# Science motivations and development status of the Laue lenses for soft gamma γ-rays (80 – 600 keV)

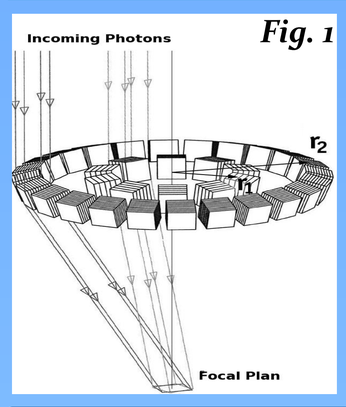
**E. Virgilli [1], F. Frontera[1][2], G. Loffredo[1], C. Guidorzi[1], M. Statera[1], L. Titarchuk[1], V. Guidi[1], R. Camattari[1], V. Bellucci[1] , V. Carassiti[3], F. Evangelisti[3], S. Squerzanti[3], E. Caroli[2], J.B. Stephen[2], N. Auricchio[2], L. Amati[2], M. Orlandini[2]**

(1) Dipartimento di Fisica – Università di Ferrara, via Saragat, 1 – Ferrara, Italy
(2) Istituto di Astrofisica Spaziale e Fisica Cosmica, section of Bologna, CNR/INAF, via Gobetti, 101 – Bologna, Italy
(3) Istituto Nazionale di Fisica Nucleare (INFN) sezione di Ferrara – via Saragat, 1 – Ferrara, Italy

## ABSTRACT

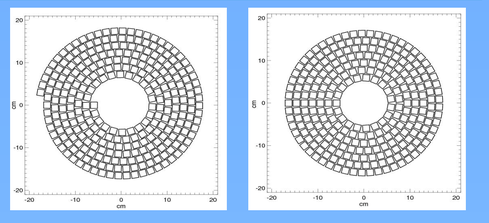
***Hard X-/soft gamma-ray band (80 – 600 keV ) represents a crucial window for the study of most energetic phenomena occurring in Galactic and Extragalactic sky. In order to take full advantage of the potential of hard X-soft gamma astronomy, a new generation of telescopes has to be considered. In order to increase the instrument sensitivity it is crucial to use focusing optics. To date, the most efficient technique to focus hard X-rays above 80 keV is the Bragg diffraction from crystals in transmission configuration (Laue lenses). In this poster we summarize some key science objectives that could be achieved with a Laue lens. We also report some details of our project, its development status and some results.***

*Fig. 1*




In a Laue lens a set of properly oriented crystals is used to focus X-rays photons via Bragg diffraction in transmission geometry (Fig. 1). Different configurations of assembling crystals in the lens can be adopted, ring or spiral (Fig. 2).

*Fig. 2*



***Goal of the project is to develop a Laue lens with:***
***- broad passband (80 – 600 keV);***
***- sensitivity about $10^{-8}$ ph/cm² s keV, T=$10^5$ s;***
***- good imaging capability ( < arcmin).***

## SCIENTIFIC MOTIVATIONS FOR LAUE LENSES

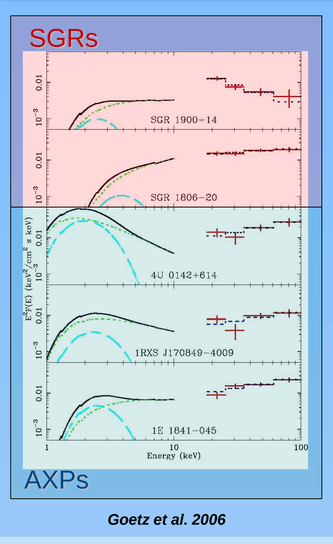


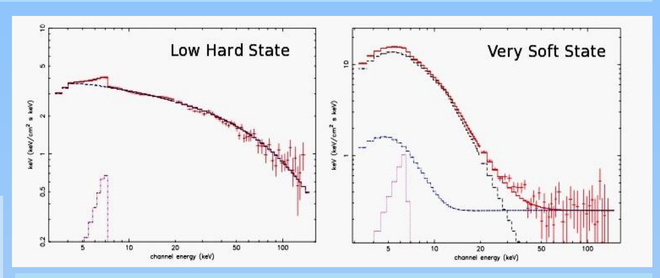

*Fig. 3*

*Goetz et al. 2006*

***Deep study of Soft Gamma Repeaters (SGRs) and Anomalous X-ray Pulsars (AXPs).***

They belong to the same class of sources (magnetars). Instruments with sensitivity higher than current non focusing instruments are needed above 100 keV to understand their high energy emission (*Fig. 3*).

