INFN Ferrara

LOGOS

(Laue Optics for Gamma-ray ObservationS)

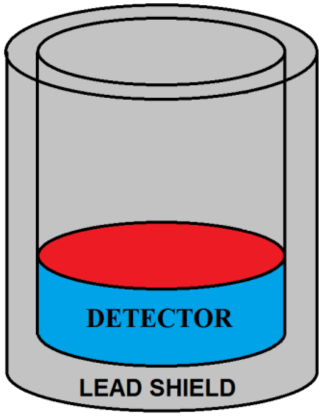
Andrea Mazzolari

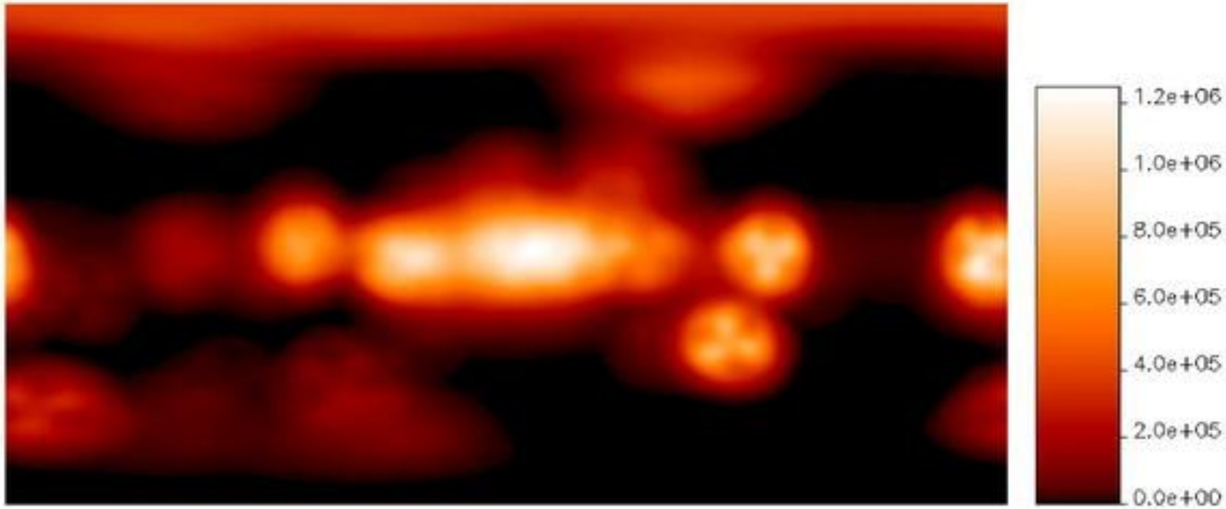
Capri, 08/10/2014

X-ray optics

Direct view instruments:

low resolution
low sensitivity
long exposition time
large weight

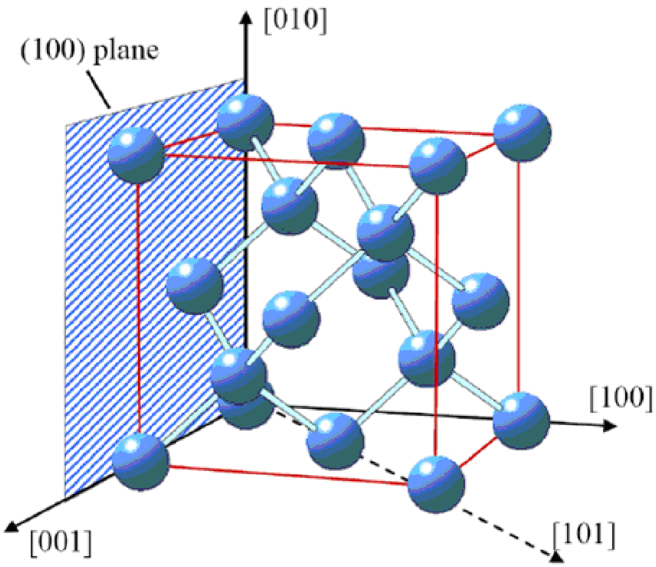


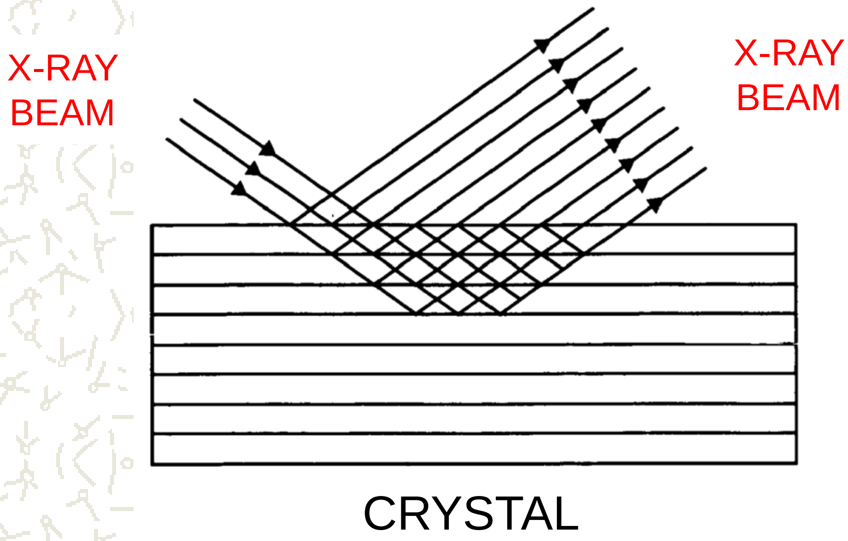


Picture of the galactic plane by INTEGRAL satellite during its first 10 months of activity.

