ThermoFisher
SCIENTIFIC

7th workshop
" Combined analysis examples using X-Ray Scattering"

- Dr. Henry PILLIERE
  (Artenay, France)

Summury

Presentation of ThermoFisher X-ray part (very quick)

Interaction X-ray and matter (no maths)

Instrumental function

XRD setup : some instruments and the information they give

- **Laboratory systems**
- **Industrial (on-line)**

Some real XRD examples :

- **Dust analysis**
- **Phase transition at (not very) high temperature**
- **Thin layer : diffraction, reflectometry, stress**
- **Micro-diffraction**
- **SAXS**

Thermo Fisher is the world leader in Serving Science

Global Scale

- 50,000 employees in 50 countries
- $17 billion in annual revenues
- Unparalleled commercial reach

Unmatched Depth

- Leading innovative technologies
- Applications expertise
- Lab productivity partner

Premier Brands

Thermo SCIENTIFIC

invitrogen

Fisher Scientific

appliedbiosystems

Unity Lab Services

Thermo Fisher Scientific – Inel Brand

Thermo Fisher Scientific – XRD research

Z.A. C.D. 405
45410 ARTENAY, France
T +33 (0)2 3880 4545
F +33 (0)2 3880 0814

Key figures

Creation : 1974 of INEL SAS
INEL integrates Thermo Fisher in Feb. 2016
Staff 2015 : 20 employees 80% technically qualified (PhD, Engineers and technicians)
Staff seniority average: 10 years

Resources

All technical and human resources are situated in our headquarter in France :

- Research & Development, technical assistance
- Informatics tools development & assistance
- Mechanical parts design & metrology
- X-Ray diffraction systems assembling
- Installation & After Sales Services for instrumentation
- Components and electronic cards design & integration

XRD-XRF product portfolio: strong, complementary technologies

EDXRF

ARL QUANT'X
Top performance EDXRF

WDXRF

ARL PERFORM'X
High performance XRF

ARL OPTIM'X – 50W/200W
Amazing WDXRF

Integrated XRF and XRD

ARL 9900 Series
Integrated XRF-XRD

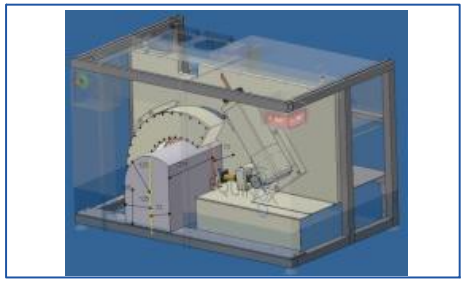
Powder XRD

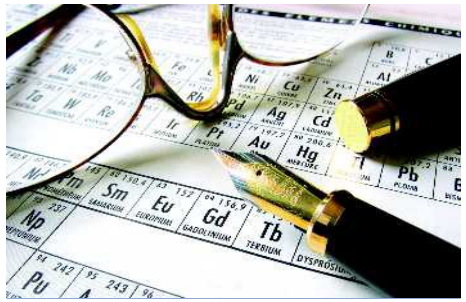
ARL X'TRA

EQUINOX XRD

More on www.thermoscientific.com/xray

Skills and expertise in Artenay





Instrumentation

Inel designs, manufactures and provides analytical instrumentation:

- X-Ray diffraction instrumentation
- X-Ray radiography instrumentation (CND)
- Extreme Ultraviolet sources instrumentation

Engineering

Your needs are specific or evolved and your equipment doesn't fit your needs anymore? Our mission:

- Project consultant & management
- Feasibility studies
- New equipment design & installation

Scientific Studies & Projects

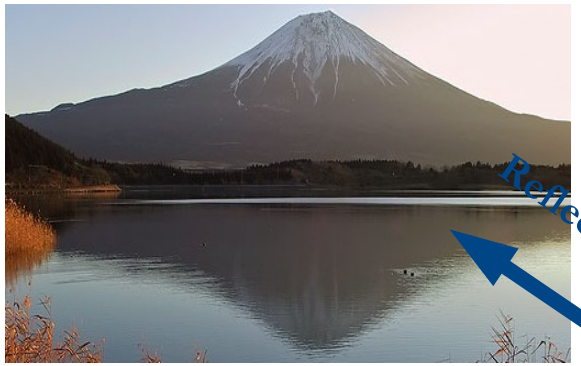
INEL participates in the European and local scale to various projects of R&D to develop Technology.

- European ENVIROMONITOR project coordination: real time automated instrument development using XRD for on-site quantitative analysis on breathable spray particles, including nanoparticles
- Scientific state projects, Thesis financing
- Works coordination & supervision
- Patents creation & operation
- SolXpert project, granted by Région Centre (Fr)
- SOLSA project H2020 raw material

… and radiation always

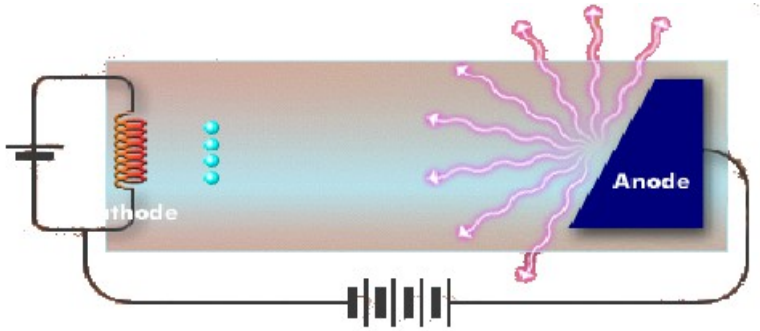
interact with matter …

Wave-matter interaction

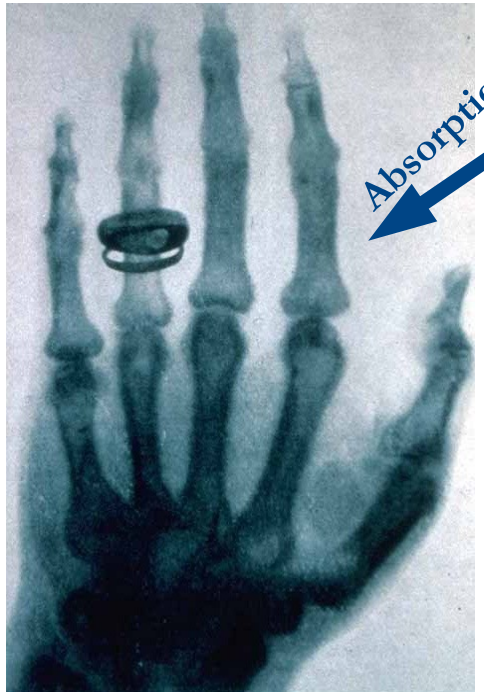


Reflection

X-rays Production : classically by excitation of external electronic level with electron beam

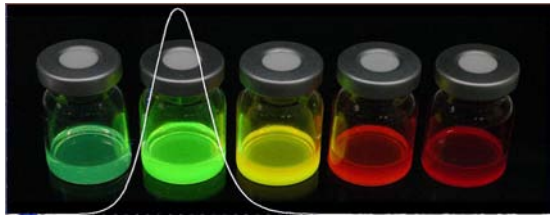


Diffusion



Absorption

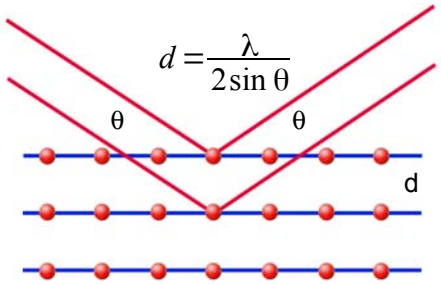
fluorescence



Diffraction

Bragg's law

$$d = \frac{\lambda}{2\sin\theta}$$



8

Interaction wave-matter

Who can see the error?

For a given source (sun), and a sample (Alpes)

refraction

diffusion

reflexion

absorption

Sun

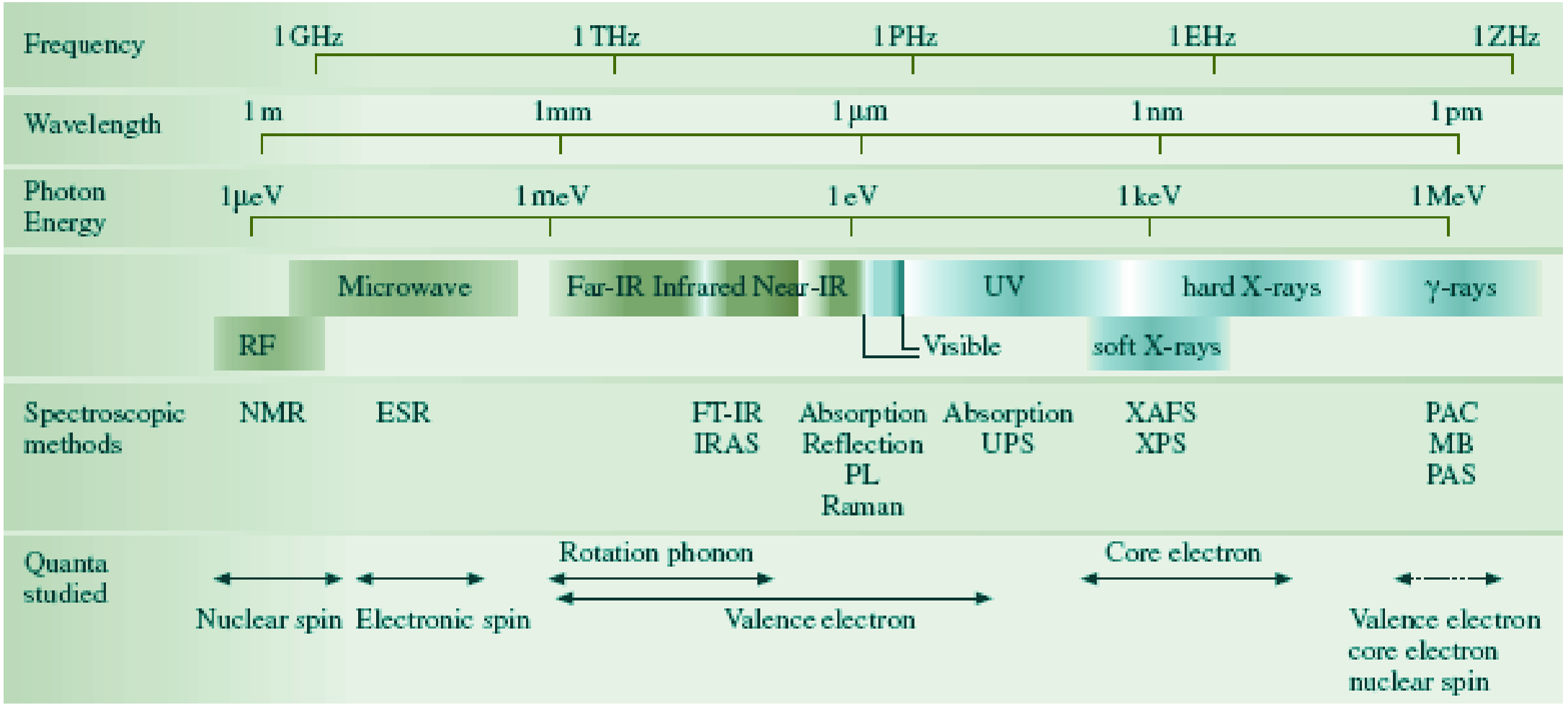
… and eye detector

Instrumentations using radiation for material analysis need to be optimized :
- source characteristics
- detection characteristics
- sample environment
- mechanical design

9

Interaction wave-matter

The energy of photons used for optical spectroscopic measurements of various quanta