*Fig. 4*




***Study of BH binaries.***

The emission of BH during High/Soft and Very High Soft states (Fig. 4) is far to be understood due to the current low instrument sensitivity. Higher sensitivity is required.

***Study of sources that origin the Cosmic X-ray background (CXB).***

A combination of different AGN populations is used (Gilli et al. 2007, Fig. 5) to resolve the CXB up to 100 keV. To test this model high sensitivity measurements beyond 100 keV of a large sample of AGNs of different populations are needed.

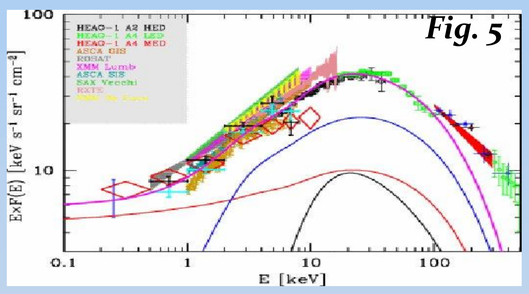



*Fig. 5*

***Annihilation line.***

e+/e- production is expected to occur in a variety of cosmic phenomena and astrophysical sites. Observation of the 511 keV emission line is a powerful tool to probe plasma properties, dark matter and antimatter (Fig. 6).

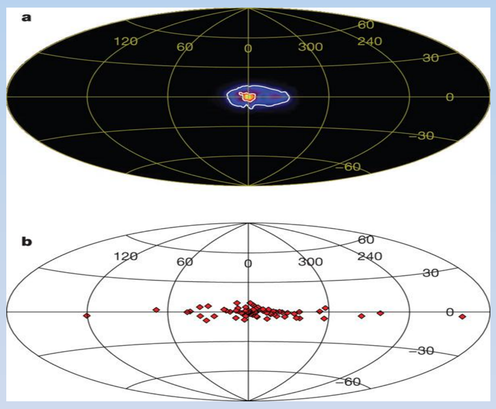



*Fig. 6 Weidenspointner et al. (2008)*

## CRYSTALS FOR LAUE LENSES

*Fig. 7*

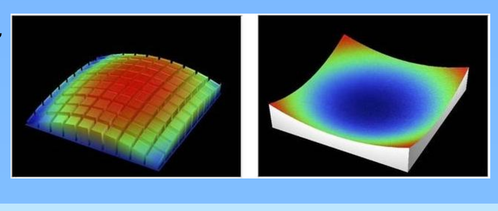
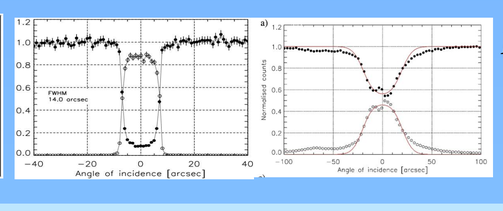


*Fig. 8*




Up to now, mosaic crystals have been considered the possible suitable crystals for Laue lenses. However the best crystals are recognized to be the bent crystals because they can have the same passband of mosaic crystals but higher efficiency. Now these crystals can be available thanks to the indentation method developed in Ferrara by Guidi et al. (2009). Figure 7 shows the profile along x and y axis of a developed bent crystal. The curvature can be adjusted to fit the lens requirements. Simulations of a Laue lens with 15 m FL (Fig. 9) show the different PSF between flat mosaic and curved crystals. The use of curved crystals also increases the sensitivity by about 1 order of magnitude with respect to mosaic flat crystals (Fig. 10).

*Fig. 9*

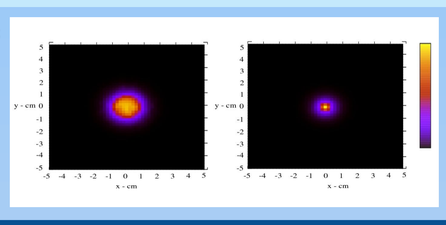
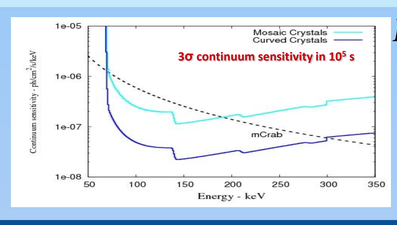