Diffraction

Crystal: solid composed of atoms in a periodic structure at long range

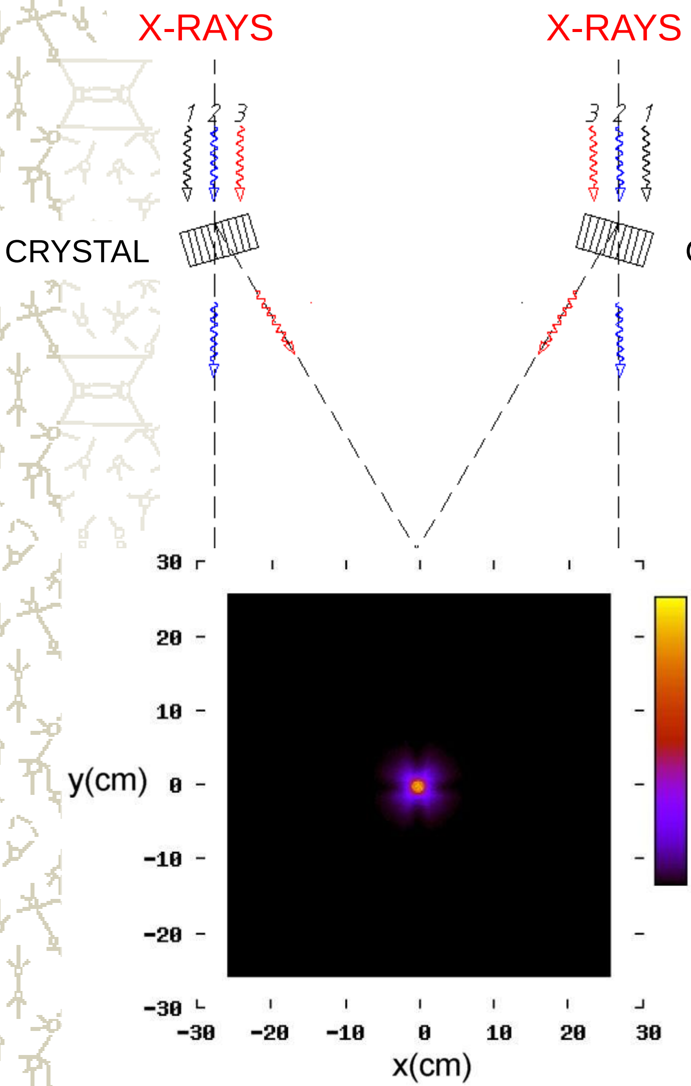




BRAGG DIFFRACTION

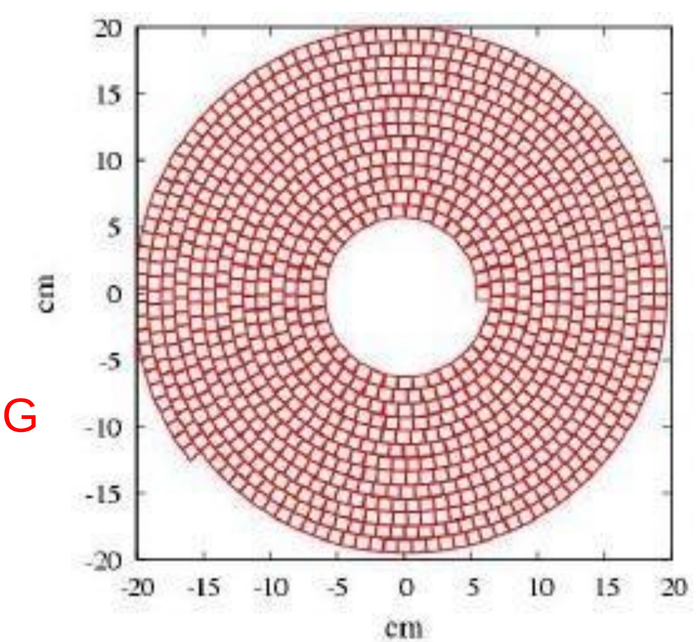
$$2d_{hkl}\sin\theta_B = n\lambda$$

X-Ray Lens

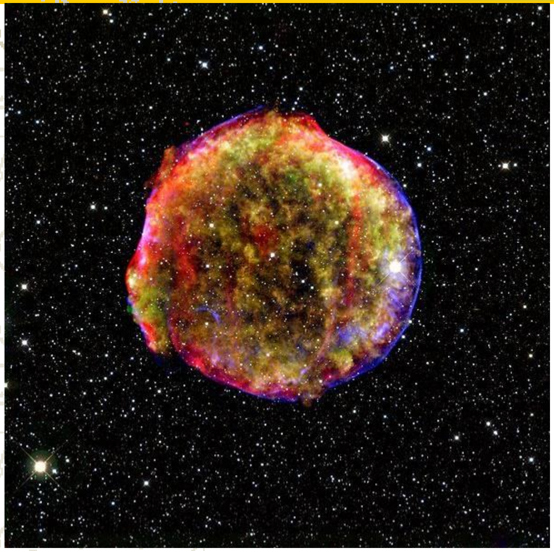


X-RAY FOCUSING

X-RAY LENS



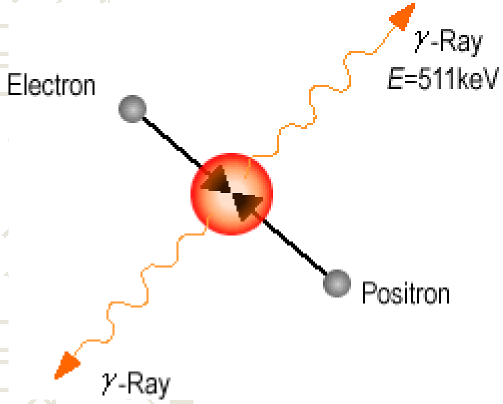
Astrophysical applications



Supenovae IA

Study of the 847 keV line emitted during the ^{56}Ni decay chain produced during explosion

Study of gamma and X-ray emission from compact objects



Positron-electon annihilation line at 511 keV

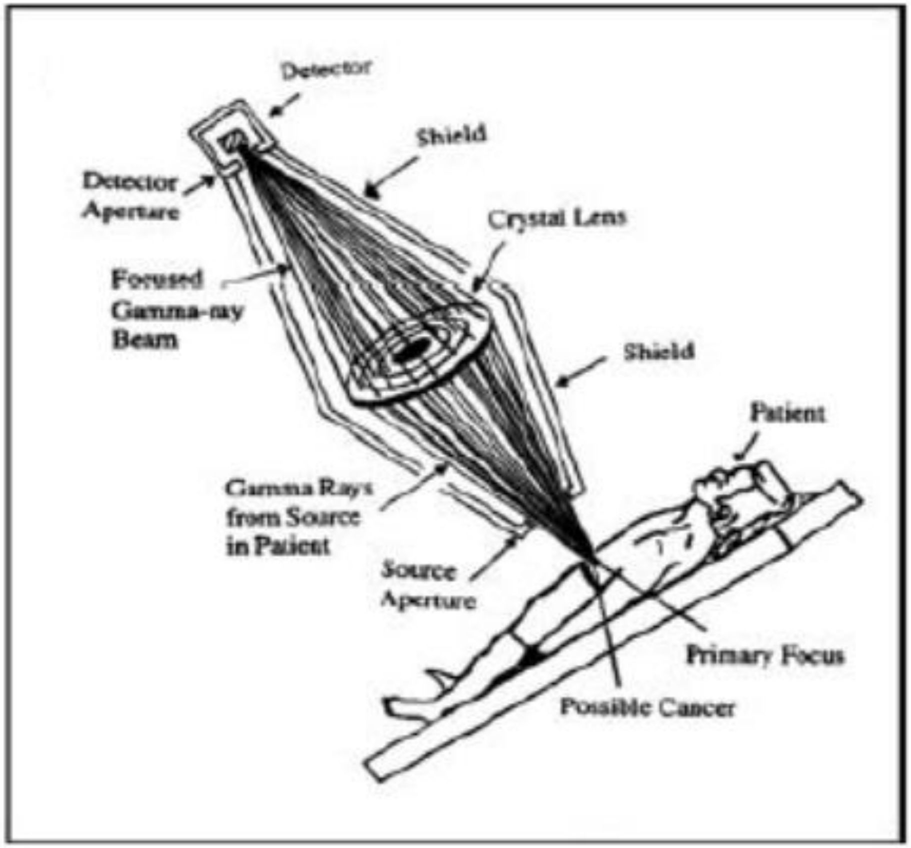
- ✓ Positron sources in the centre of galaxies
- ✓ Supernove type 1 A
- ✓ Distribution of antimatter
- ✓ Distribution of dark matter

Medical applications

Nuclear Medicine

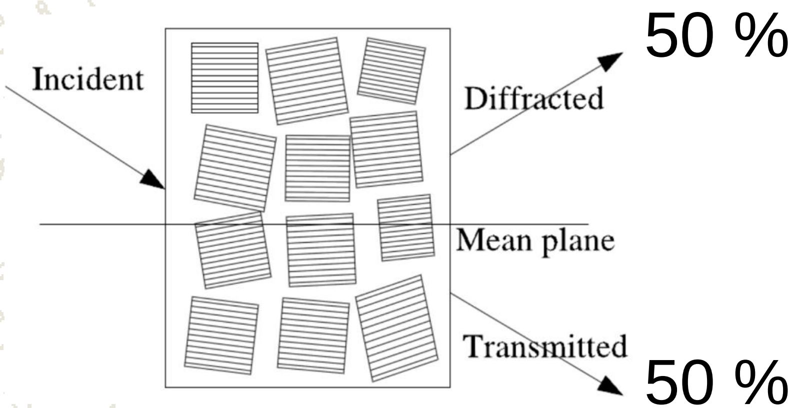
✓ Increase in the SPEC resolution and sensitivity