EHz : exahertz (10^{18}) - ZHz : zettahertz (10^{21}) - YHz : yottahertz (10^{24})

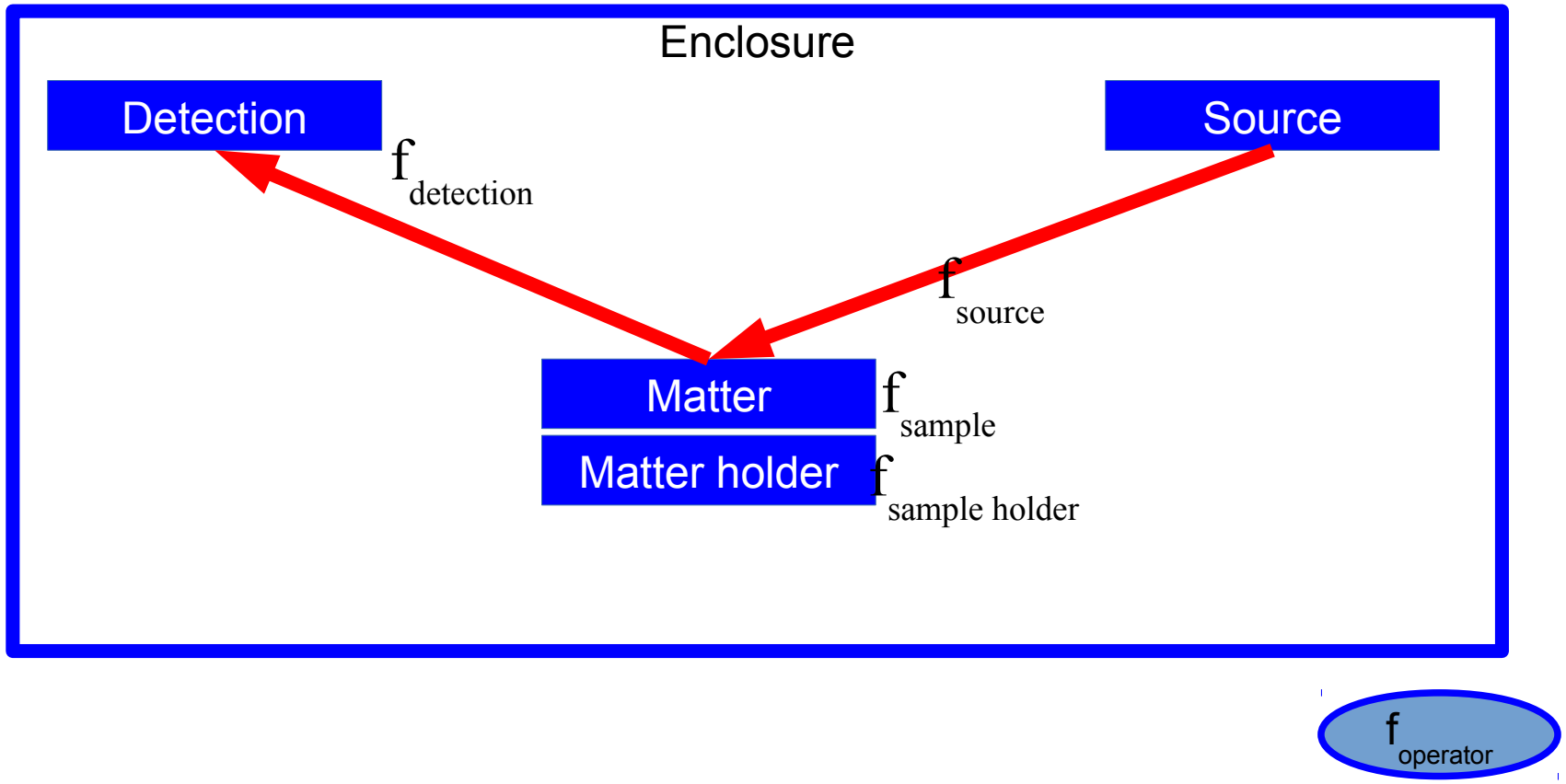
Instrument is designed

for the need

we are looking for !

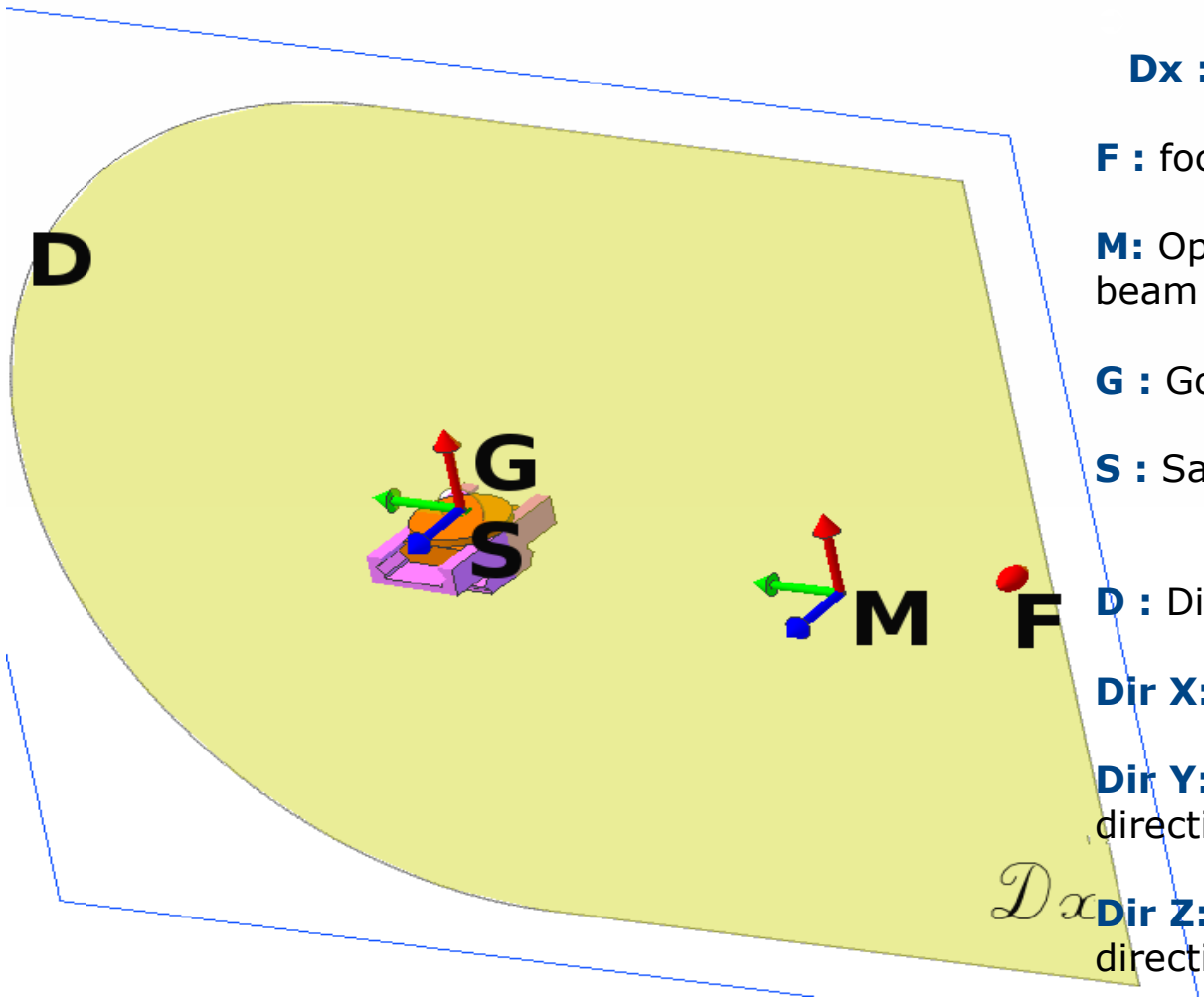
Building an instrument

Instrument using a wave for probing matter is defined by several functions :



Most instruments using radiation corresponds to this scheme :
XRD – XRF- FTIR- Raman-UV …

Building an instrument: definition



Dx : Diffraction plane

F : focus of the source

M: Optical position (monochromator, mirror), involving a primary beam deviation

G : Goniometer center where is localized the sample

S : Sample position

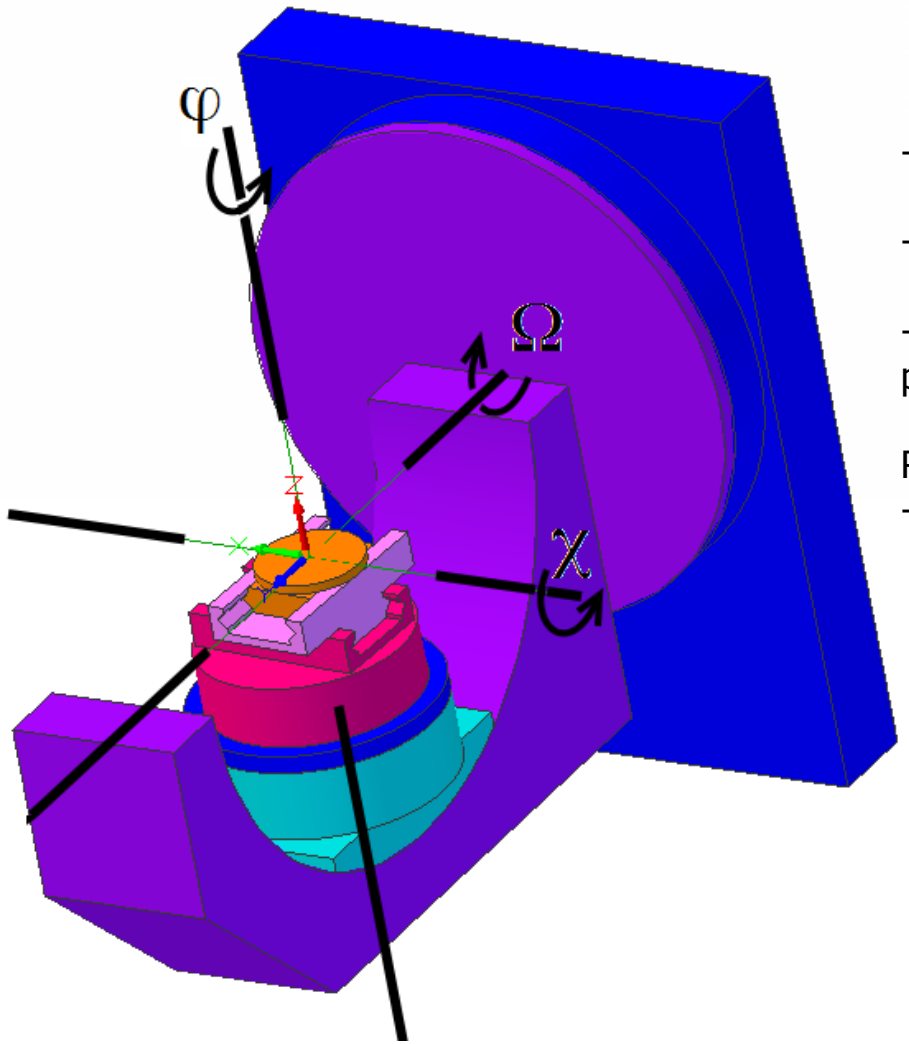
D : Diffraction device

Dir X: Direction of the primary beam

Dir Y: Direction perpendicular to the diffraction plane (axial direction)

Dir Z: Direction perpendicular to the sample surface (equatorial direction)

