Phase Contrast sensitive Imaging

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Statement of Problem

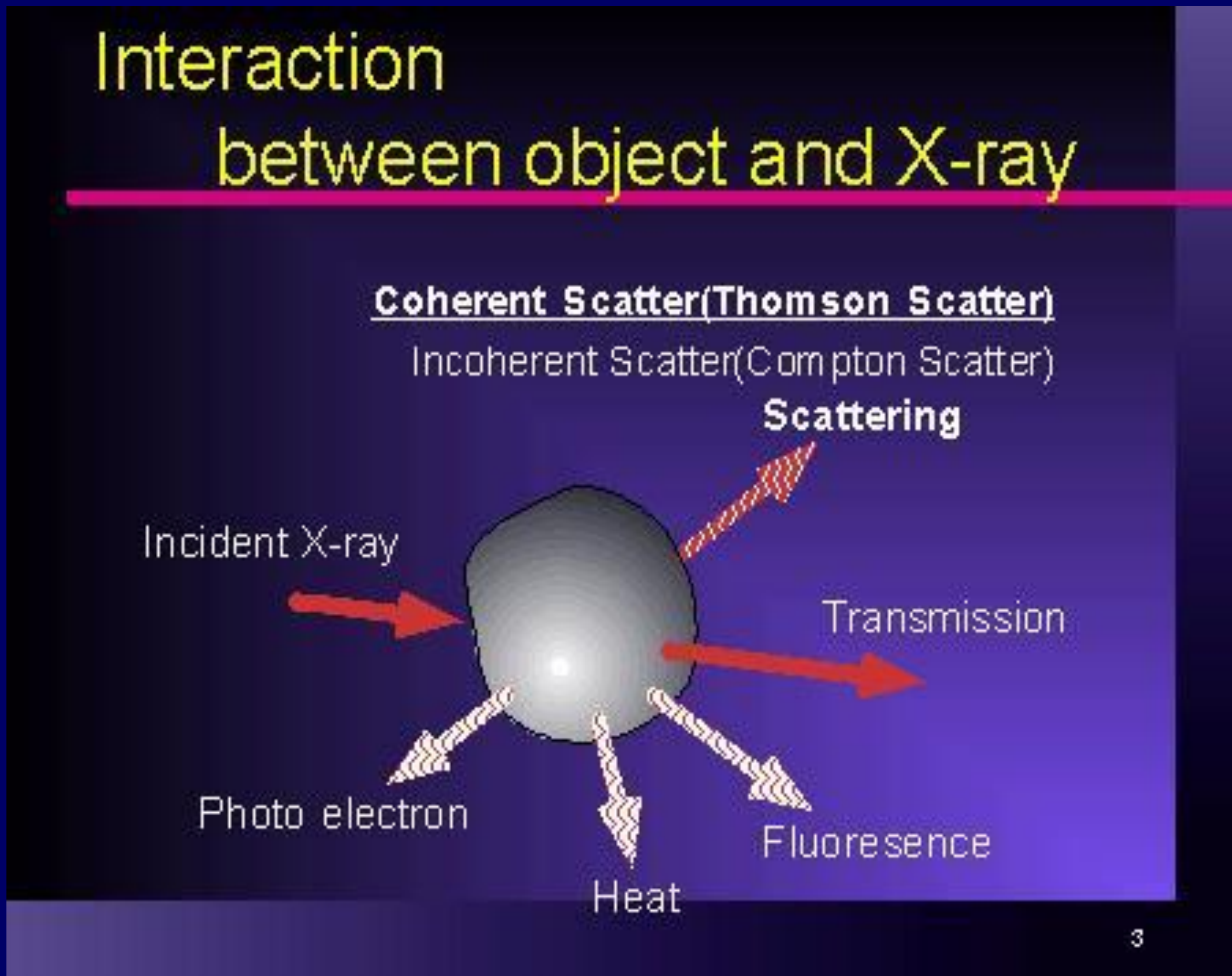
Deficiencies of the Current Imaging Techniques

- Poor contrast between healthy and diseased soft tissues (eg; Breast tissues)
- Presence of scatter, which further degrades the contrast
- Low Specificity in Mammography (50%)
- No molecular and cellular changes is possible in early stages
- Only Bulk changes are visible
- Types of materials consisted in a specific tissue are not accessible

What is the SOLUTION?