✓ Reduction of the dose of radioisotope to inject

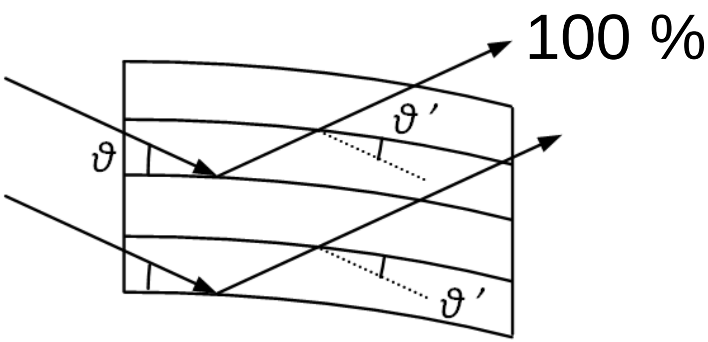


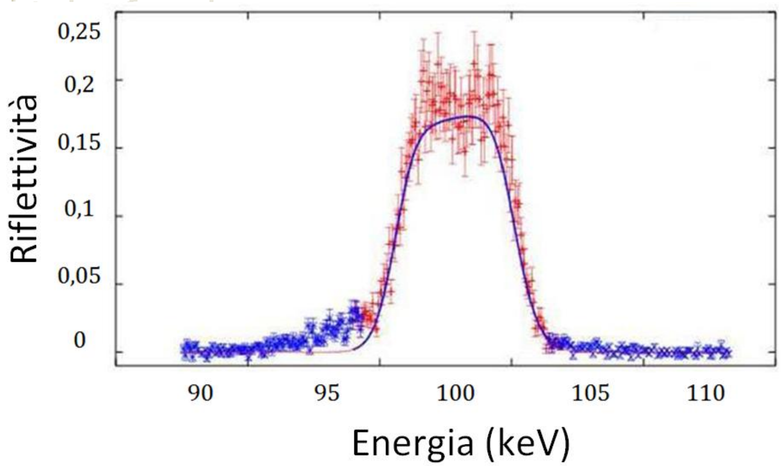
Mosaic or curved crystals

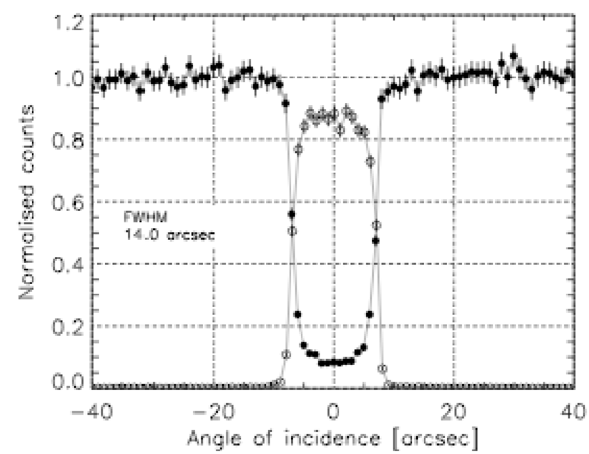
mosaic



curved

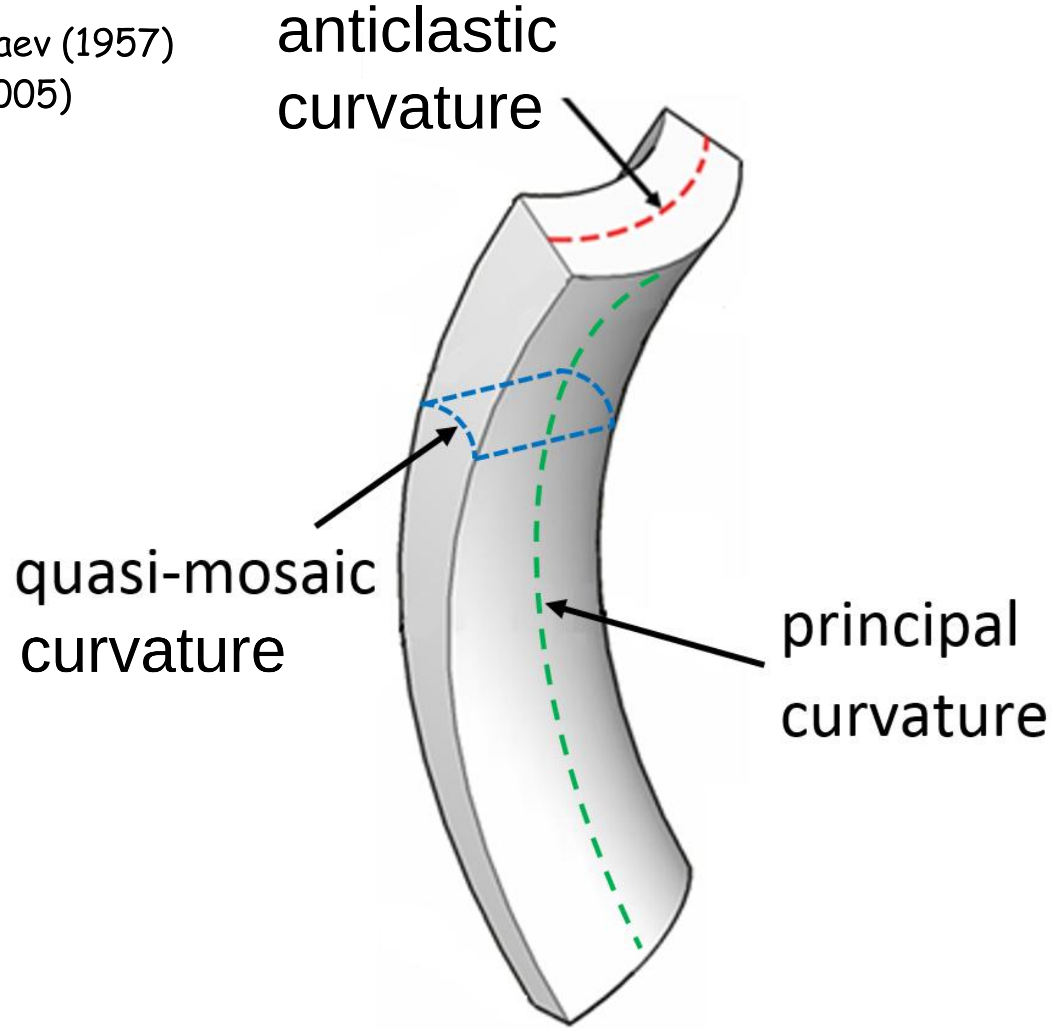




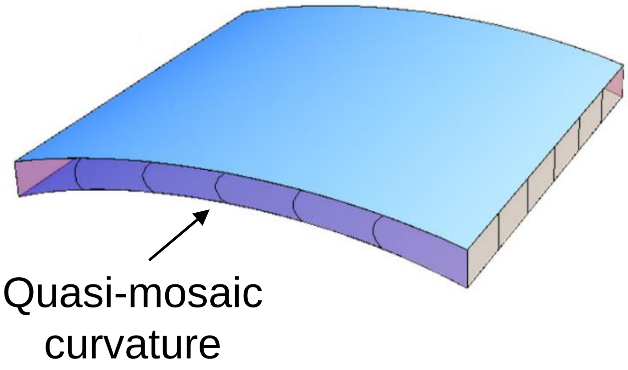


Quasi-mosaic crystals

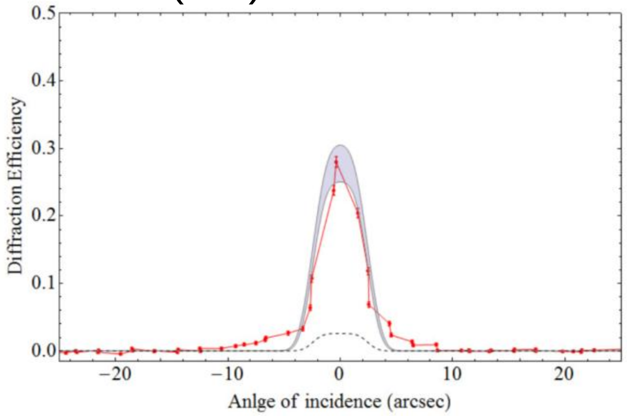
O.I.Sumbaev (1957)
Ivanov (2005)



