# Small-Angle X-Ray Scattering and Diffraction Enhanced Imaging from Human Breast Tissues

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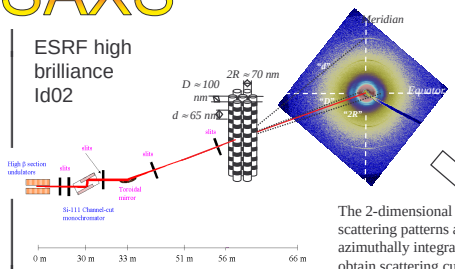
## SAXS

ESRF high brilliance Id02




Scattering vector

$$s = \frac{2\sin\theta}{\lambda} \qquad k = \frac{4\pi\sin\theta}{\lambda}$$

θ is the scattering angle and λ is the radiation wavelength

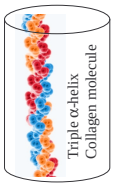
Distances in the real space can be calculated from the position of the peaks in units of scattering vector.

$$d = \frac{2\pi}{k} = \frac{1}{s}$$

The 2-dimensional scattering patterns are azimuthally integrated to obtain scattering curves.

Tissue samples are scanned through the beam in 1-0.25 mm steps along a rectangular grid, and the beam size is 0.2 mm.

A complete SAXS pattern is obtained from every point.




Collagen fibril

### D-spacing and malignicity

The *d*-spacing can be calculated from the peaks positions for every probe position in the sample.

These curves are gaussian approximations to the statistical distribution of the collagen period in few samples:

**A**: Carcinoma lobulare[1]

**C**: Carcinoma ductale[1]

**G**: Mastopathic tissue[2]

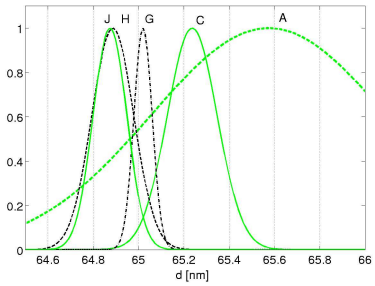
**H**: Fibroadenoma[2]

**J**: Carcinoma ductale (benign region)[1]

The comparison shows clearly that the *d* value is clearly bigger in the case of malignant tumours than the benign, or benign areas of malignant tumours [1].

[1] The carcinoma is a malignant tumot of the breast (green curves).

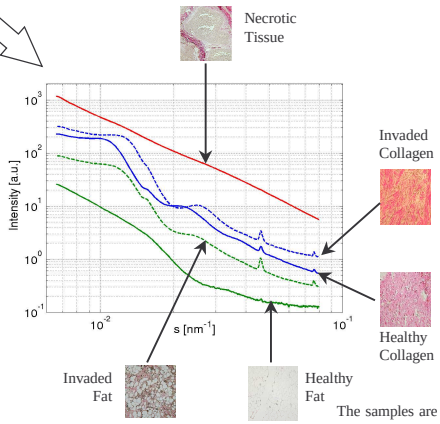
[2] Fibroadenoma and mastopathies are benign lesions of the breast (black curves).




### Tissue characterization

Every tissue present in the breast has his own characteristic scattering pattern. Adipose or fatty tissue shows a low intensity, featureless scattering curve. Scattering from collagen rich tissue shows typical diffraction peaks. The highest scattered intensity arises from necrotic tissue.

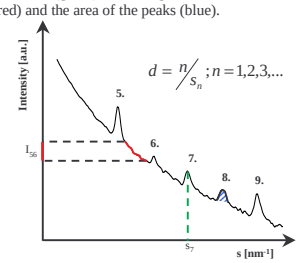
Particularly interesting is the increase of intensity of scattering in **cancer invaded** tissues, either fatty or collagen-rich.




### SAXS indicators

Many features of the scattering patterns can be used as indicators of the type of tissue and/or the degree of ordering of the collagen fibrils.

The position of the many orders of the collagen axial reflection (green), the background scattered intensity (red) and the area of the peaks (blue).