- Refractive/*interference effects is about 1000 times larger than* absorption

- If interference-related effects of scattering is properly exploited, much more intense information is obtained


Interaction
between object and X-ray
Coherent Scatter(Thomson Scatter)
Incoherent Scatter(Compton Scatter)
Scattering
Incident X-ray
Transmission
Photo electron
Heat
Fluoresence
3

Conventional Imaging

- Conventional x-ray images show differences in x-ray absorption among various tissue.
- These images provide excellent visualization of tissues with significantly different absorption characteristics resulting from differences in physical density and atomic number.
- When these differences are slight, eg Mammography, conventional x-ray imaging methods are limited.

PHASE-CONTRAST X-RAY IMAGING

- In addition to absorption differences, x-rays also experience phase shifts during transmission.
- At x-ray energies in mammography, the phase shifts may exceed the absorption differential by as much as 1000 times.
- Hence, it is possible to observe phase contrast in the image when absorption contrast is undetectable.

PHASE-CONTRAST X-RAY IMAGING

Three Basic principals detect phase differences:

1- x-ray interferometry: recording the interference between the scattered wave and transmitted wave.

2- Diffraction-enhanced imaging

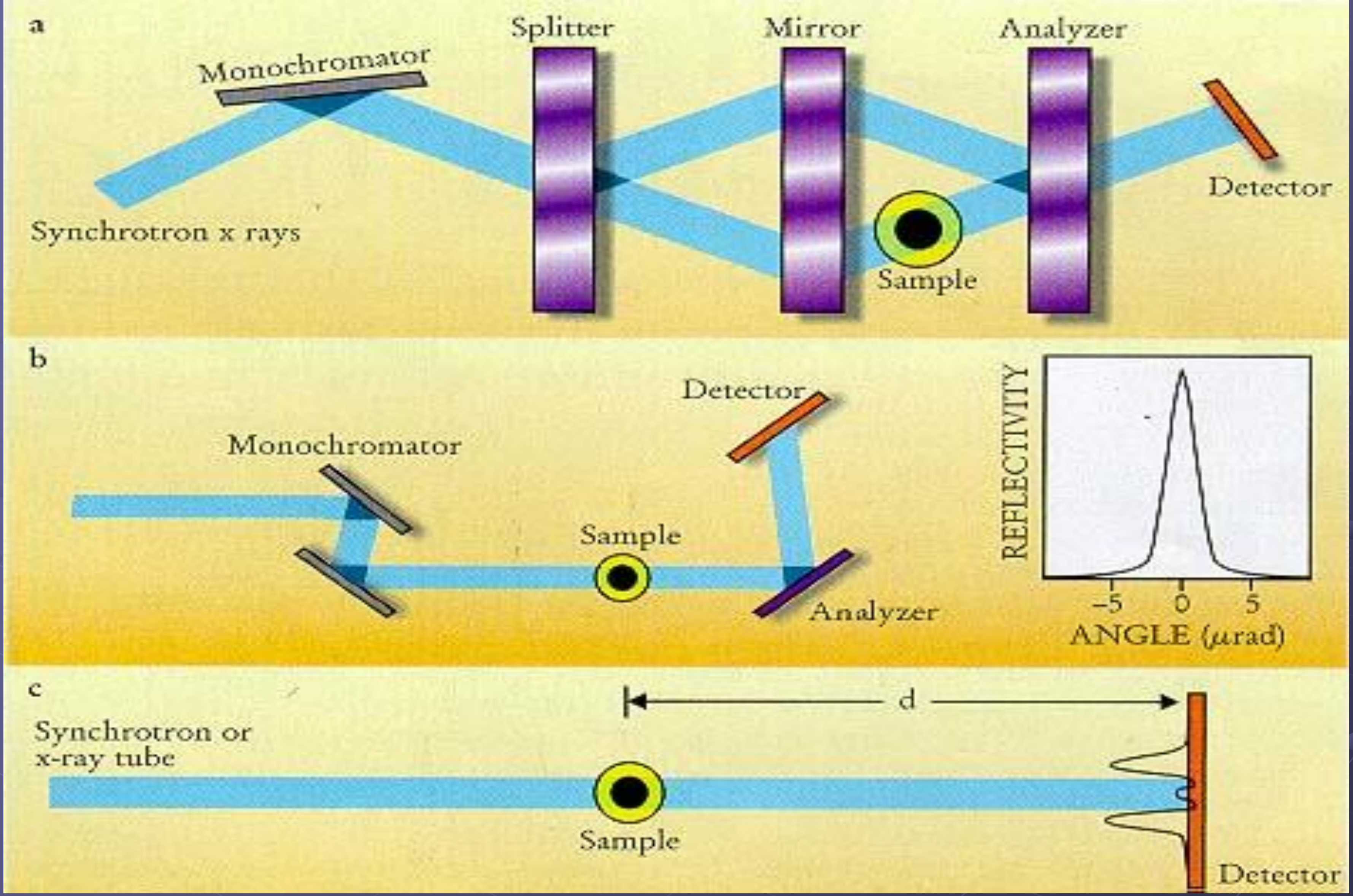
3- Measuring selectively the changes in propagation direction