Building an instrument: definition



Goniometer

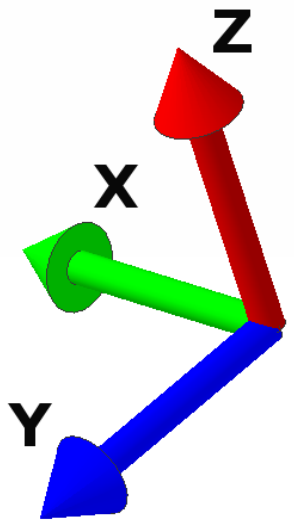
Sample orientation is defined by 3 Euleriean angles:

- "Ω" angle is the incident angle on the sample surface

- " φ" angle is the rotation belongs the normal axis to the sample surface

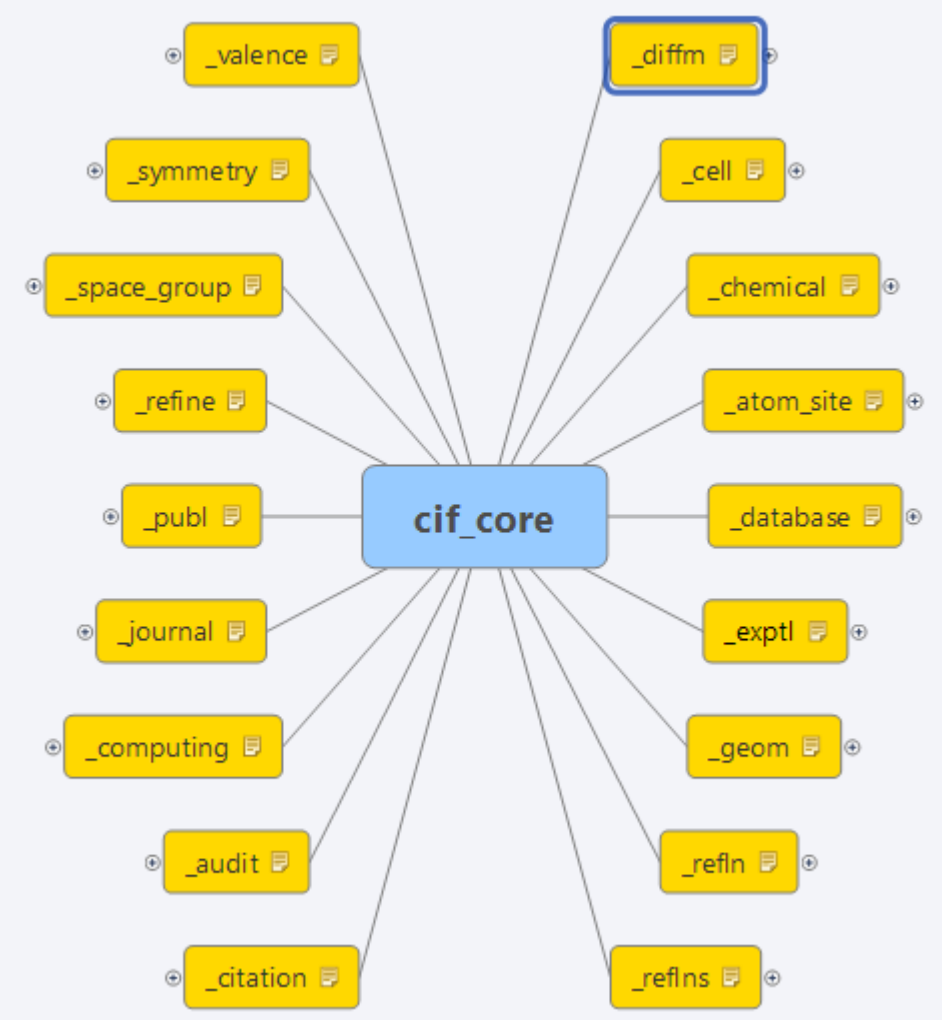
- "χ" angle allows to tilt sample belongs the axis intercept of the diffraction plane and sample surface

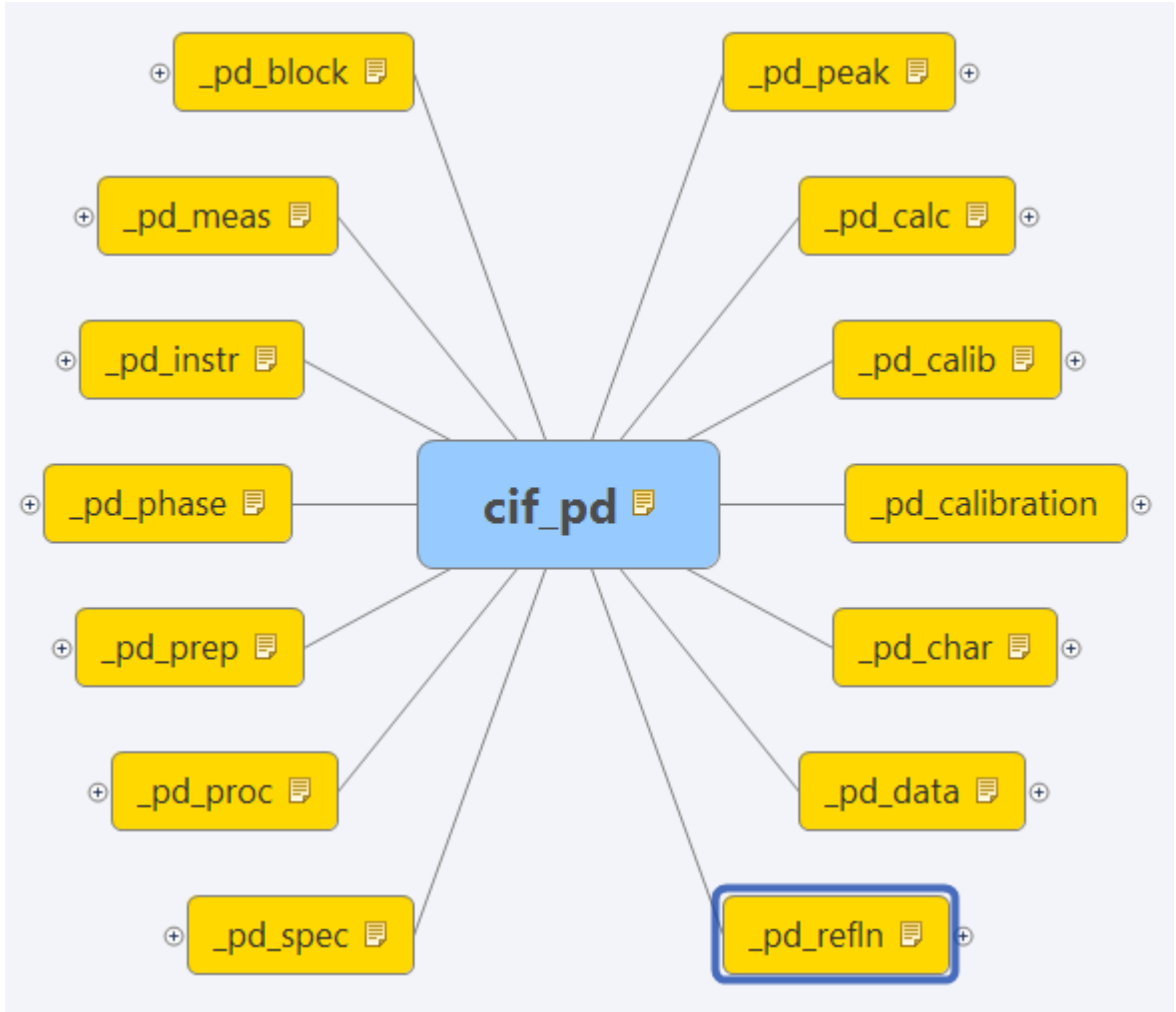
Remark:
- "2θ" angle belongs to the detection part



A dictionary to describe the system: CIF

Defining and listing parameters make description easier !

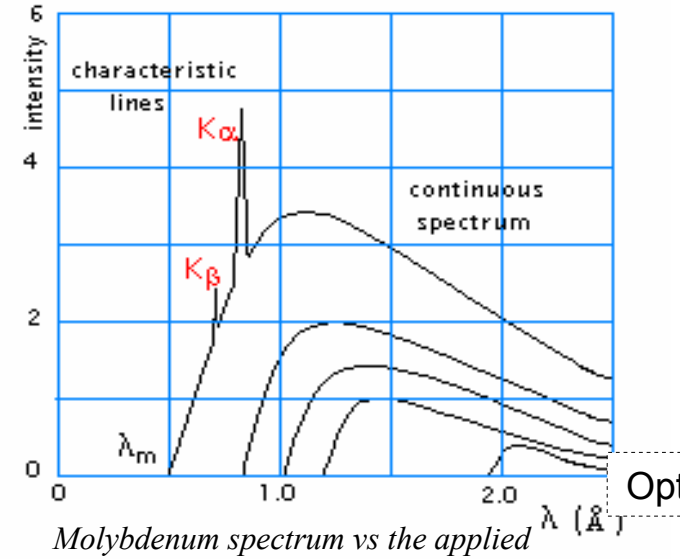




http://www.iucr.org/__data/iucr/cifdic_html/1/cif_core.dic/index.html

ThermoFisher SCIENTIFIC

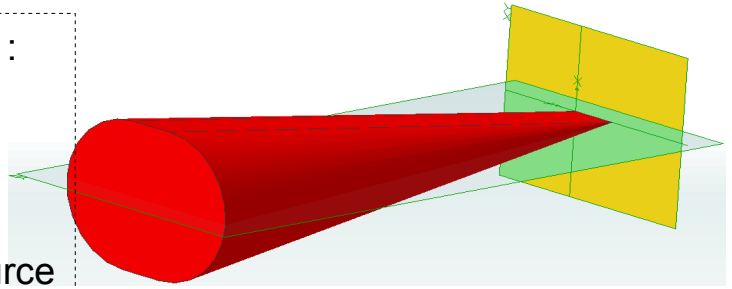
Function source



Molybdenum spectrum vs the applied voltage

A light emission characterized by :

- a spectral range
- a solid angle
- intensity
- dimension and shape of the source

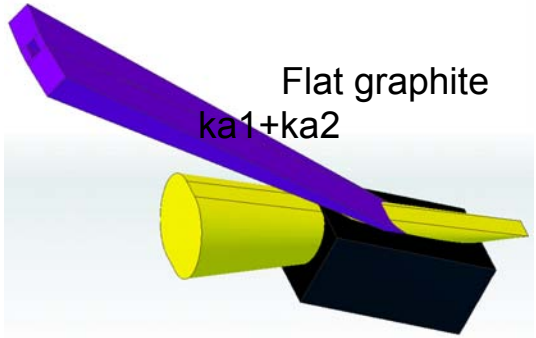


Optimizing the characteristics of a source allows to focus on a given interaction

	fluorescence	imaging	diffraction	reflection	diffusion
Spectral range	large	large	Monochromatic (excepted Laue)	monochromatic	monochromatic
Solid angle	Few degrees	Large (60°)	Small to parallel or focusing	Very small	Very small or focusing
Source size	Small or large	Small for resolution improvment	small	small	small
Source shape	point/linear	point	Point or linear	linear	Point or linear

This is achieved by using appropriate optics (1D, 2D, monochromator, mirror, collimator, slits ...)

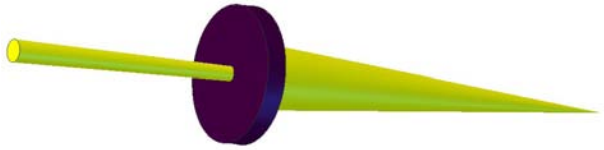
Function source; shaping the beam !

