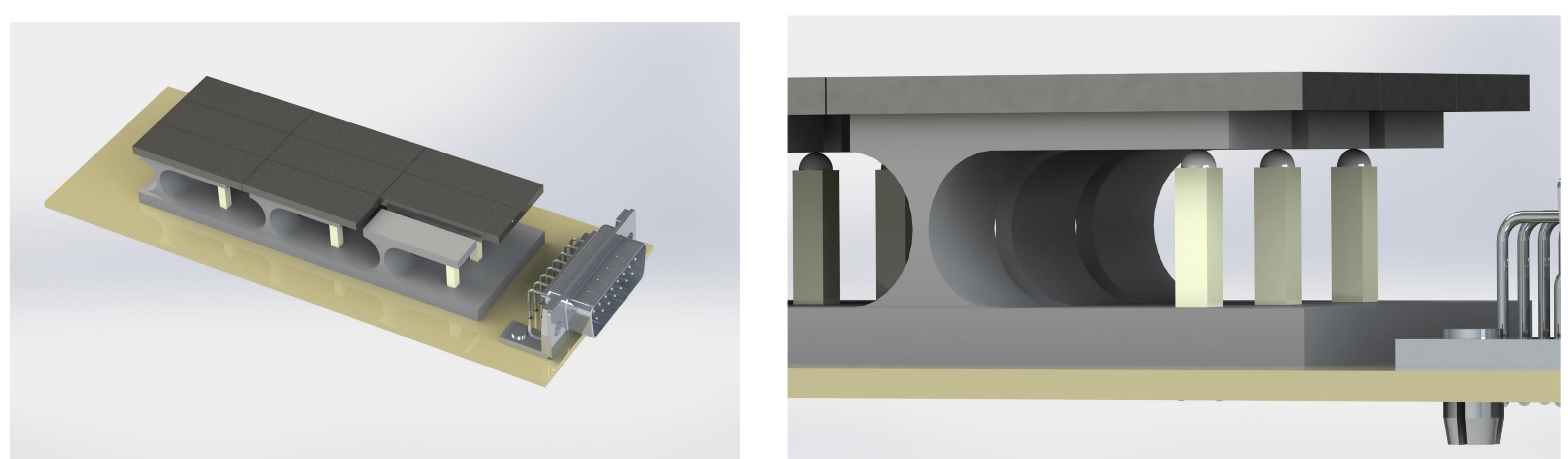

Fig. 4. Left: Prototype of 9 crystals tilted using 9 piezoelectric actuators (2 ⨉ 2 mm² cross section) through a joint flexure. The baseline substrate materials are aluminum or titanium, but other low Z/density materials such as space-qualified ULTEM, polymers, Silicon Carbide, or carbon fiber are being explored. Right: Detail of the AGO mechanism, showing 3 crystals with their respective piezo-actuators.

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