4- Constructive interference between coherent scatters from atoms, molecules of the a material

For most phase-contrast x-ray imaging, a spatially coherent source of x rays is required.

1) Synchrotron radiation sources.

2) Small x-ray tubes with a microfocal x-ray source



a- Interferometer

b) *diffraction-enhanced*

c) Propagation Imaging

Interferometry

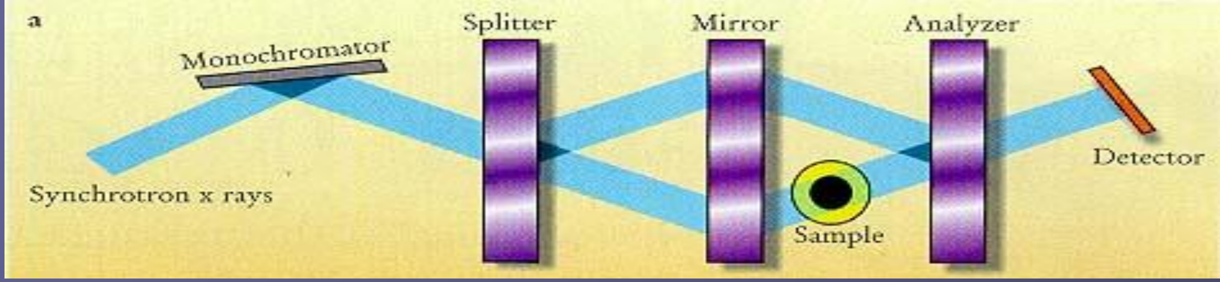
- Direct access to the phase change, introduced by an object is possible with a crystal X-ray interferometer