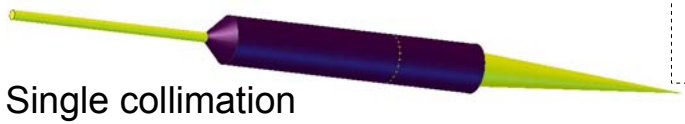


"Monochromaticity"

Divergence

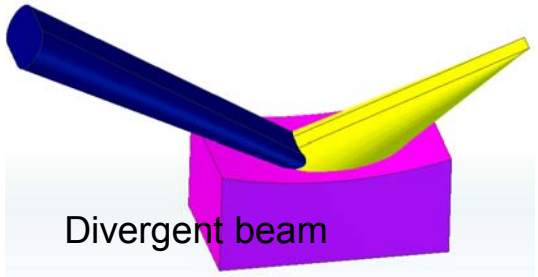
Focusing

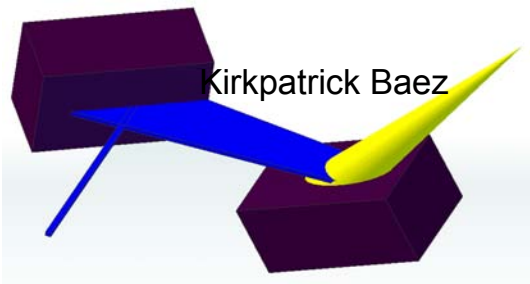


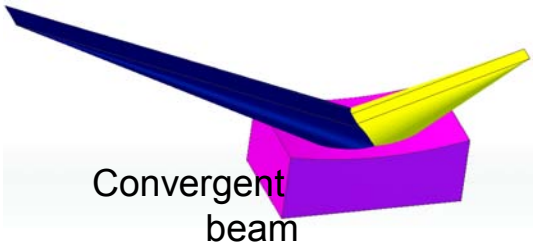


An optic is characterized by :

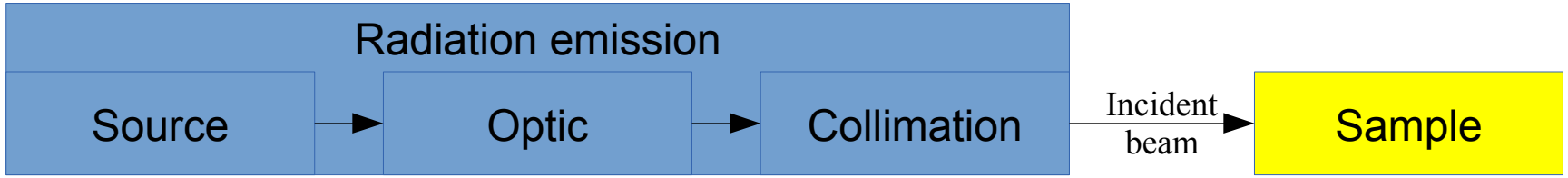
- mosaicity → spectral range
- a capture angle → beam size
- divergence → resolution

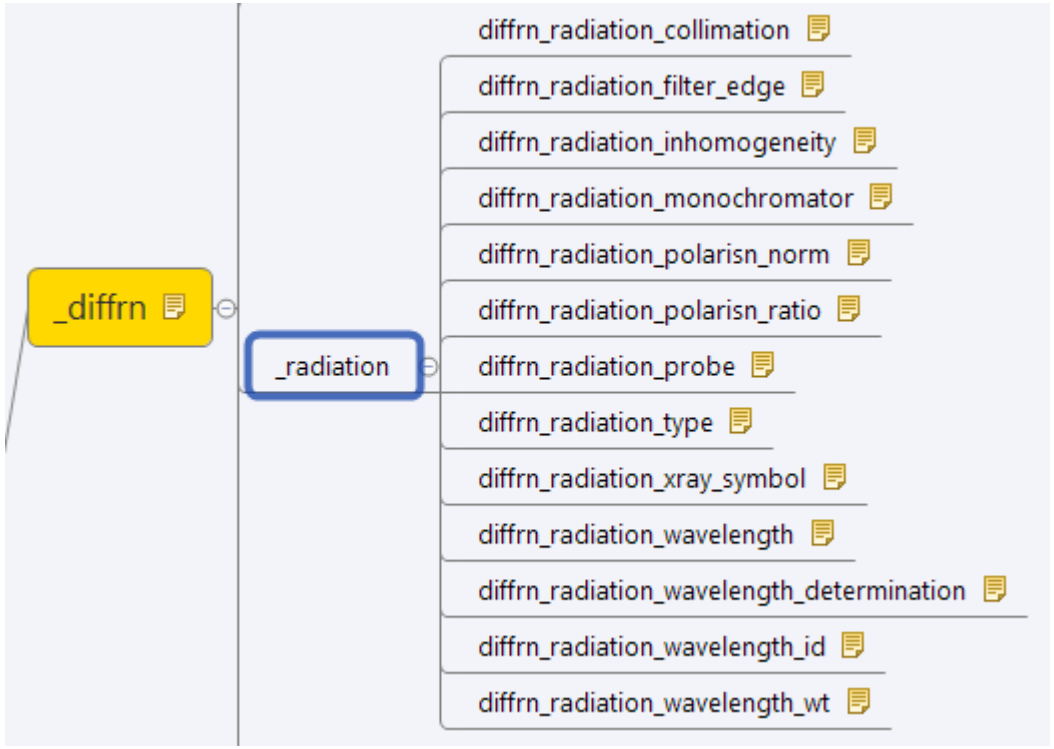


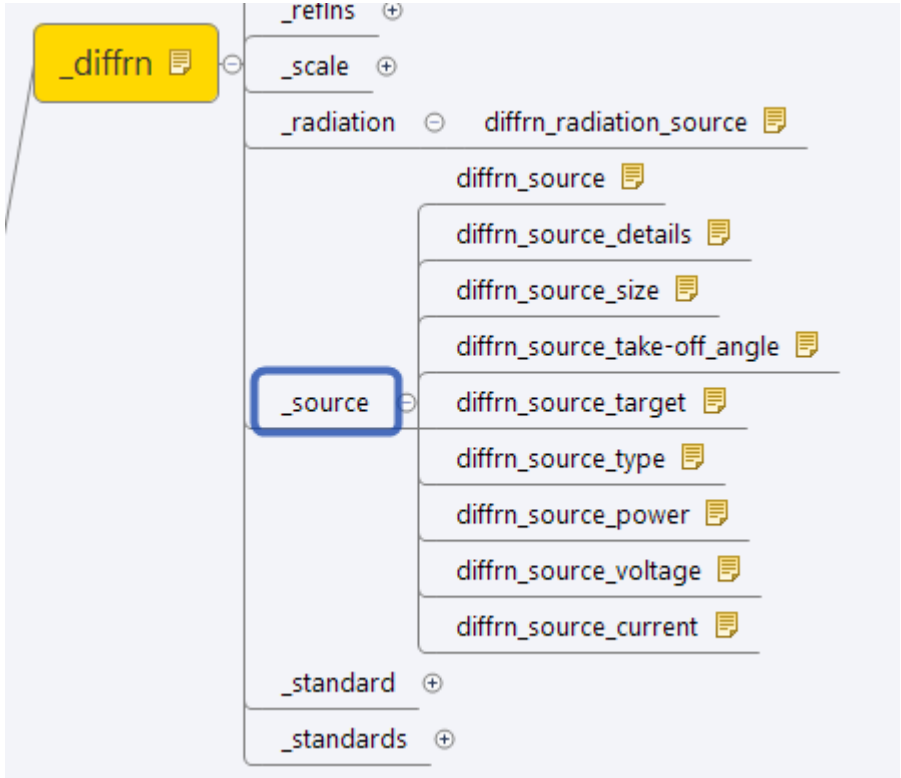




A dictionary to describe the source



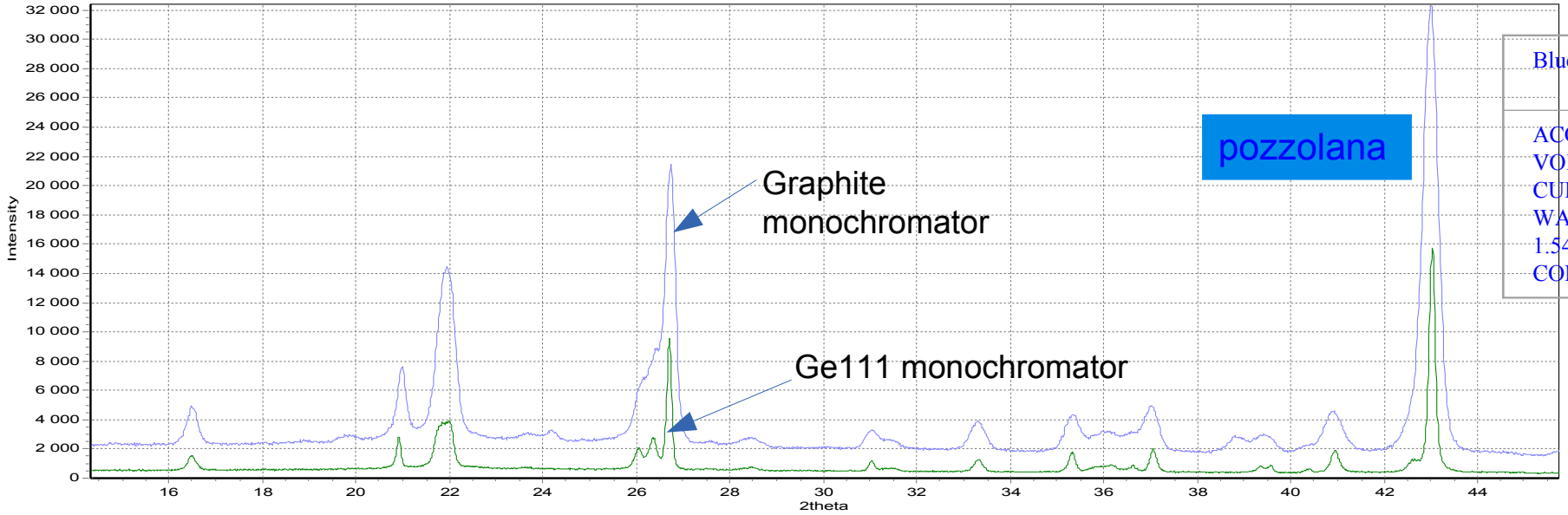




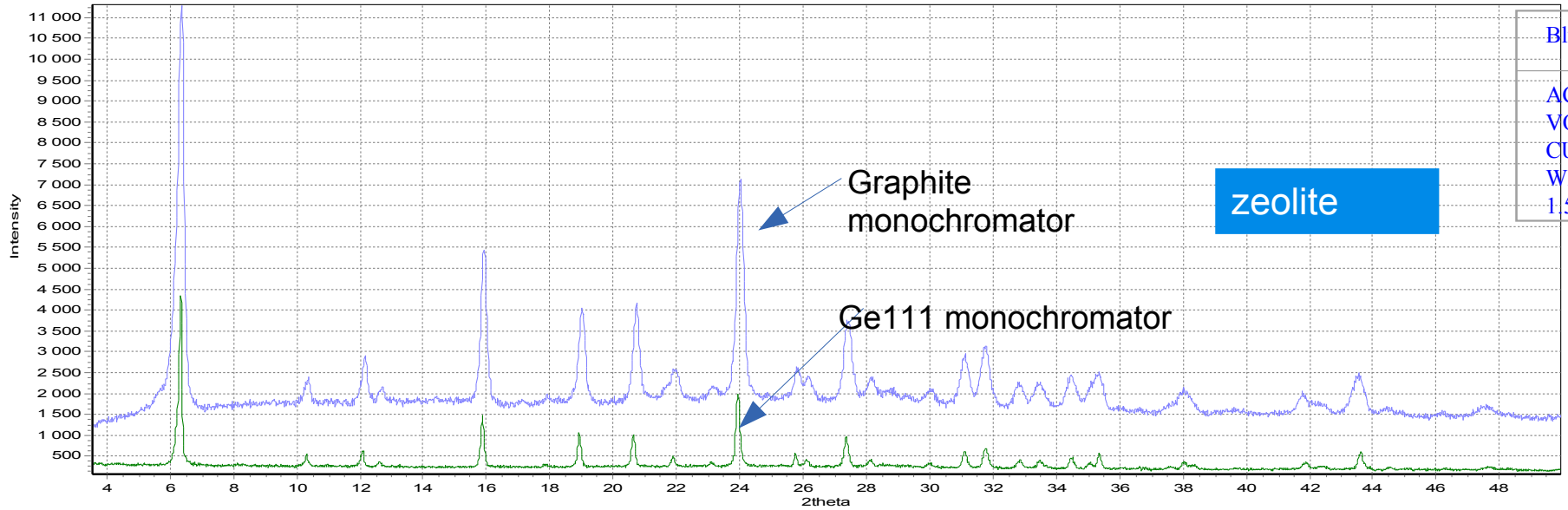
Deeper in the CIF !

