	Experiment title: Development of a Laue lens for nuclear astrophysics: Study of copper low mosaicity crystals and Si-Ge crystals with a gradient of concentration.	**Experiment number**: MA-173
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Shifts: 21	**Local contact(s)**: Thomas Buslaps	*Received at ESRF:*

Names and affiliations of applicants (* indicates experimentalists):

Dr Pierre Bastie*	Laboratoire de Spectrométrie Physique, UJF, Grenoble, France
Nicolas Barrière*	CESR, Toulouse, France
Dr Nikolai Abrosimov*	IKZ, Berlin, Germany
Dr Pierre Courtois*	ILL, Grenoble, France
Pr Peter von Ballmoos	CESR, Toulouse, France
Gilles Roudill*	CESR, Toulouse, France
Julien Rousselle*	CESR, Toulouse, France

Report:

This experiment is the continuation of the experiment ME-1203. It concerns the development of a Laue lens for a space borne gamma-ray telescope.

A Laue lens focuses gamma rays using Bragg diffraction in the volume of crystals (Laue geometry). Crystals tiles are positionned on concentric rings such that they diffract incident radiation of a given energy onto a common focal spot [1]. In a given ring, all crystals are identical and diffract a given energy. To cover a large energy bandpass, each ring must diffract an energy band large enough to overlap partially the energy band diffracted by the neighbouring rings. For us, this constraint implies a mosaic spread between 15 arcsec and 1 arcmin.

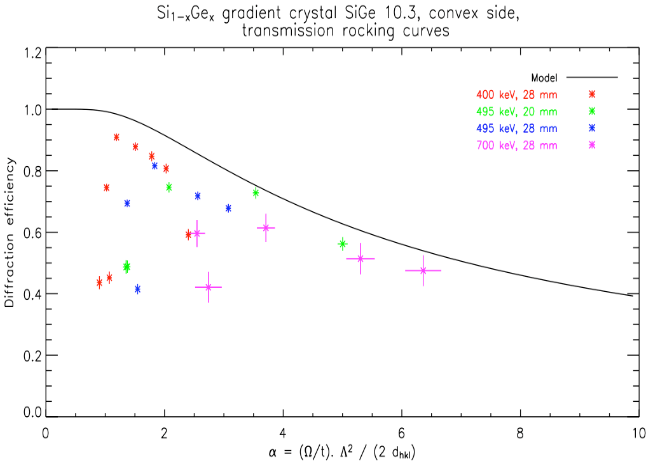
Since the previous ESRF experiment, the concept of a space borne gamma-ray telescope has evolved. It is now called Gamma-Ray Imager (GRI) [2] and is based on a Laue lens made of about 28000 crystal slabs (15mm x 15mm), in germanium, silicon-germanium, and copper. This mission has been proposed recently as a medium class mission to the European Space Agency (ESA), as a response to the first Announcement of Opportunity of the Cosmic Vision 2015-2025 program. The GRI lens is designed to focus radiation from 250 keV up to 950 MeV (for the first diffraction order), aiming to address astrophysical topics such as the Type Ia supernovae explosion mechanism, the origin of the soft gamma ray background radiation, the physics of the disk and jets in black holes and neutrons stars, and particle acceleration in the strongest magnetic fields in the universe.

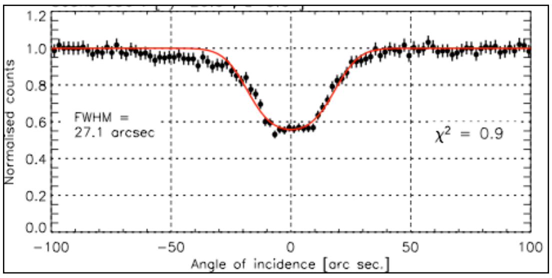
This experiment took place in the framework of two different R&D actions (one funded by CNES and the other by ESA), sharing the same objective of developing efficient diffracting materials for a Laue lens exploitable at nuclear line energies. Our aim is to characterize 2 types of samples: low mosaicity copper crystals grown at the Monochromator Group of ILL (Grenoble, France), and crystals made of a binary alloy of silicon-germanium with a gradient of concentration along the growth axis, coming from the Institute of Crystal Growth (IKZ, Berlin, Germany).

The first part of the experiment has been devoted to the study of various SiGe samples. These crystals are mainly composed of Si. The increase of Ge ratio along the growth axis ([111] in our case) induces a continuous deformation of the lattice spacing, resulting in a curvature of the (111) planes. SiGe gradient crystals are interesting for a Laue lens because they combine a high theoretical diffraction efficiency (up to

100%, disregarding the absorption through the sample) and a square shaped rocking curve, which is good for the focusing.

We measured 5 samples of SiGe having different values of mean gradient (the concentration gradient is not constant along the growth axis, inducing a change in the curvature of the planes) at 300 keV, 400 keV, 500 keV and even 700 keV. Thanks to this we have been able to investigate a large domain of the α parameter, which is defined by: $\alpha = \frac{\Lambda_L}{rW_{dyn}} \propto \frac{\Omega\,E^2}{t_0}$ (r being the radius of curvature of the planes, Λ_L the extinction length, W_{dyn} the Darwin width, Ω the FWHM of the rocking curve, t_0 the thickness, and E the energy diffracted). Results obtained with our best sample (SiGe 10.3) are shown in the left figure. The theoretical model used is $r^{\max} = \frac{I_{diffr}}{I_{trans}} = 1 - exp\left(-\frac{2\pi}{\alpha}\right)$[3].





Left*: Diffraction efficiency vs α for the SiGe10.3 sample at 400 keV, 495 keV and 700 keV.*

Above*: fit of a transmission rocking curve of a Cu (220) crystal (8.6 mm thick) measured at 489 keV.*

Two samples of SiGe crystals with a constant gradient of concentration have also been tested, the aim being to obtain a crystal with constant parameters over its cross section. These samples were less homogeneous than expected, but we are still in an experimental phase and these measurements have already been taken into account for the next iteration.

The second part of the experiment was devoted to copper crystals. The aim was to accurately characterize samples cut from a very low mosaicity ingot grown by the ILL Monochromator Group, which had been previuously characterized in their Hard X-Ray Diffractometer. Especially, we were interested in the accordance with the Darwin model (considering the dynamical theory of diffraction), and in the homogeneity of the samples.

We investigated 4 samples at 300 keV, 500 keV and 700 keV. Two of them were stepped in order to check our calculation of optimal thickness. Unfortunately the uniformity was not as good as expected, mainly due to the fact that the samples came from the neck of the ingot, which is a transition zone between the seed and the low mosaicity part. Despite this irregularity, the samples were in good accordance with the theory (right figure), which is very important for the Laue lens simulation, and their mosaicity ranged below 1 arcmin. The fit of the rocking curves with the Darwin model allowed us to extract the ‘length of crystallite’, which was ranging between 40 µm and 80 µm. These values give a diffraction efficiency close to the theoretical maximum, which is very satisfactory.

This experiment permitted the investigation of SiGe gradient crystals at the highest energy yet performed. The data obtained are helping us to revise the theory, and allow us to better define the suitable crystalline parameter for a Laue lens. Copper crystals are showing very good features, but more systematic measurements need to be performed, especially in the centre of the bulk. Iterations with crystal growth are in progress, and new measurements will have to be performed shortly.

References

[1] Barrière et al., *proc. SPIE* **6266**, pp.70-78, 2006
[2] Knödlseder et al., *proc SPIE* (2007), to be published
[3] Malgrange, Cryst. Res. Tech., **37** (2002), 7, 654-662