- It needs parallel and Monochromatic radiation

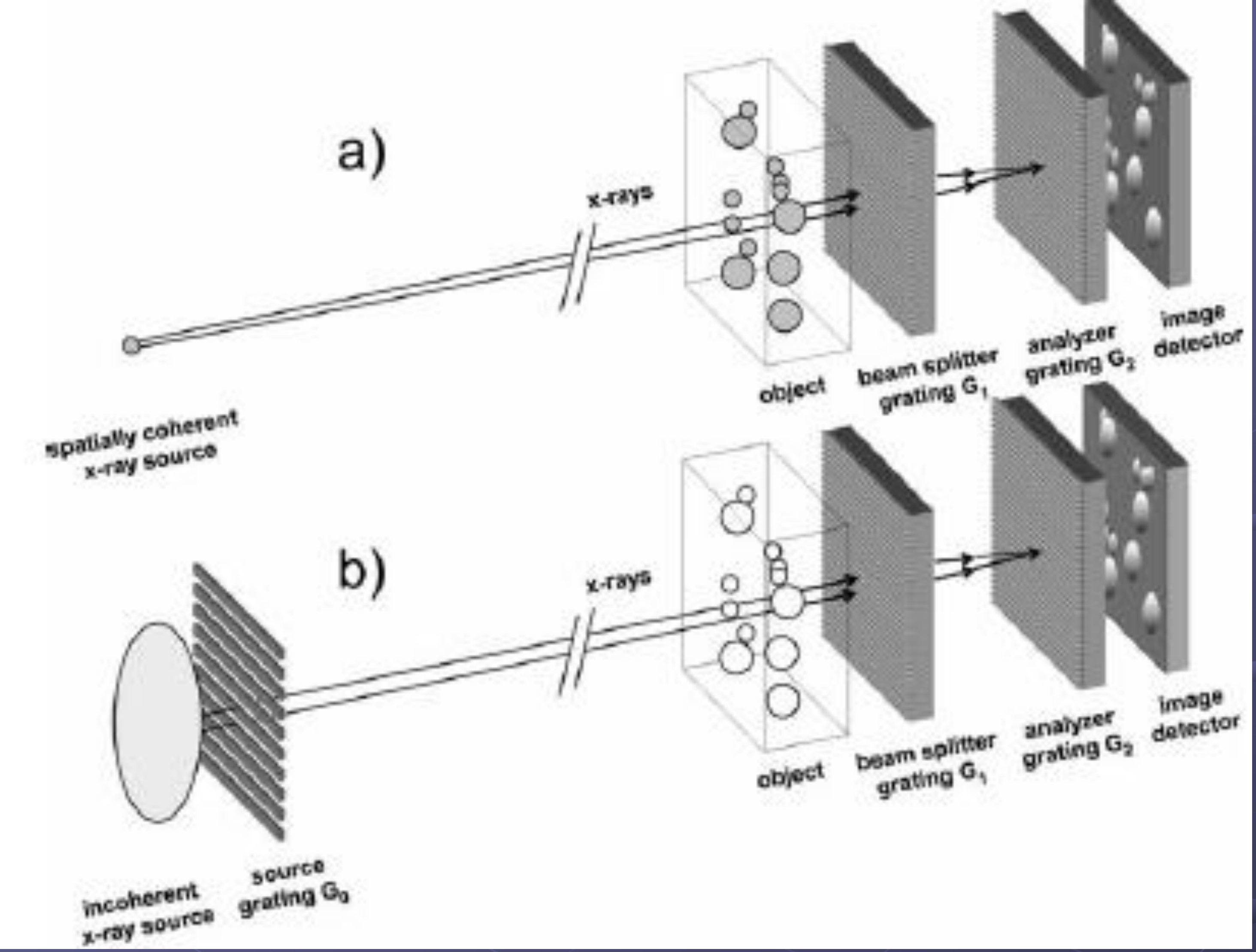
- It is the most sensitive method for detecting the minute differences in refractive index in soft tissue, corresponding to density variations on the order of 10^{-3} g cm^{-3}.

- the phase shift, can be assumed to be proportional to the specific gravity (density).