Ones doing programming will see « object oriented programming »

Effect of optic: comparison between high resolution and high flux

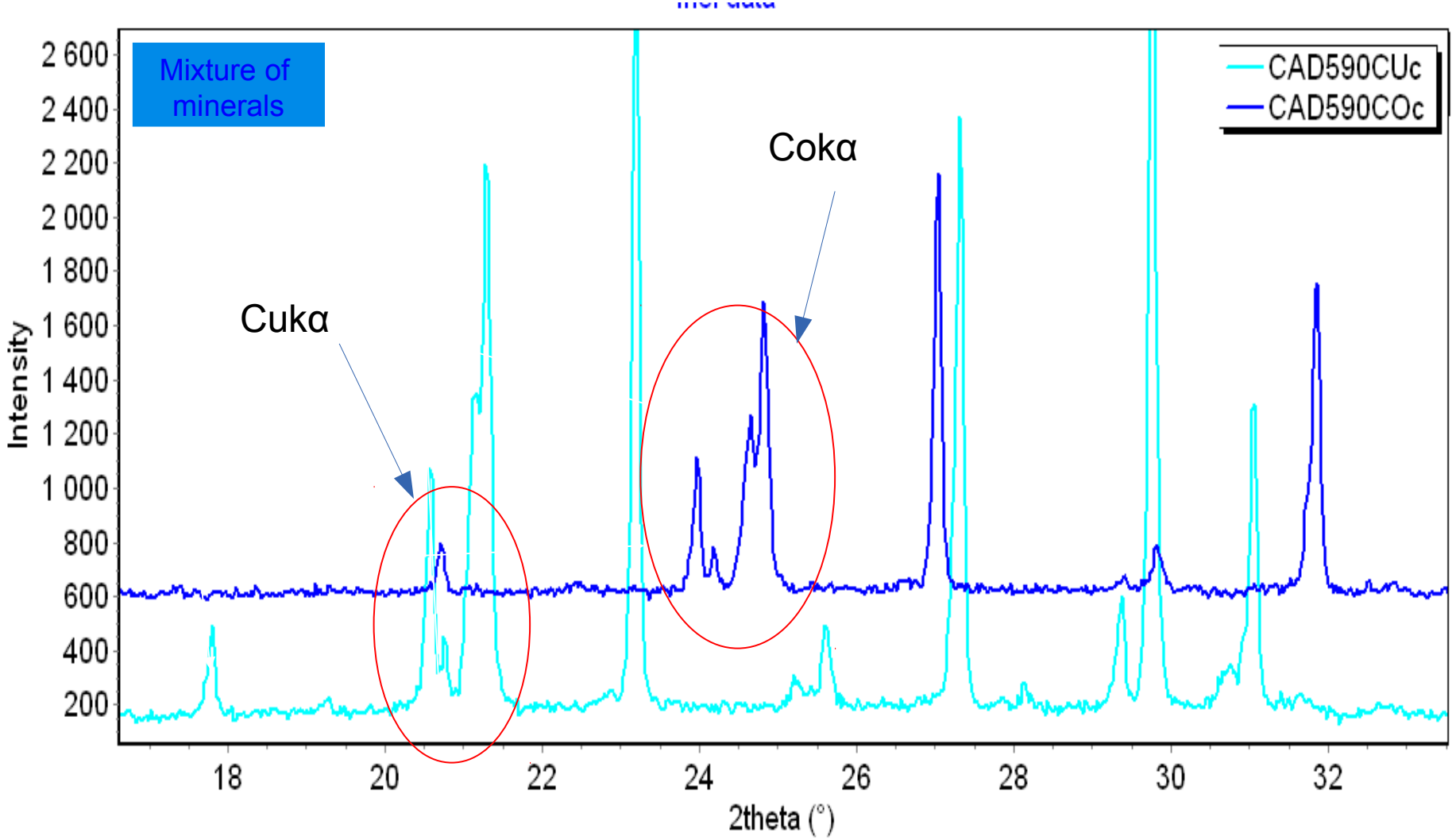


Blue	Green
ACQTIME 300 VOLTAGE 35 CURRENT 35 WAVELENGTH 1.54056000 COMMENT1 inc=10 SFspin	ACQTIME 27815 VOLTAGE 35 CURRENT 35 WAVELENGTH 1.54056 COMMENT1 inc=8 spin



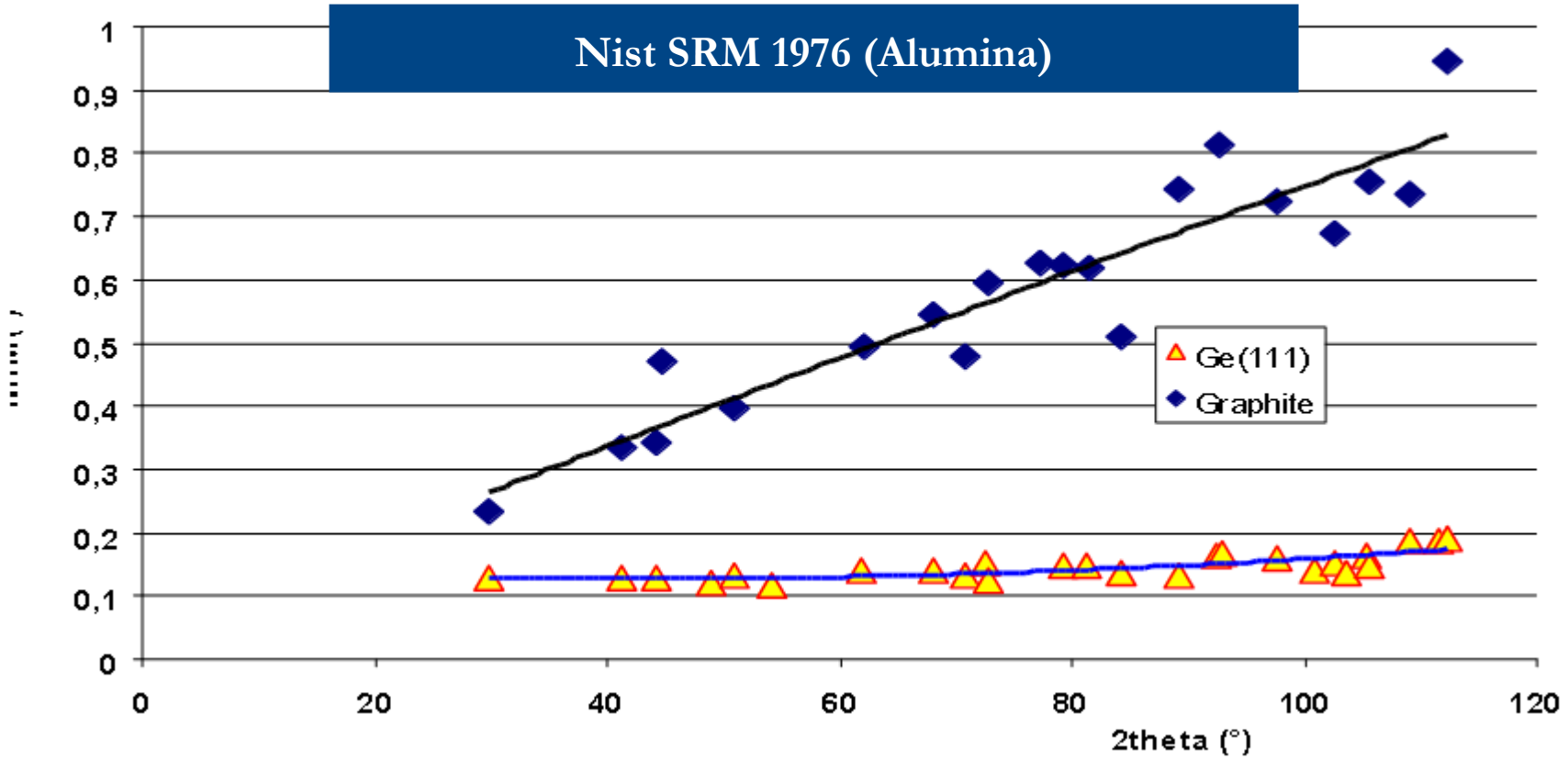
Blue	Green
ACQTIME 1800 VOLTAGE 35 CURRENT 35 WAVELENGTH 1.54056000	ACQTIME 18000 VOLTAGE 35 CURRENT 35 WAVELENGTH 1.54056

Effect of wavelength



Effect of optic

With graphite, ka_1/ka_2 doublet is considered as a single peak.



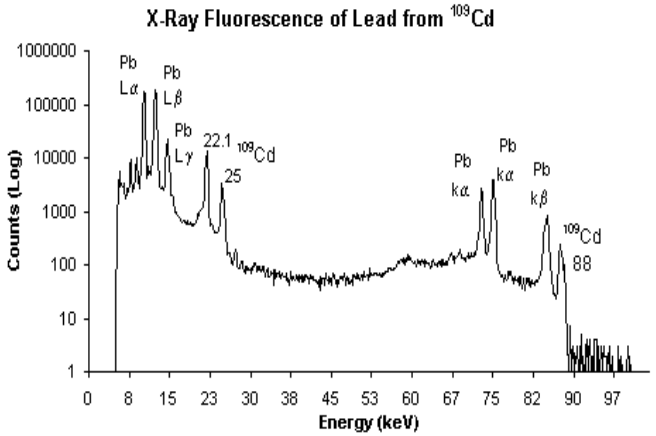
Flux ratio	
Ge(111)	1
Graphite	5
parab. Mirror	15
Elliptical mirror	20

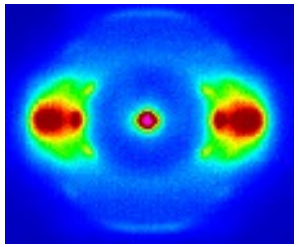
Function detection

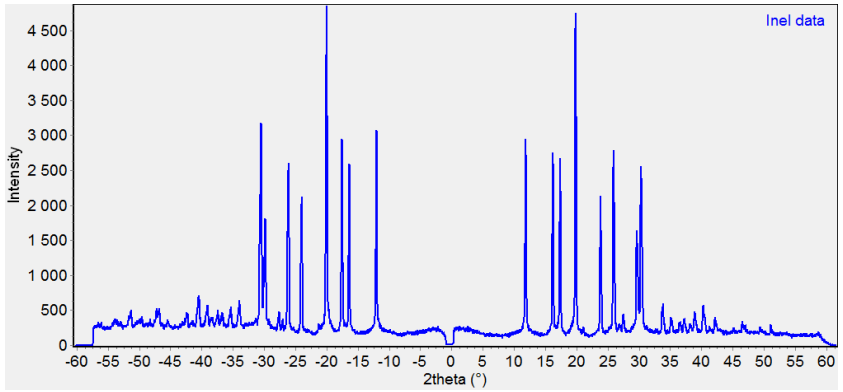
A detector is characterized by :
- spacial resolution
- dynamic range
- energy resolution
- dimension