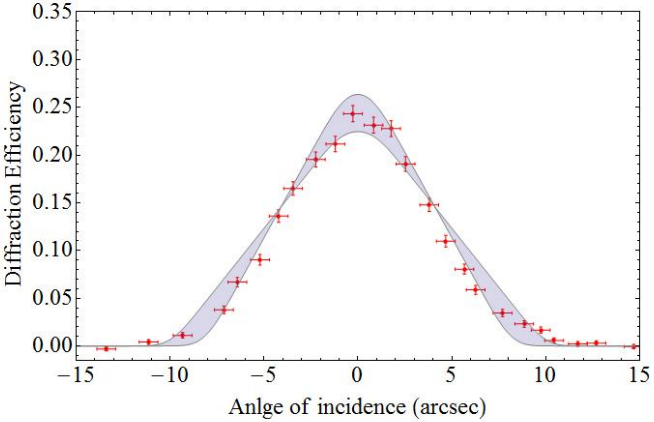
Quasi-mosaic curvature



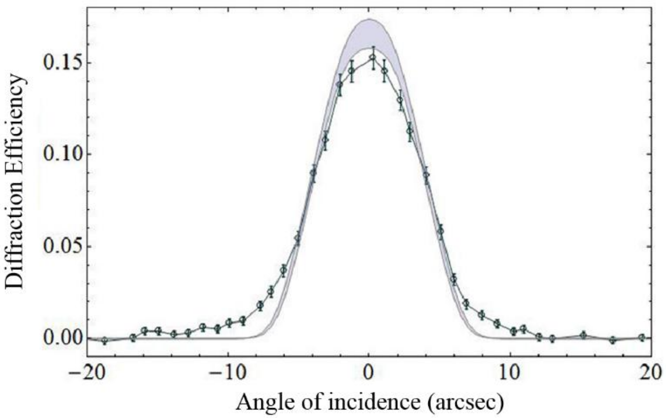
(111) diffraction



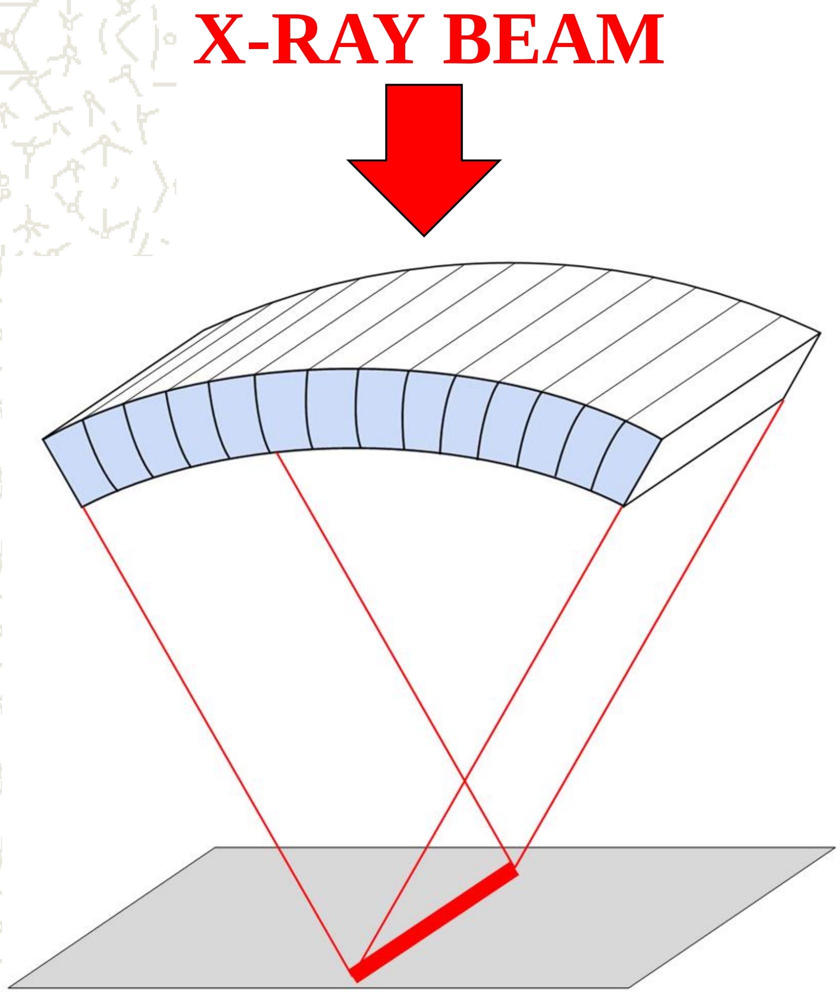
(422) diffraction

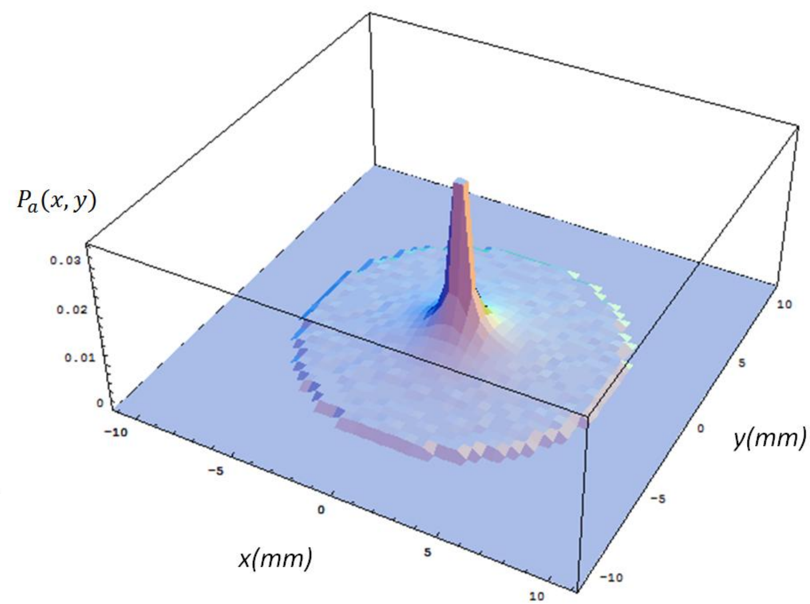


(311) diffraction



Focusing crystals

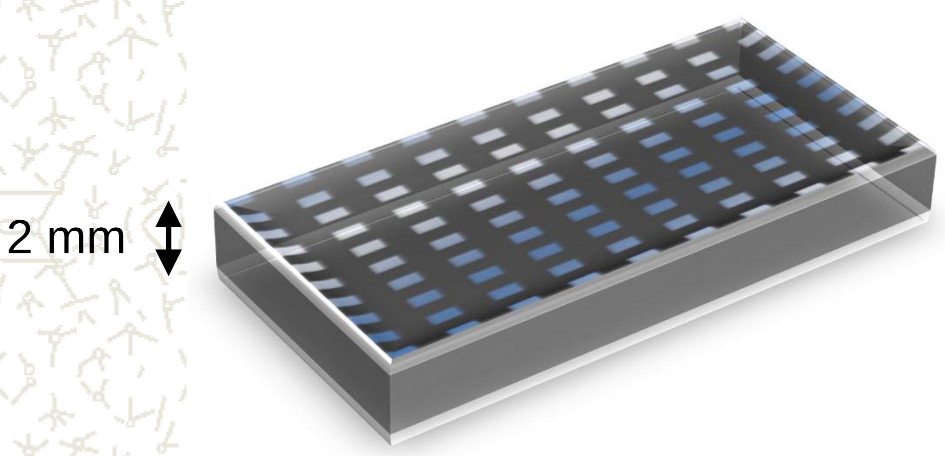




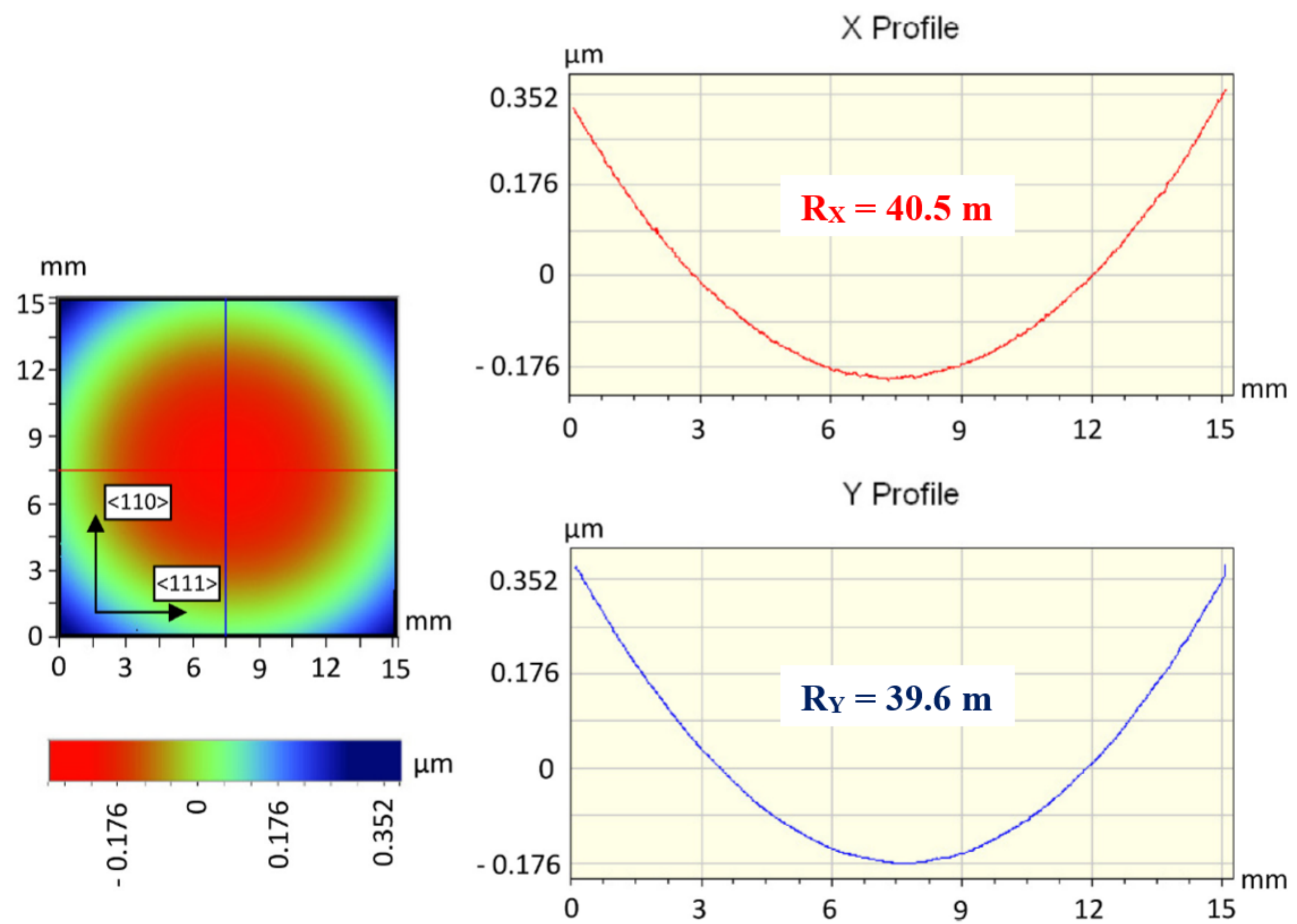
Crystals production - Grooving

MECHANICAL MANUFACTURING:

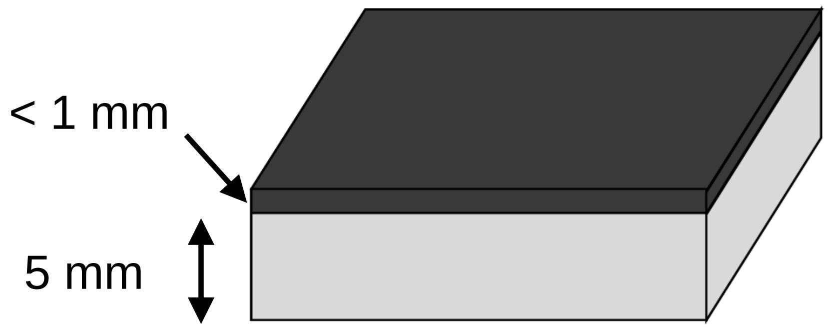
- **Machine : DISCO** **Automatic dicing saw** **DAD 3220**

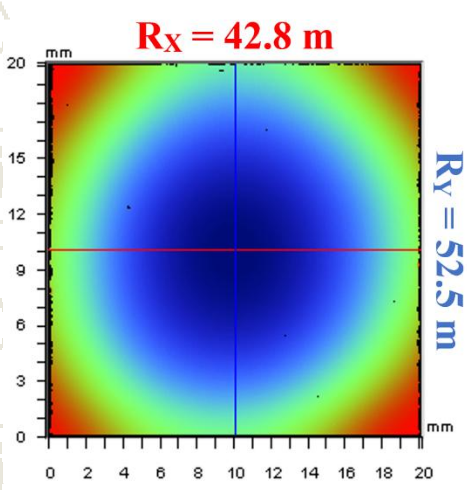


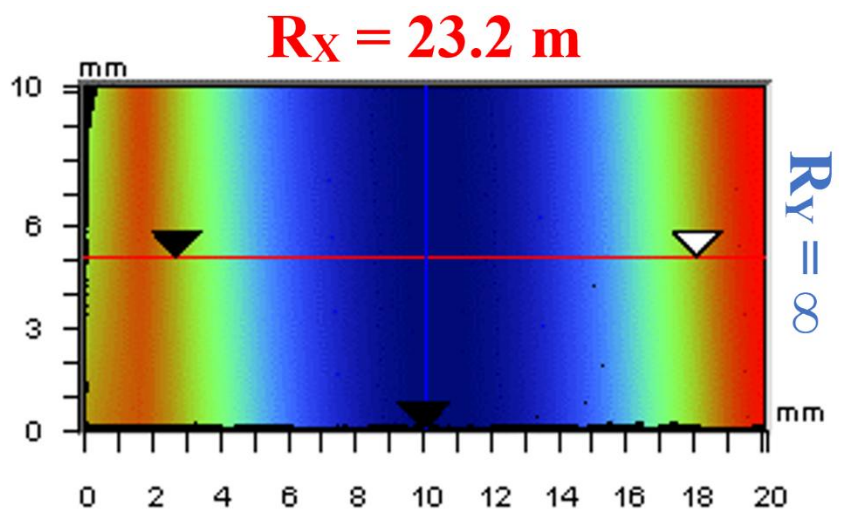
Crystals production - Grooving



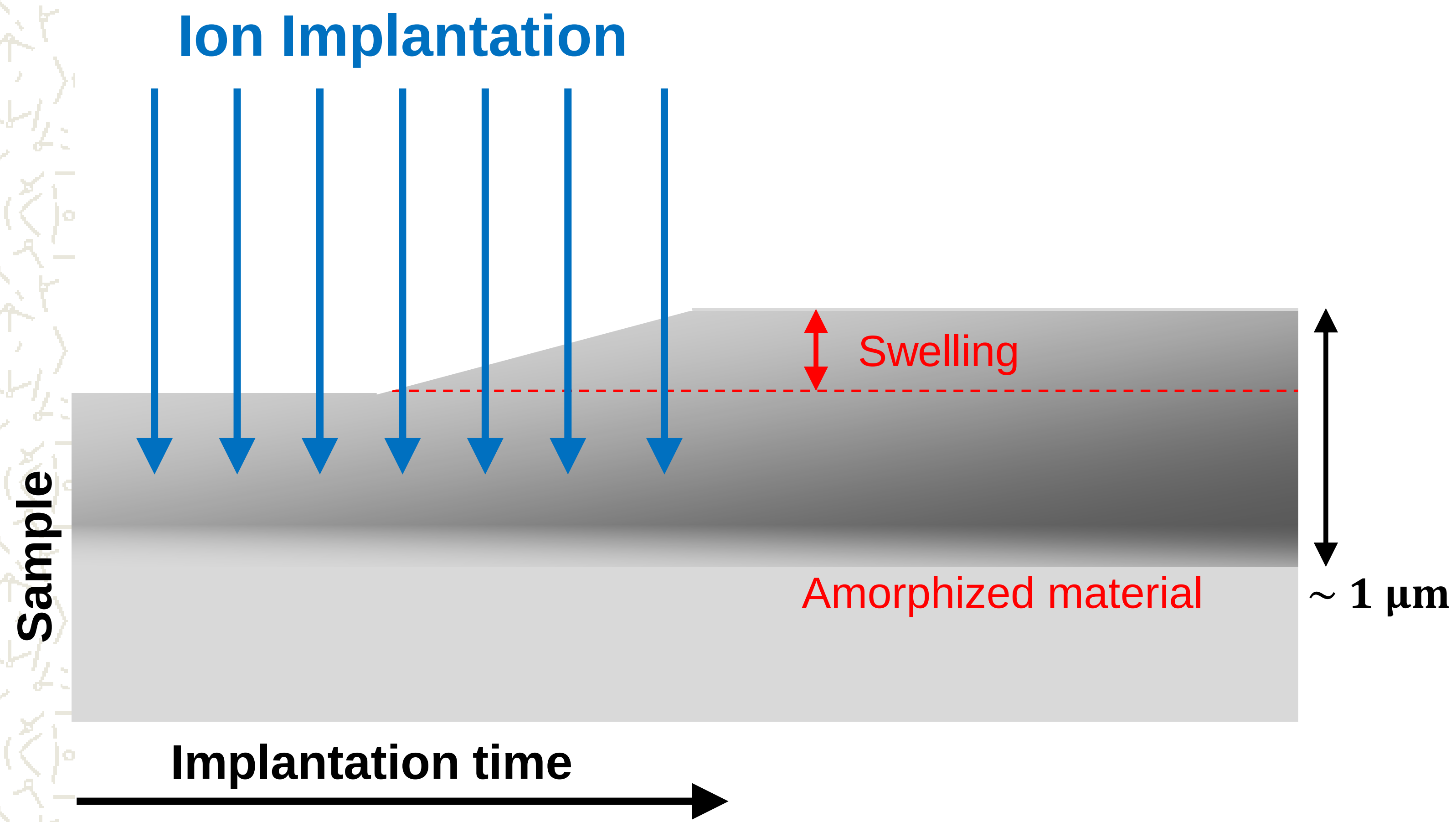
Crystals production – Carbon Fiber



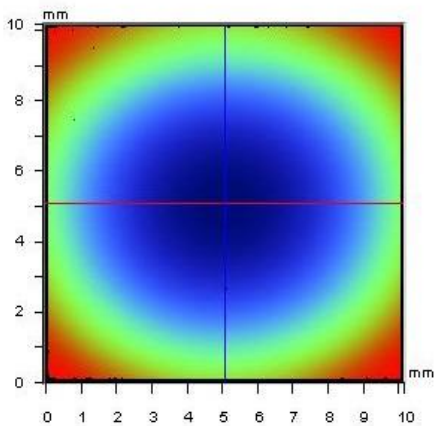




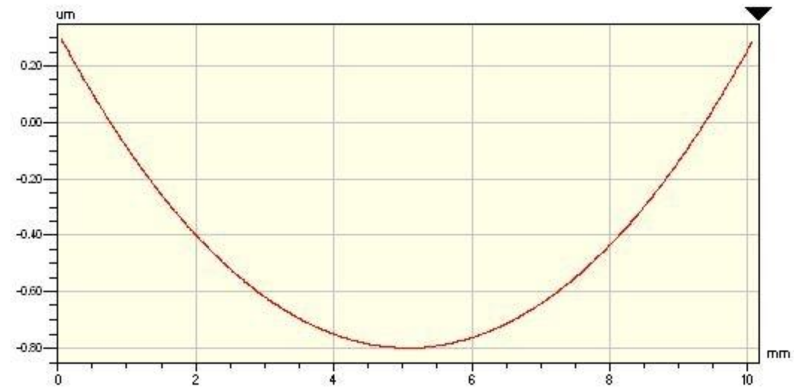
Crystals production – Ion Implantation



Crystals production – Ion Implantation



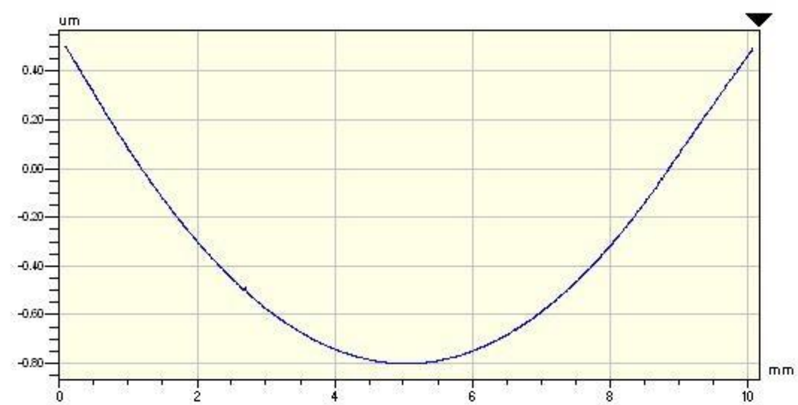
X Profile



Rq	0.32	um
Ra	0.28	um
Rt	1.09	um
Rp	0.29	um
Rv	-0.80	um

Angle	0.00	mrad
Curve	11.53	m
Terms	None	
Avg Ht	-0.44	um
Area	-4477.55	um2

Y Profile

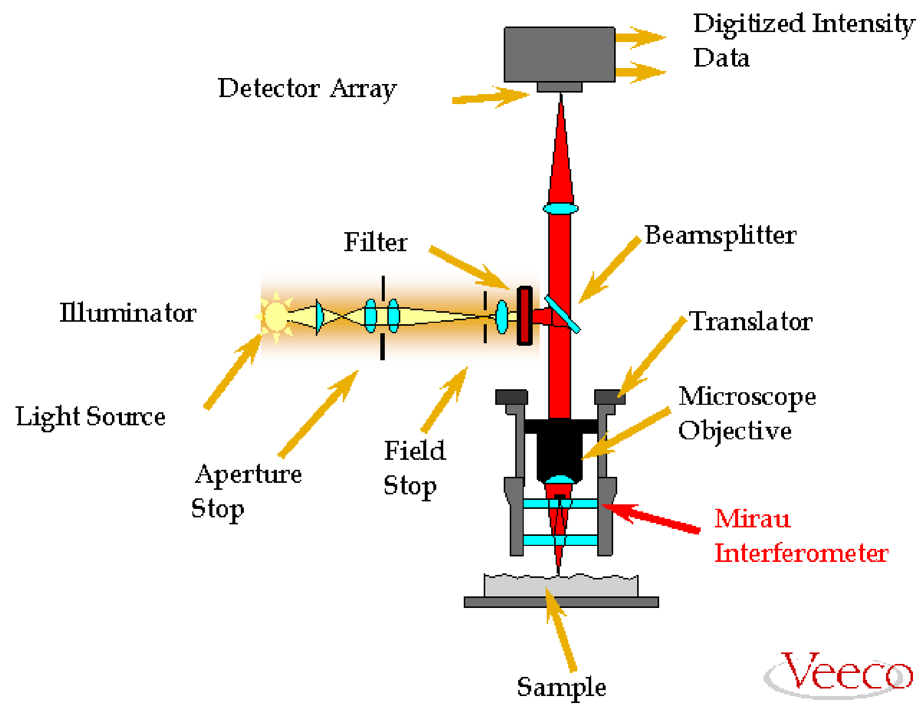


Rq	0.40	um
Ra	0.34	um
Rt	1.30	um
Rp	0.50	um
Rv	-0.80	um

Angle	0.00	mrad
Curve	9.35	m
Terms	None	
Avg Ht	-0.35	um
Area	-3533.93	um2

Sample thickness
0.2 mm

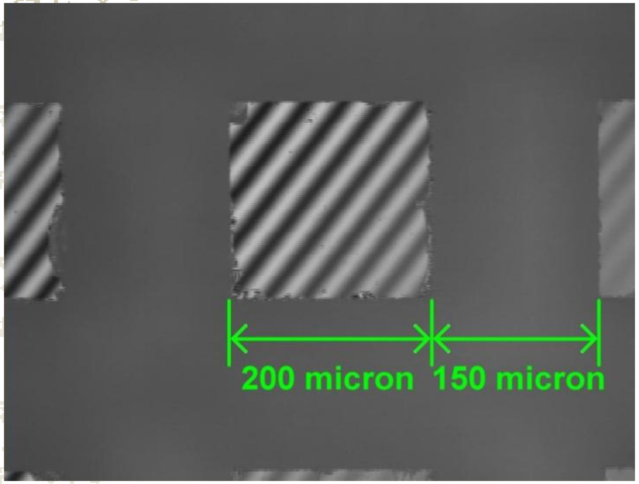
Interferometric profilometer

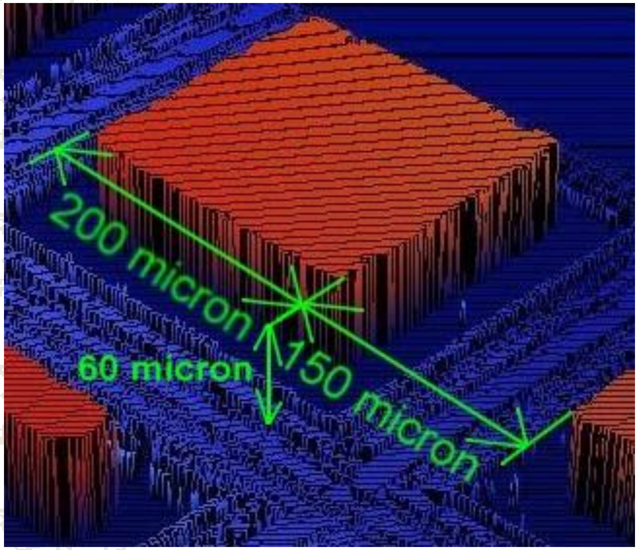


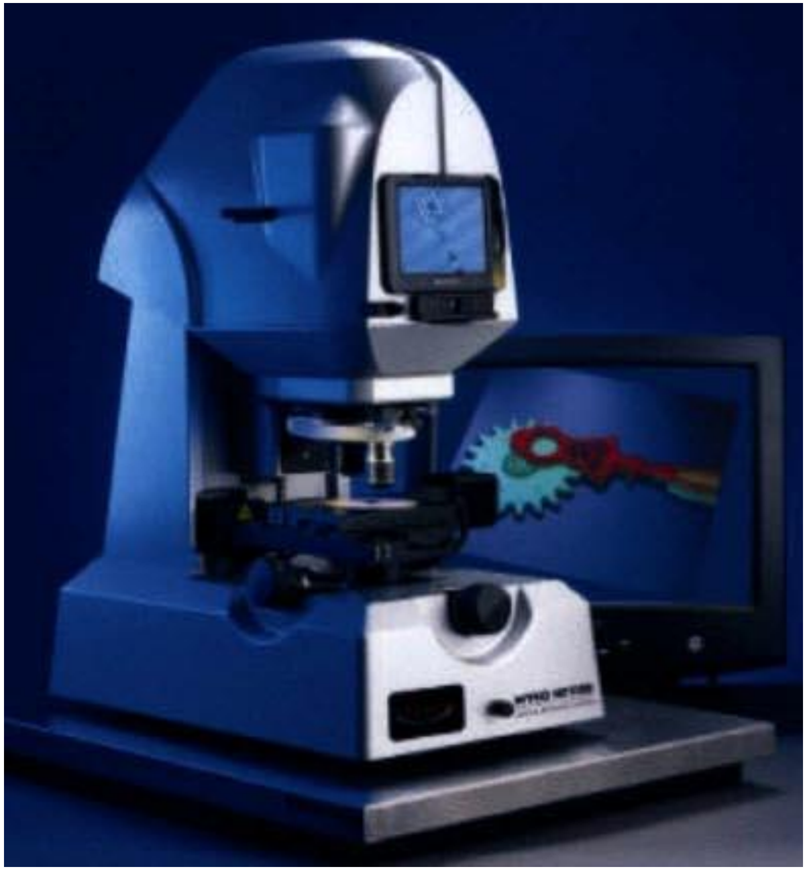
Vertical resolution 1 nm