Interferometry



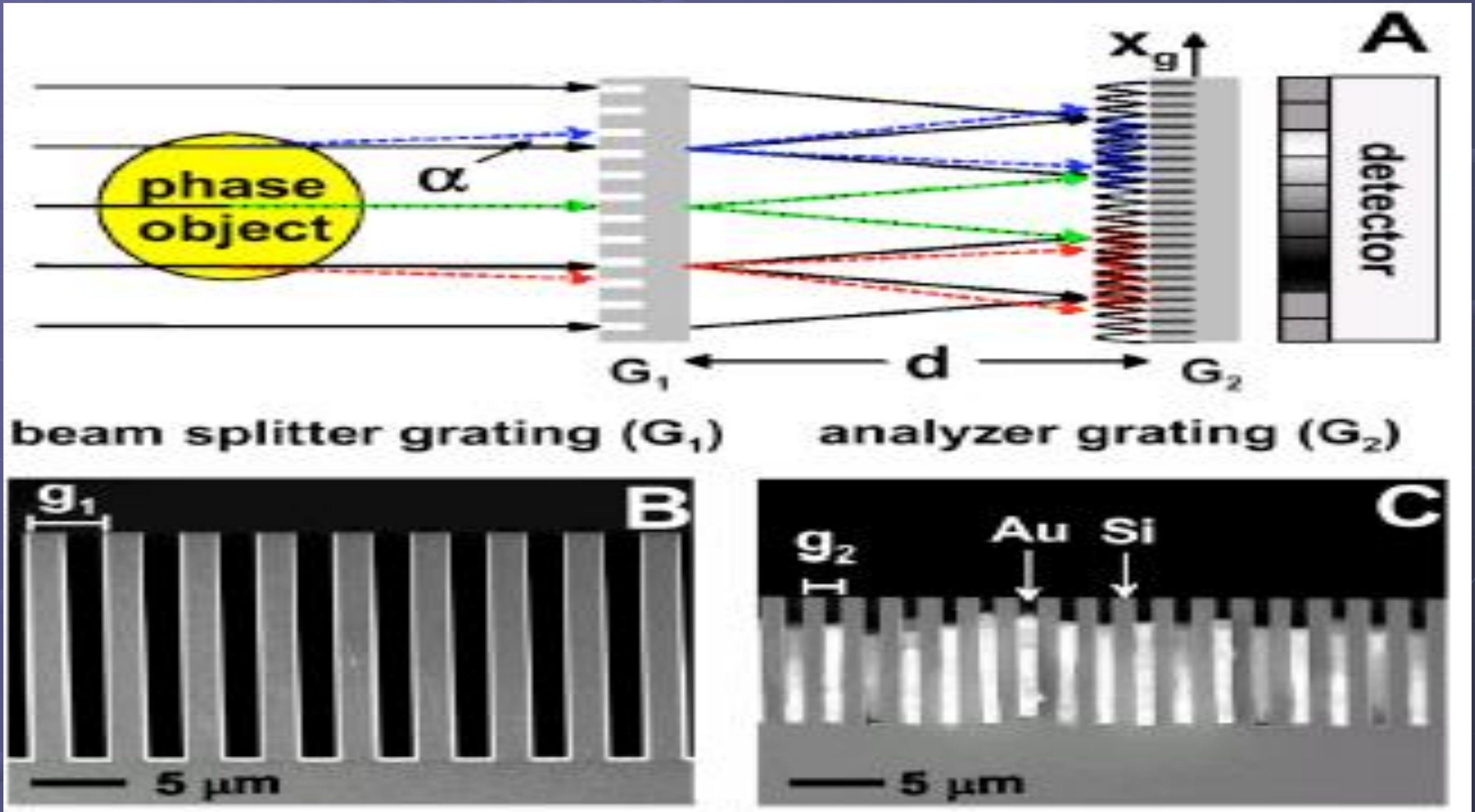
- Three matching perfect crystals function as an x-ray interferometer.
- The first crystal splits the incident x-ray beam
- The middle crystal acts as a mirror, sending the beams back toward each other.
- The beams meet at the third analyzer crystal, which recombines them.
- A sample (placed between the mirror and analyzer) will introduce phase shifts in the beam and distort its wavefront.
- Consequently, the recombined beams will generate interference fringes at an x-ray detector.



Grating inter-ferometer (differential phase images)

Two gratings G1 and G2 between object and detector act as an array of collimating slits that allow a transmission depending on the angle of incidence. Thus, any local phase gradients in the object cause a local change in intensity recorded on the detector.