Optimizing the characteristics of a detector allows to improve the measurement

	fluorescence	imaging	diffraction	reflection	diffusion
Spacial resolution	none	good	good	none	medium
Dynamic range	3	4~5	3~5	6~8	3~4
Energy resolution	~200eV	None Filtering possible	None or 1KeV	None or 1KeV	None or 1KeV
dimension	0D	2D (1D)	0D, 1D, (2D)	0D(1D)	1D-2D





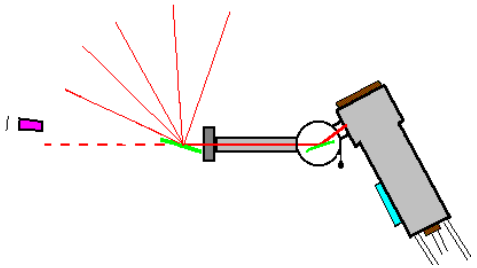


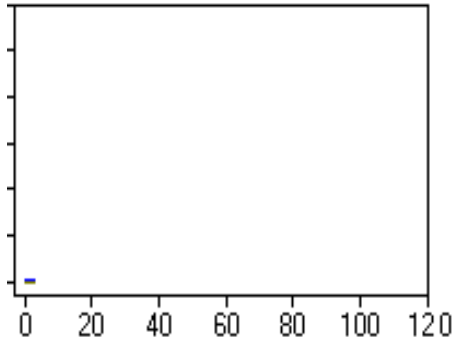
Function detection

0D Detection :

Acquisition is done Stepwise

2θ and statistics are time dependent

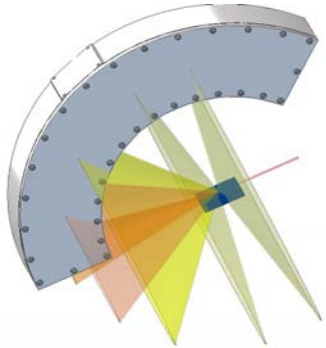


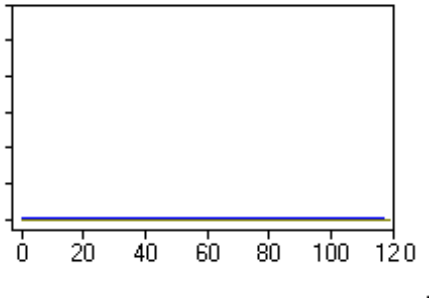


1D Detection :

Acquisition is done in snapshots

Statistics is time dependent



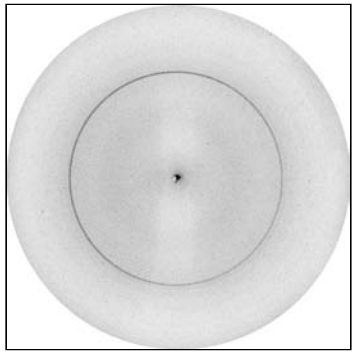


2D Detection :

Acquisition is done in snapshots

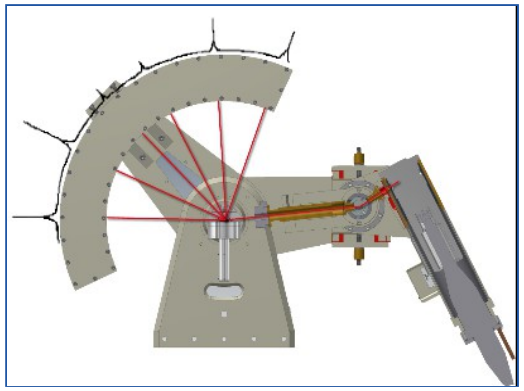
Statistics is time dependent

Texture information but point beam required



ThermoFisher SCIENTIFIC

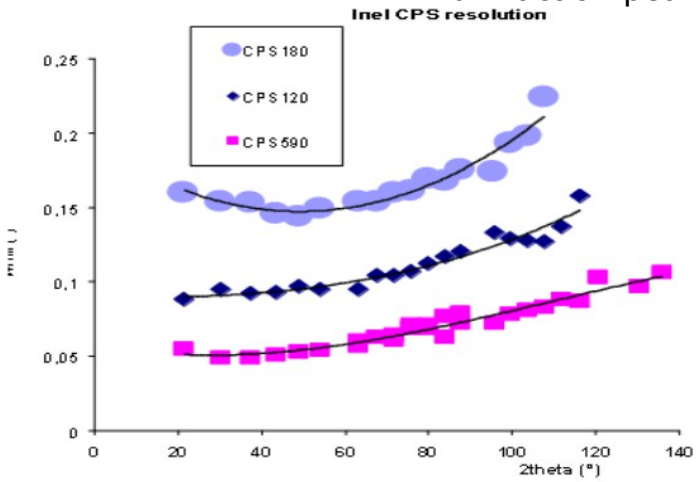
A unique detection mode

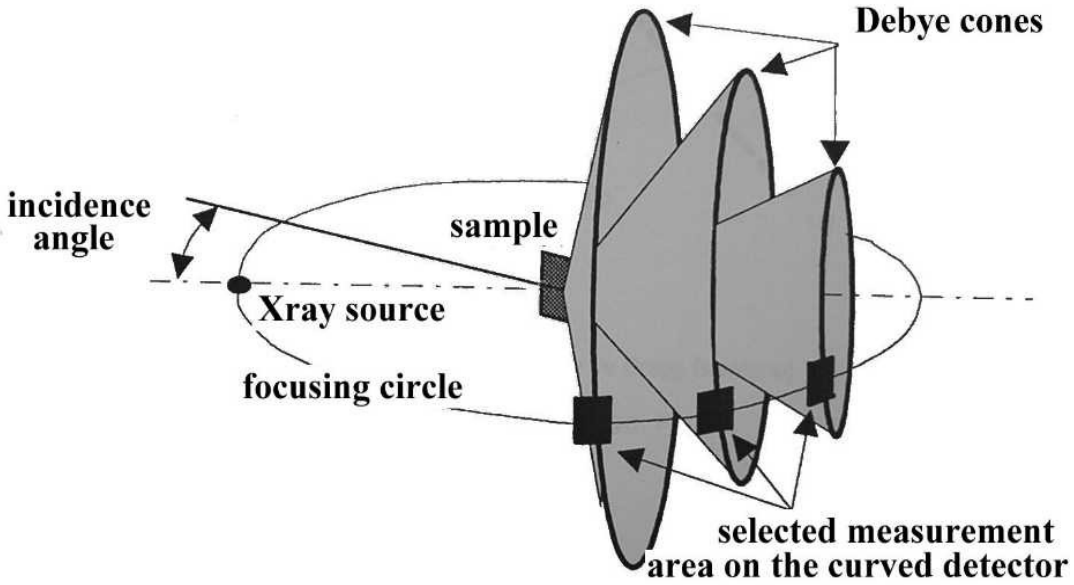


Curved detectors principle

The EQUINOX diffractometers use the curved detectors principle, namely real time acquisition across a wide acquisition range.

- No motorization required: neither on sample nor on detector incidence
- Asymmetric acquisition mode: for a fix θ sample incidence you can see all diffraction peaks on 2θ on the detector





3 detector types

	Detection angular range	Curvature (mm)
CPS 590	90° 2θ	R = 500
CPS 120	120° 2θ	R = 250
CPS 180	180° 2θ	R = 180

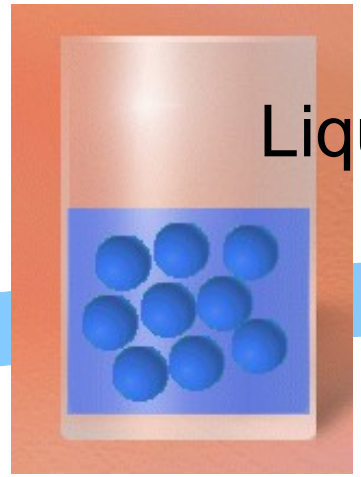
Analysis speed
& resolution
No maintenance

The detector choice depends on the requirements of the measure to be made:

- The more the detector is far from the sample, the better the resolution will be
- The more the detector is near the sample, the faster the acquisition will be

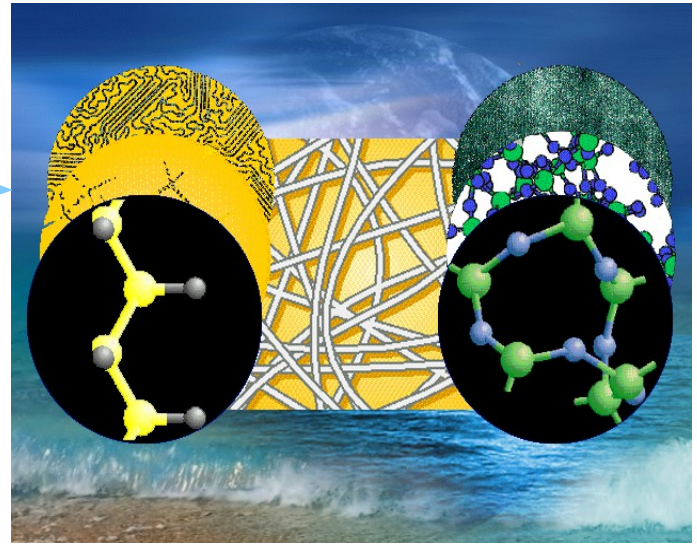
Function matter

Gas



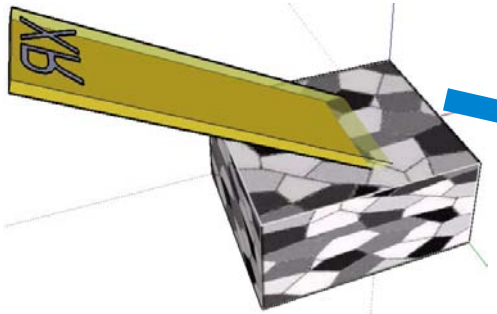
Liquid

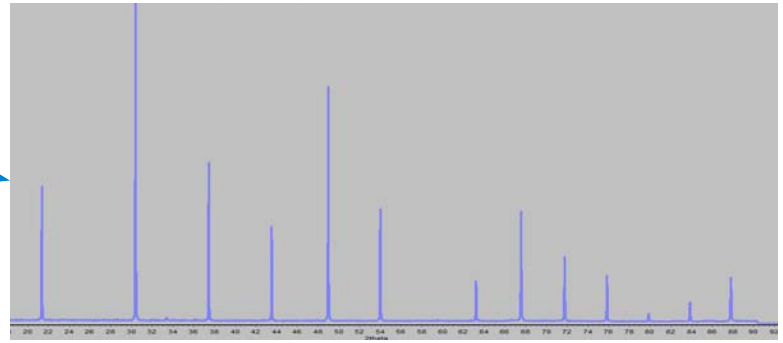
States of matter

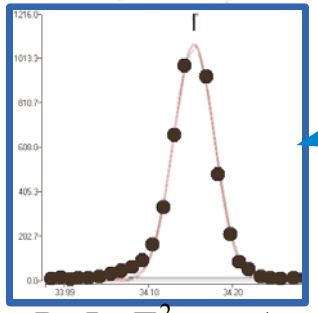


whatever the state,
XRD allows to evidence and measure
structural parameters in matter