Orizontal resolution 1 um

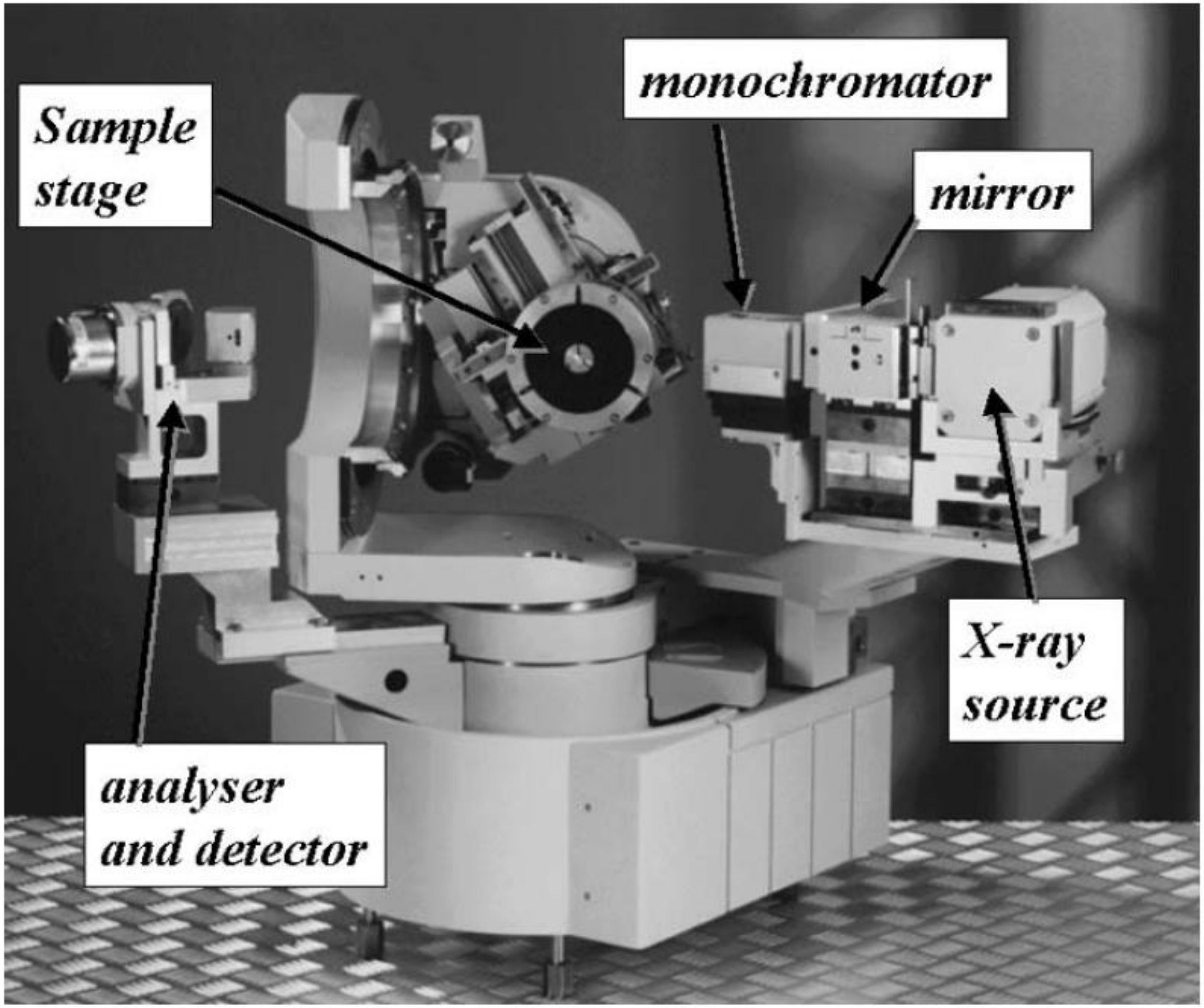
Interferometric profilometer



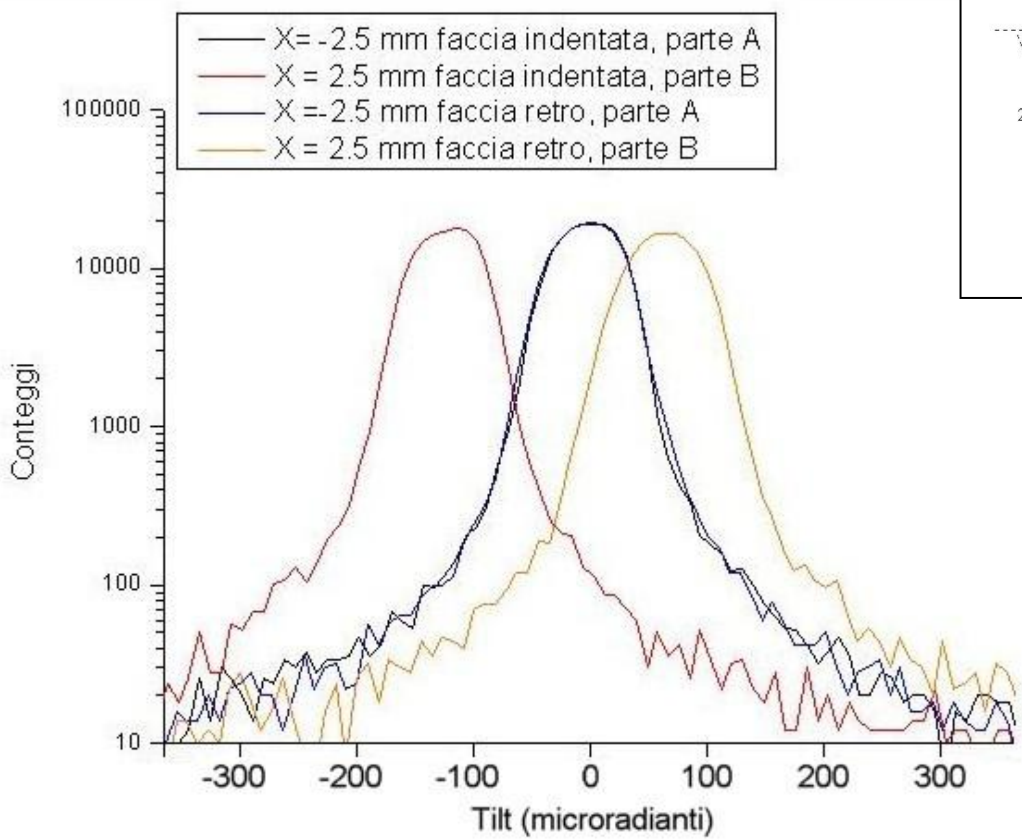


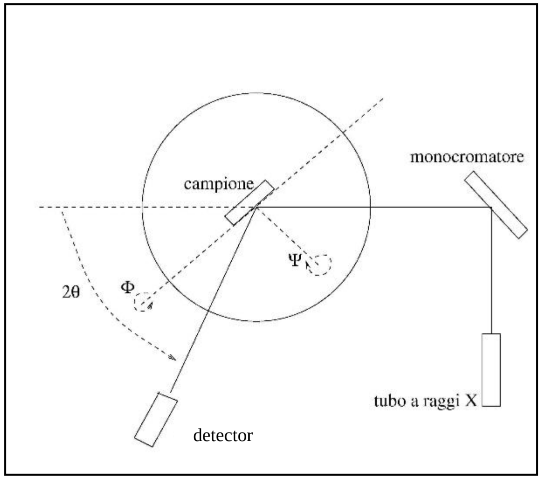


High resolution X-ray diffractometer



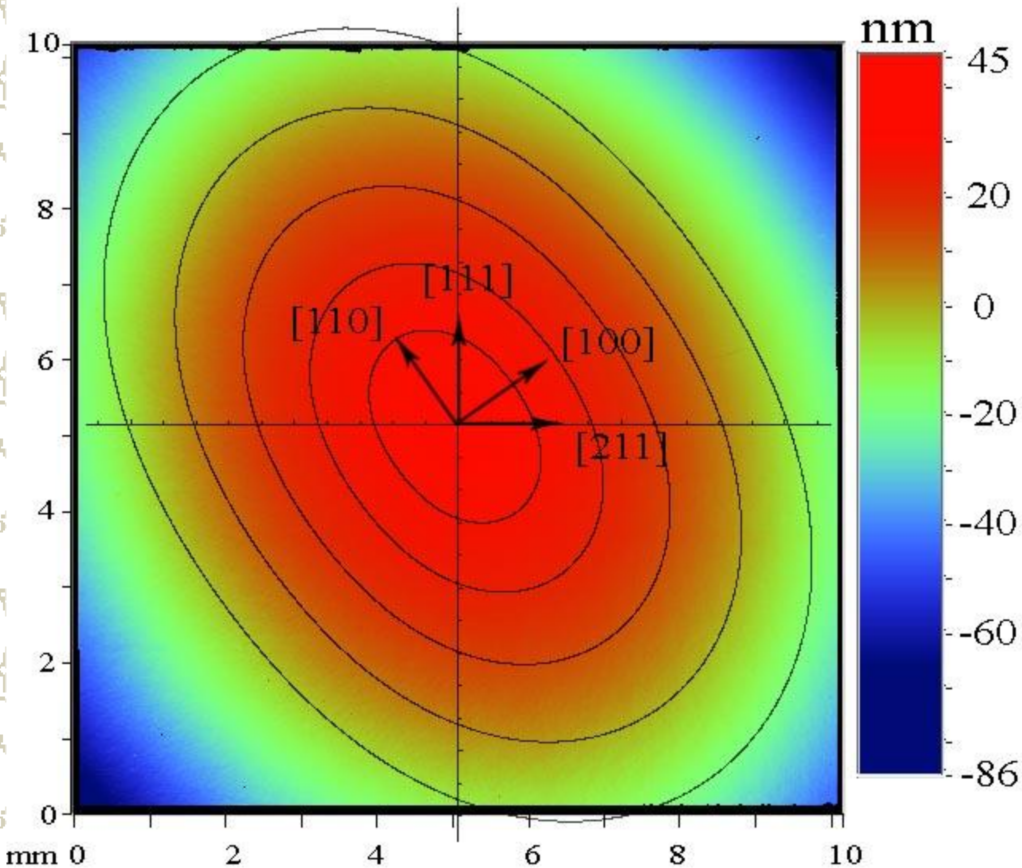
High resolution X-ray diffractometer

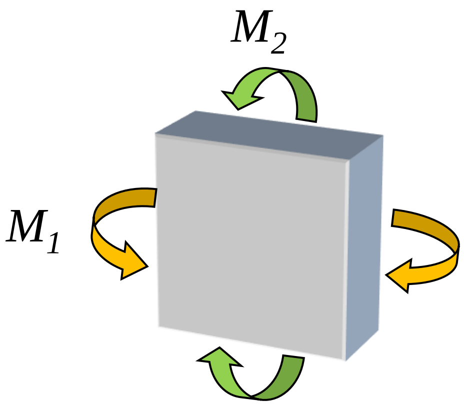




Modelization – Theory of Elasticity

Main surface (110)
Black curves: theoretical expectation
Colors: experimental measure





Along X direction

$$\frac{1}{R} \propto \frac{d^2w}{dx^2} = -\frac{M}{I}(S_{11} + S_{12})$$

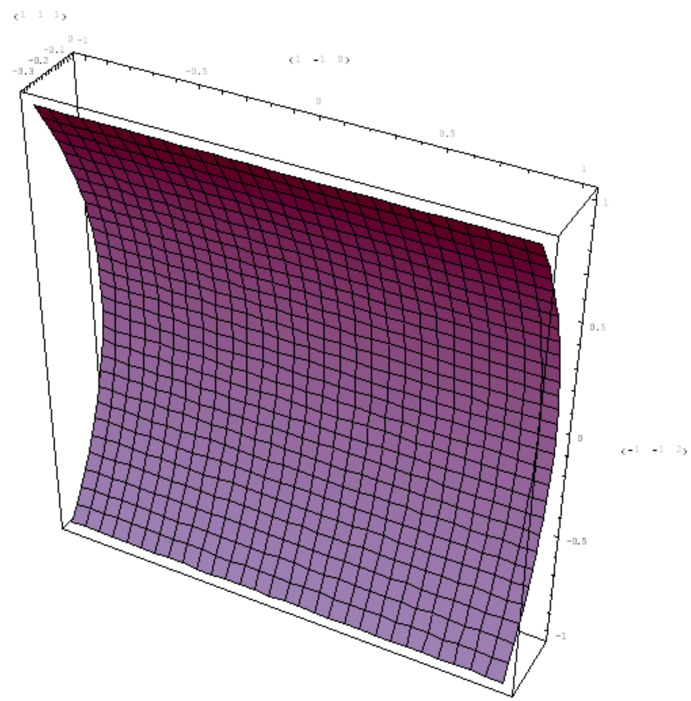
Along Y direction

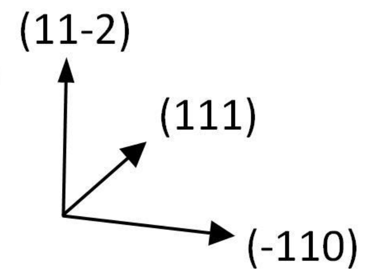
$$\frac{1}{R} \propto \frac{d^2w}{dy^2} = -\frac{M}{I}(S_{12} + S_{22})$$

Modelization – Theory of Elasticity

Quasi-mosaic effect

Curvature of internal (111) planes





$$\frac{R_s}{R_p} = \frac{S_{12} + S_{22}}{S_{41} + S_{42}} \cong 2{,}6$$