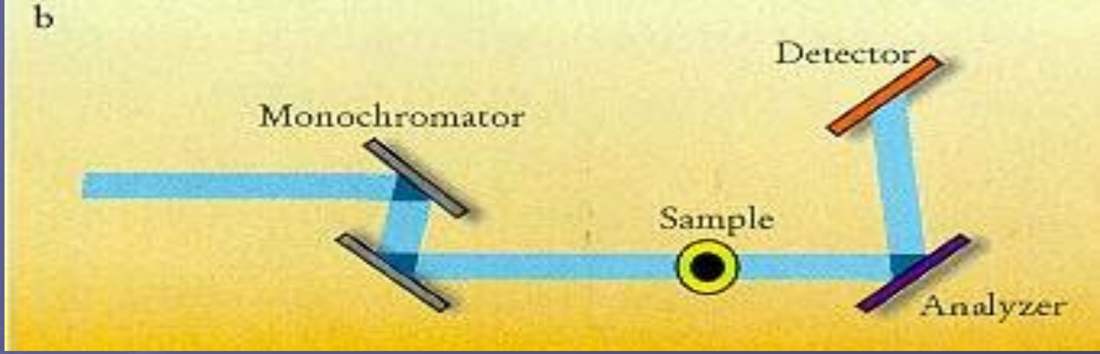
Medical X-ray Phase Contrast Imaging at New Laboratory X-ray Sources.



Diffraction-enhanced imaging (DEI):

- If interference pattern is not observable, high-resolution angular registration of the radiation is transmitted through an object with the aid of an additional crystal analyzer.
- Synchrotron parallel radiation that emerges from a monochromator is essential.
- Refractive and diffractive properties of the object are examined.

(DEI):



- As the x rays traverse a sample, they can be absorbed, scattered coherently or incoherently, or refracted through very small angles (microradians) due to the tiny variations in the refractive index.
- X rays emerging from the sample will satisfy the conditions for Bragg diffraction only for a very narrow window of incident angles.
- The analyzer will filter out any x rays that are scattered or refracted by more than a few microrad.
- Refracted x rays within the window will be reflected depends on the incident angle (rocking curve).
- The resulting image at the x-ray detector will resemble a standard x-ray radiograph but with enhanced contrast due to the scatter rejection.