Informations obtained by XRD

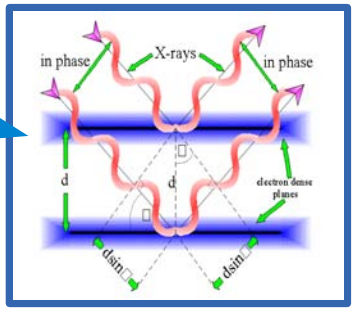






$$I = I_0 . P . L . F^2 . m . A . e^{-2M} \frac{.1}{V^2}$$

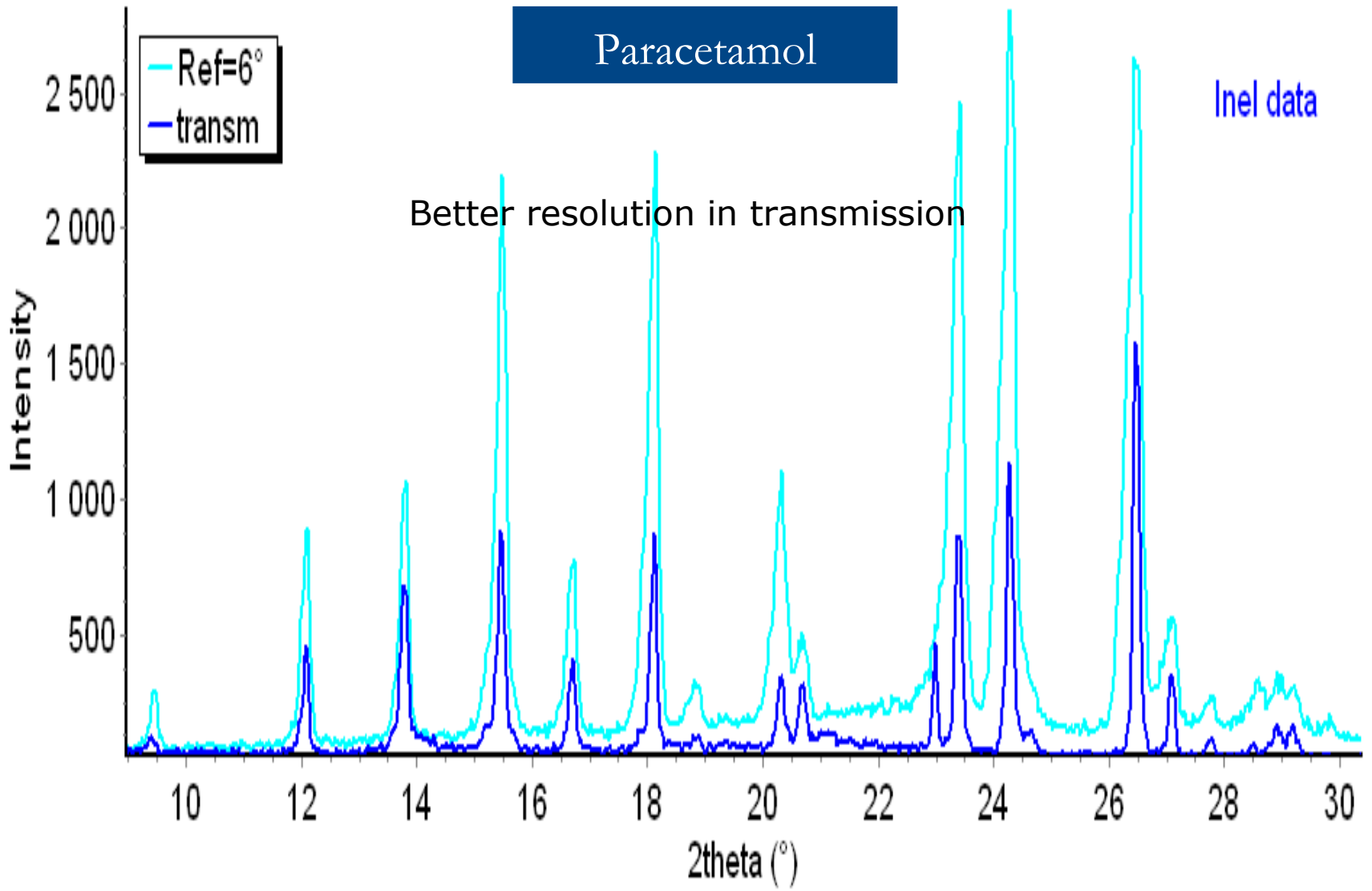
Overall analysis of peaks shape, position and intensity and background function



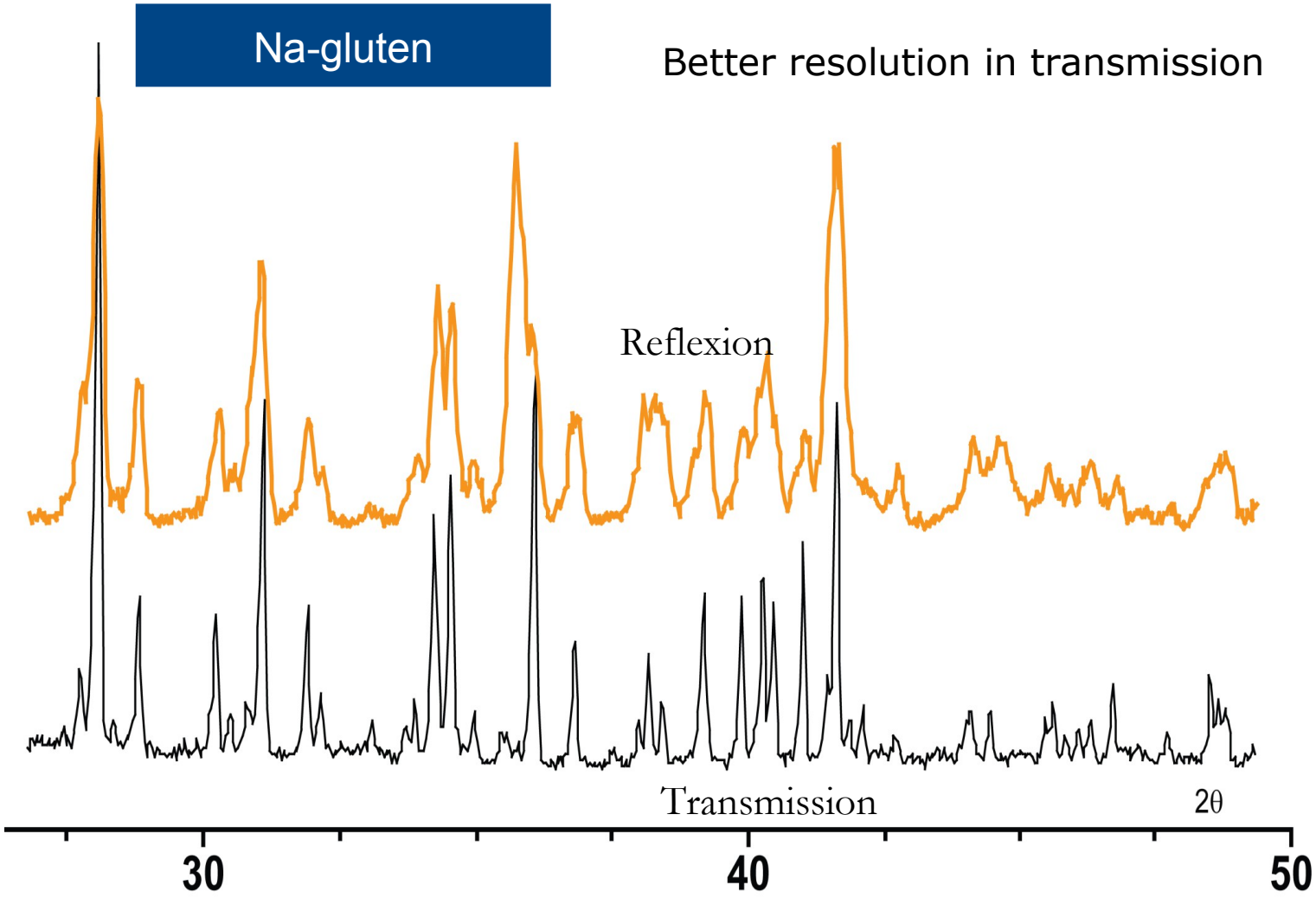
$\lambda = 2d_{hkl} \sin(\theta_{hkl})$

What is the composition?	Phase identification
and how much?	Phases quantification
what is the cristallite size and morphology?	Particles size,
Is-there any constrains inside cristallite?	micro strains
Or in the overall sample?	Stress analysis
Is there an organisation at the cristallite scale?	Preferred oritentation (powder) or texture (bulk)
And can we quantify a distribution? Pole figures,	ODF
Structure, organization of electronic density levels :	cell parameters, valence, atomic occupation, ...
What is the structural modification of my sample vs physical parameters (P, T...)?	dilatation, phase transition
Structural anisotropy :	stress, texture, thin film characterization ...

Function sample holder



Function sample holder



X-ray diffraction setup

Understanding how to get the result

- appropriate instrumental configuration

- appropriate sample conditioning

- appropriate calibrations / corrections

		Type of solid	
		Single crystal	polycrystalline
Type of radiation	monochromatic	Rotating crystal Method	Powder XRD
	polychromatic	Laue Method	ED-XRD

Instrumental function for XRD

Some rules :

- Instrumental function is governed by all components of the XRD instrument :
  - source characteristics
  - optics and collimation
  - detection device
  - sample environment

- XRD components should be compatible to each other
  - Example : 1D optic is not recommended with a 2D detector (equatorial aberration)

- The good knowledge of the instrumental function allows to estimate as well the quality of the result
- Example : absorption correction or LP correction are not the same in Bragg Brentano or in Debye Scherrer

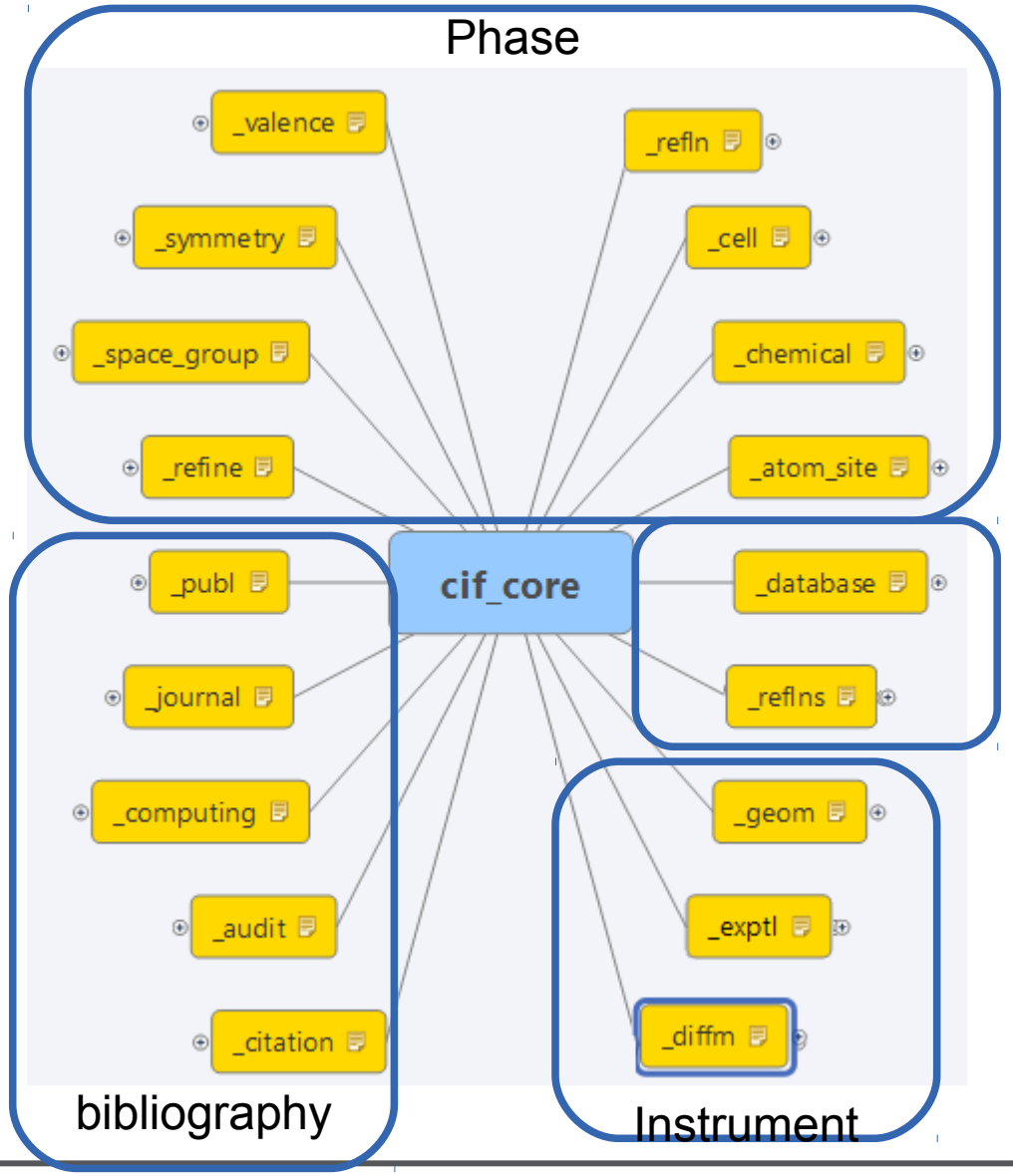
- The instrument must be adapted to the requested measurement
- Example : performing transmission measurement with Bragg-Brentano XRD is not appropriate