*Fig. 10*




## PROJECTS

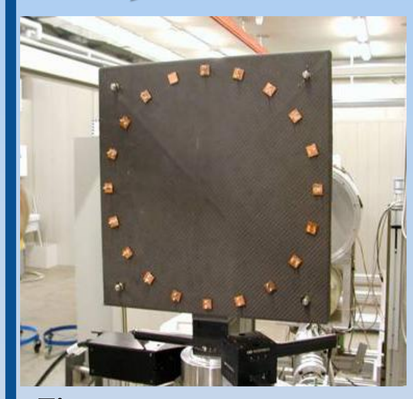


*Fig. 11*

The first Laue lens prototype (*Fig. 11*) developed in Ferrara was made of 20 Cu (111) mosaic crystal tiles. Figure 12 shows the prototype measured PSF (black region is the region where all the photons were expected to fall in the case of a perfect assembling). Figure 14 shown the percentage of collected photons (red line) with respect to the theoretical expectation (black line) .

*Fig. 12*

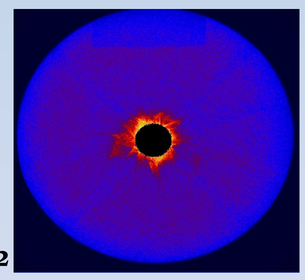
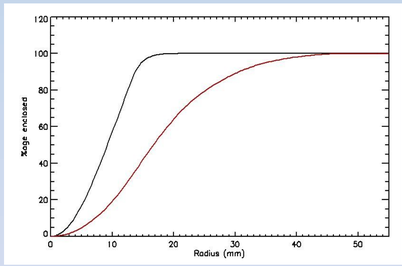


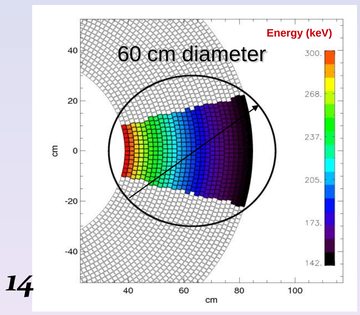
*Fig. 13*




A new project (LAUE) is ongoing with industry involvement (main contractor DTM - Modena). The goal is to build and test a petal of a lens with 20 m focal length using curved crystals (Fig. 14).

The petal prototype will be enterely build and tested in the LARIX facility of the Physics Department of Ferrara University (Fig. 15).

*Fig. 14*



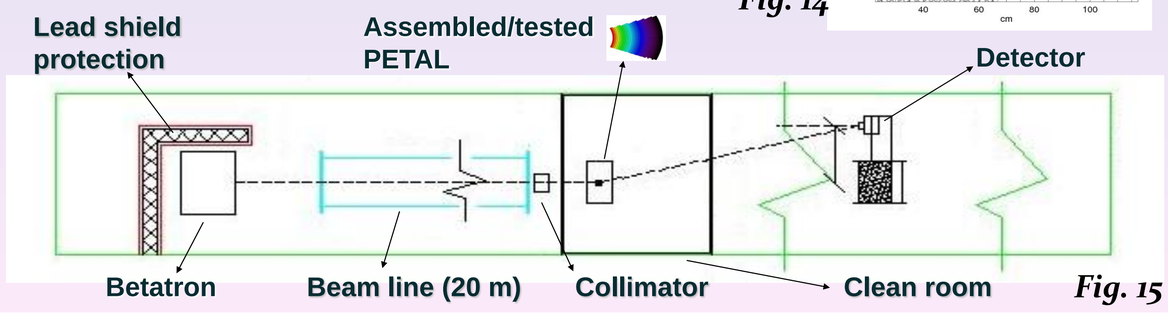




*Fig. 15*

## CONCLUSIONS

The hard X-/gamma-ray band covered by Laue lenses is crucial to understand phenomena like the emission physics of Galactic and extragalactic sources, to understand the origin of high energy CXB, to establish the origin of positron annihilation line observed with INTEGRAL.

Big efforts have been already performed and still in progress for the development of focusing Laue lenses. Low focal Laue lenses (up to 10 – 15 m) technique has been already tested and optimized. Technology for building high focal length Laue lenses under development (LAUE project) with industry involvment.

Have been demonstrated that curved crystals can be produced with the requested properties. Curved crystals improve sensitivity and angular resolution of the Laue lenses by an order of magnitude with respect to flat crystals. A sensitvity of a few times $10^{-8}$ ph/cm² s keV can be realistically achieved in $10^5$ s.