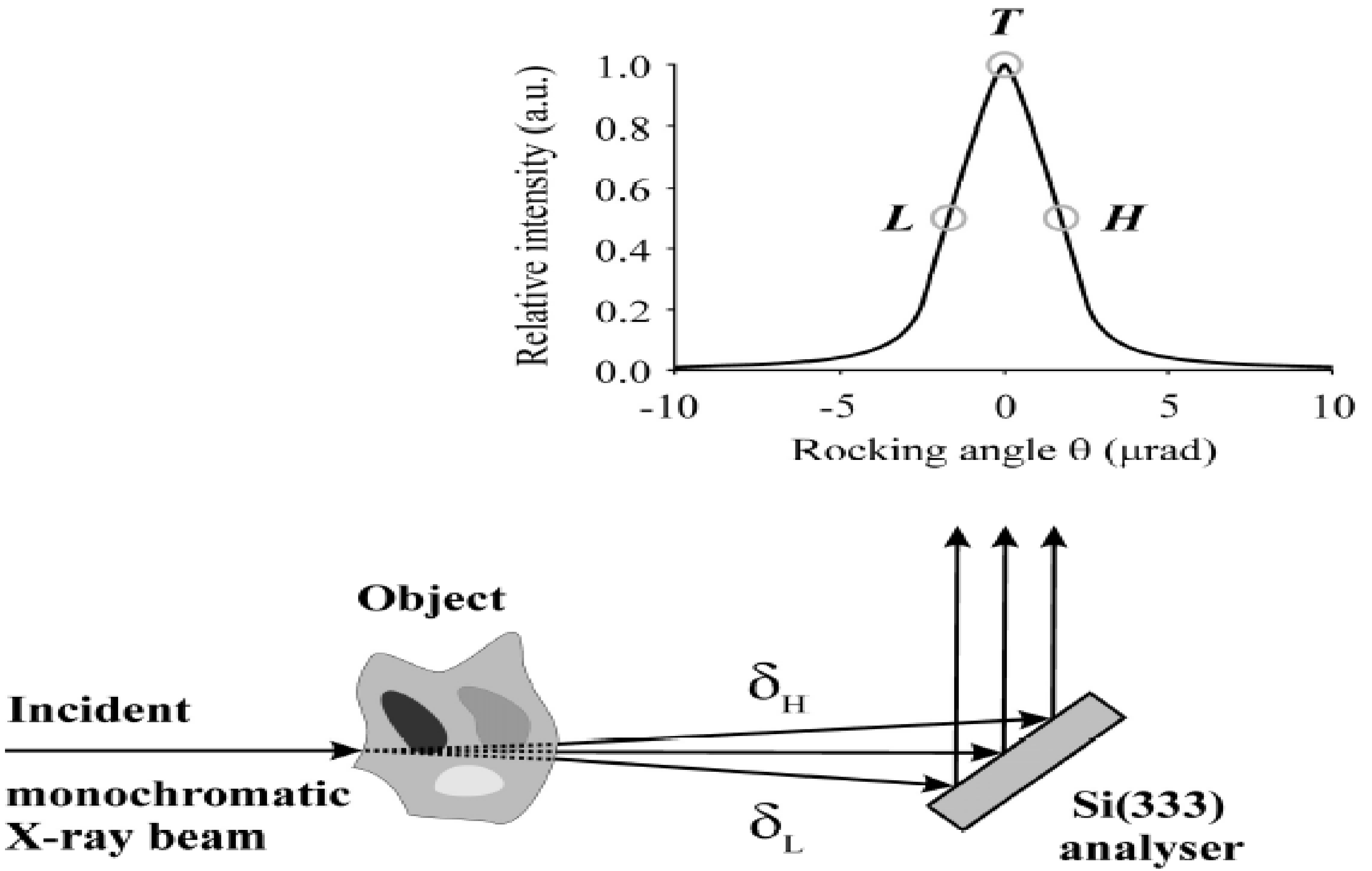
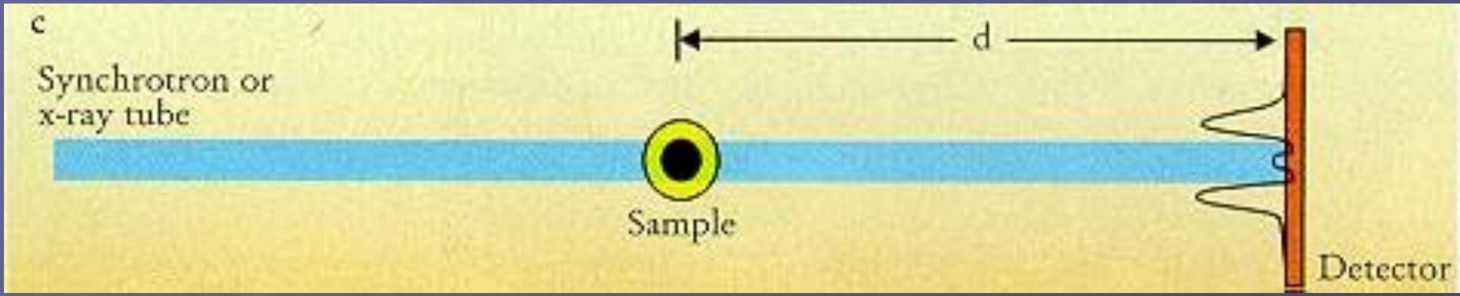


Figure 8. The double-crystal RC of Si(333) Bragg reflection at 25 keV and the principle of the DEI method. The analyser crystal converts the small angular changes in the refracted X-ray beam caused by the object to changes in intensity observed at the detector placed behind the analyser. The low-angle, top and high-angle positions on the RC are indicated by L , T and H , respectively.

Propagation imaging or Phase-contrast Radiography

- The x rays emerging from the sample at their various angles will propagate through free space until they reach the detector.
- With the detector immediately behind the sample, one will get a conventional absorption image.
- If the source is very highly coherent and the detector is placed very far behind the sample, one will observe a fringe pattern as the beam is diffracted by the sample, and interfere with each other

Propagation



- This method is based on observation of the interference pattern between the diffracted (phase shifted) and undiffracted waves.
- Needs a spatially coherent (microfocal) X-ray beam propagates through an object.
- When the detector is placed at an intermediate distance (Region of Fresnel diffraction), the small-angle (Phase) change at the interfaces between the structures (eg. Edges) can be resolved.

differential phase images