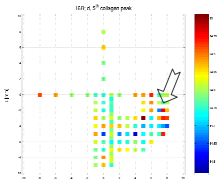



• The background intensity between the 5th and 6th collagen peaks ($I_{56}$) is an indicator of the type of tissue as well as its pathology.

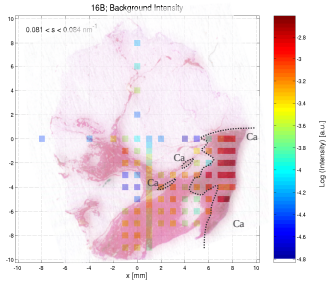
• The position of the collagen peaks ($s_n$) can be used as an indicator of the collagen degradation. Upon cancer invasion, the collagen *d*-period increases of 0.3 nm about.

### Mapping tissues with saxs

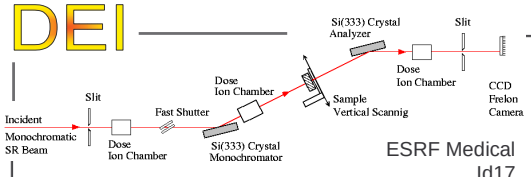
The samples are scanned through the beam. A complete SAXS patterns is acquired at every measurement point. Scattering curves are obtained, and some of the SAXS indicators are used to build maps. The correlation with the histology is very good. In the histology, the collagen stains dark red and fat, light pink. The areas containing cancer cells (Ca) are indicated with a broken line. Intensity code: blue/green-fat, red-collagen, dark red-invaded collagen.



Map of the *d*-spacing distribution. The collagen *d*-spacing is larger in the invaded zones (arrow).



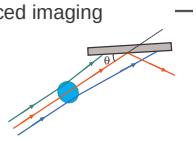

## DEI




ESRF Medical Id17

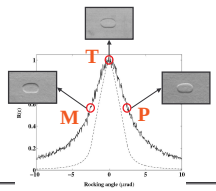
### Diffraction enhanced imaging

The analyzer crystal rejects all the radiation with an angle different than the crystal transmission window θ+Δθ (Δθ/θ ~ $10^{-4}$).



The three tuning positions of the analyzer crystal: ***T*** (top), ***M*** (minus) and ***P*** (plus).

Three images of an air bubble in formalin are shown. The images were taken with the analyzer crystal tuned at different positions. Note the contrast inversion at the upper and lower edges of the bubble from ***M*** and ***P*** images.




***Top***, or scattering free image. In contrast with ***Minus*** and ***Plus***, this image shows no edge contrast.

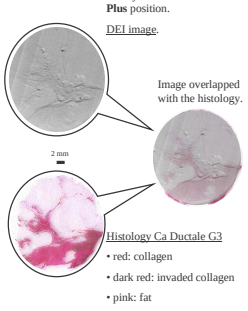
### DEI images compapared with histology

Scanning the samples through the fan beam, images are acqured line by line using a FReLoN (ESRF) camera.

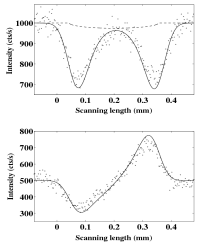
The same samples are used for the SAXS and for the DEI studies.

The samples are about 1 mm thick, and they are formalin fixed. After the imaging, thin histological slices of the samples are obtained.

The images are an integration of the whole thickness of the sample, and they correlate very well with the histology.




### DEI effect, nylon wire




Measurement (dots) and calculated curve (solid) of the intensity of a narrow x-ray beam from a conventional source through a nylon wire. The effect of absorption is given by the broken line [3]. ***Top*** (**T**) and ***Plus*** (**P**) positions of the analyzer are used [3].

$$n = 1 - \delta - i\beta$$

Thanks!

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[1] M. Fernández *et al*. (2002) *Phys. Med. Biol.* **47**, 577-592.
[2] D. Chapman, W. Thomlinson *et al*. (1997) *Phys. Med. Biol.* **42**, 2015.
[3] Keyriläinen *et al*. (2002) *Nuc. Instrum. Meth. Phys. Res. A* **488**, 419-427.