$$S\left[\begin{pmatrix}-1\\1\\0\end{pmatrix},\begin{pmatrix}1\\1\\1\end{pmatrix},\begin{pmatrix}1\\1\\-2\end{pmatrix}\right] = \begin{pmatrix} 0.00589997 & -0.000958611 & -0.00155153 & 0.00167703 & 0 & 0 \\ -0.000958611 & 0.00530705 & -0.000958611 & 0 & 0 & 0 \\ -0.00155153 & -0.000958611 & 0.00589997 & -0.00167703 & 0 & 0 \\ 0.00167703 & 0 & -0.00167703 & 0.0172747 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.014903 & 0.00335406 \\ 0 & 0 & 0 & 0 & 0.00335406 & 0.0172747 \end{pmatrix}$$

Modelization – Theory of Diffraction

Reflectivity

$$\eta = \frac{I_D}{I_0} = \left(1 - e^{-\frac{t\pi^2 d}{\Lambda^2 \alpha}}\right) e^{-\frac{\mu t}{cos\theta}}$$

Temperature

$$I = I_0 e^{-\frac{k_B T G^2}{M\omega^2}}$$

Intrisic width

$$LD(\theta) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(\theta-\theta_B)^2}{2\sigma^2}}$$

Mosaicization

$$MC(\theta) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(\theta-\theta_B)^2}{2\sigma^2}}$$

Variation of interplanar distance

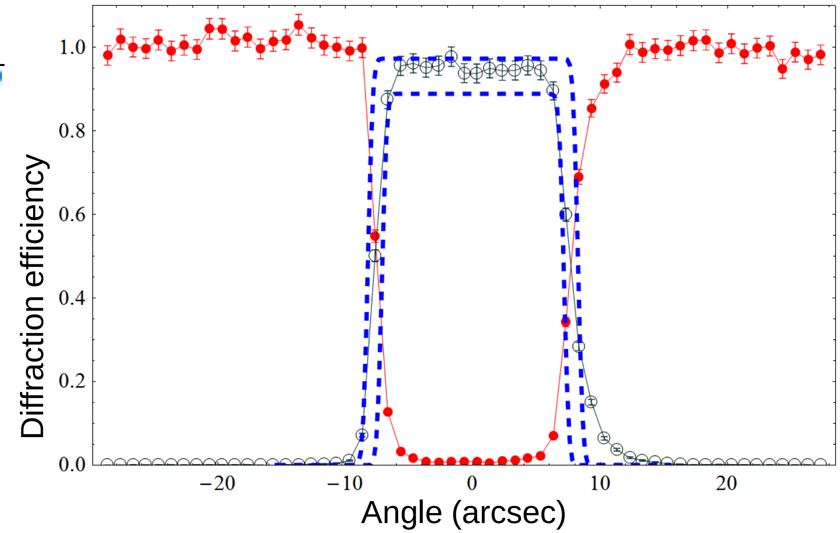
$$DP(\theta) = \begin{cases} \frac{1}{|\theta_+ - \theta_-|} & \theta_B + \frac{\Delta\theta}{2} \geq \theta \geq \theta_B - \frac{\Delta\theta}{2} \\ 0 & altrove \end{cases}$$

Beam chromaticity

$$CF(\theta) = \begin{cases} \frac{1}{\Delta\theta_{cr}}, & \theta_B + \frac{\Delta\theta_{cr}}{2} \geq \theta \geq \theta_B - \frac{\Delta\theta_{cr}}{2} \\ 0\ , & altrove \end{cases}$$

Beam divergence

$$DF(\theta) = \begin{cases} \frac{1}{\Delta\theta_{div}}, & \theta_B + \frac{\Delta\theta_{div}}{2} \geq \theta \geq \theta_B - \frac{\Delta\theta_{div}}{2} \\ 0\ , & altrove \end{cases}$$



Material	**Si**
Lateral dimensions (mm2)	25×25
Thickness (mm)	1
Grooves number	15×15
Grooves depth (mm)	0.5 ± 0.01
Grooves width (mm)	0.15
Distance between grooves (mm)	1
Surface curvature radius (m)	341 ± 25
FWHM experimental (arcsec)	15.4 ± 1.1
Diffraction efficiency (theoretical)	93.1 ± 4.2
Diffraction efficiency (experimental)	94.0 ± 3.0

Conclusion

Curved focusing crystals
produced by

- ☑ **Indentation**
- ☑ **Carbon Fiber Deposition**
- ☑ **Ion Implantation**

Hardware

- ☑ **Interferometer**
- ☑ **Dicing Machine**
- ☑ **Diffractometer**

Software modelization

- ☑ **Theory of Elasticity**
- ☑ **Theory of Diffraction**