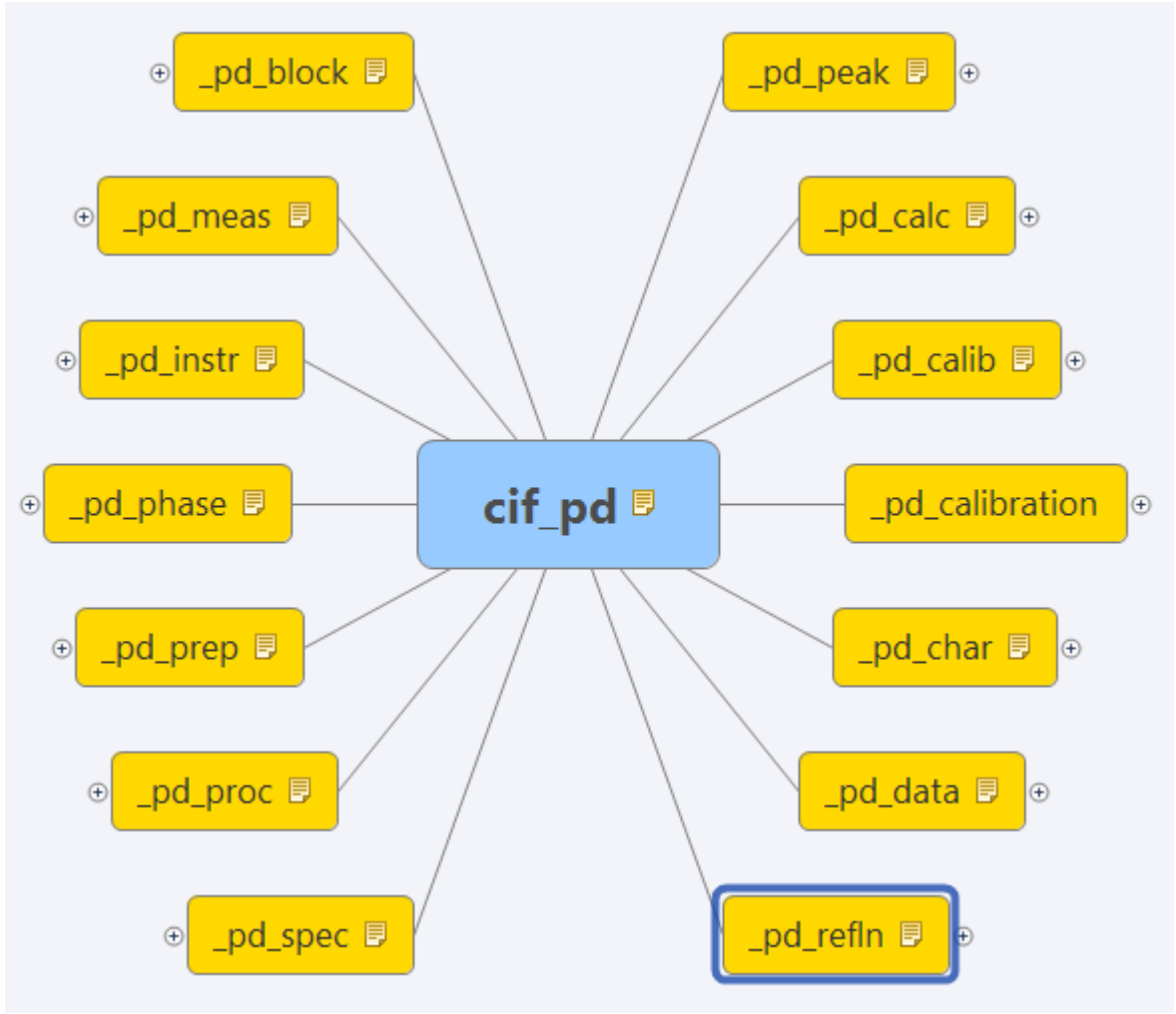
- Instrumental conditions must be correctly chosen (reproducibility of results)
- Example : choose of the appropriate wavelength vs sample

- Use of appropriate standards

Example : in reflexion, eccentricity is influenced by transparency. Using standard with same absorption can correct this

A dictionary to describe the system: CIF





Existing Instruments

And

applications

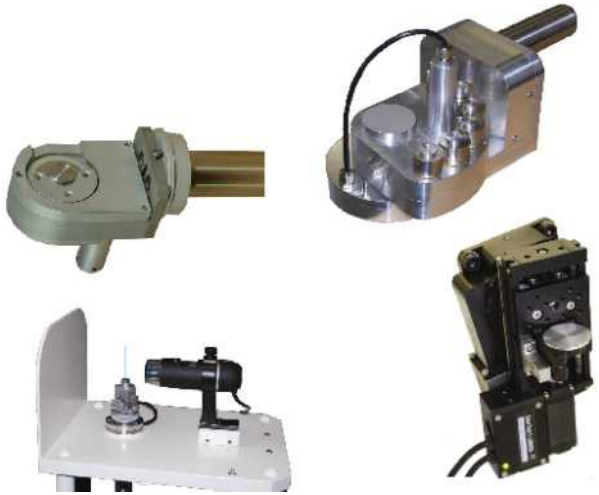
EQUINOX 100, stand alone benchtop XRD

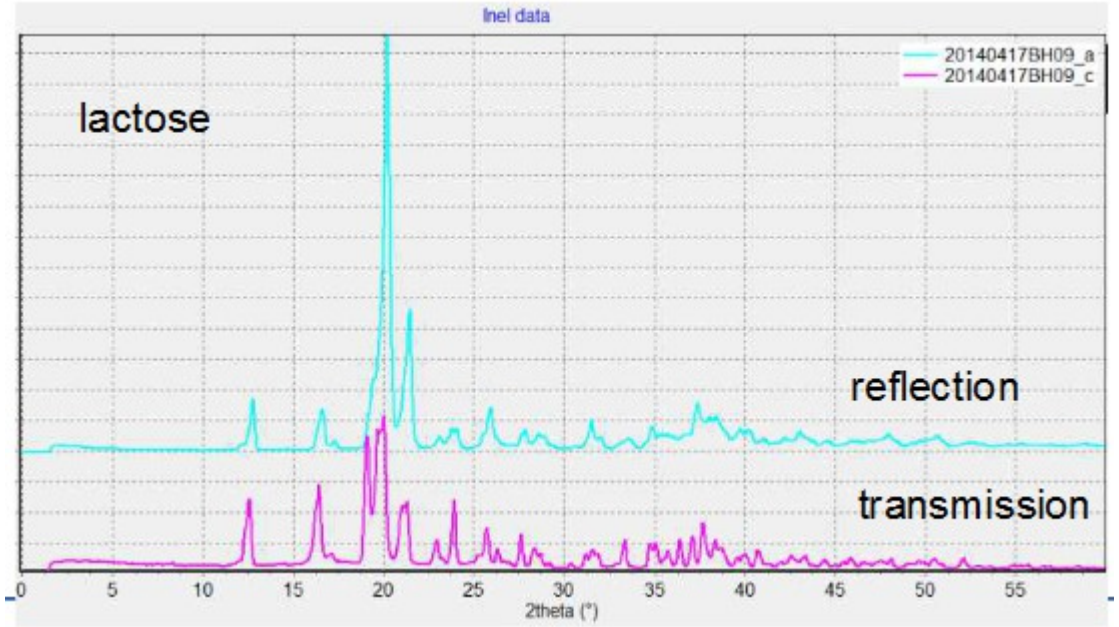
A stand alone benchtop X-ray diffractometer

Designed for crystalline phases analysis (qualitative, quantitative, structural…) on powder or bulks.
It is an ideal instrument for academic and QA/QC laboratories that need a small and easy to use equipment.

- Real time detection across 110°/2θ (CPS180)
- Simplified goniometric deck with no motorization
- No external water cooling
- Works on standard power supply (110V-20A/230V-16A)
- Friendly-user instrument driving & data treatment software

Applications: qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation...



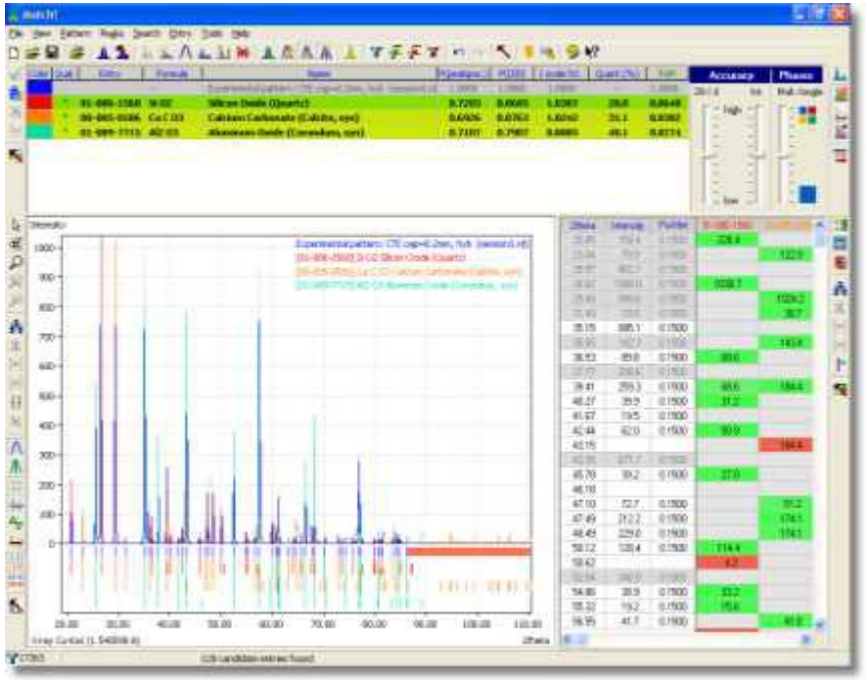


EQUINOX 1000, benchtop XRD

A fast and powerful benchtop XRD

with small dimensions, ideal for all your X-ray diffraction applications on powder.

It is a very easy using instrument. No diffractometer alignment is required and the operating protocol is saved by the software. XRD experiments are available to anyone in a few moments.



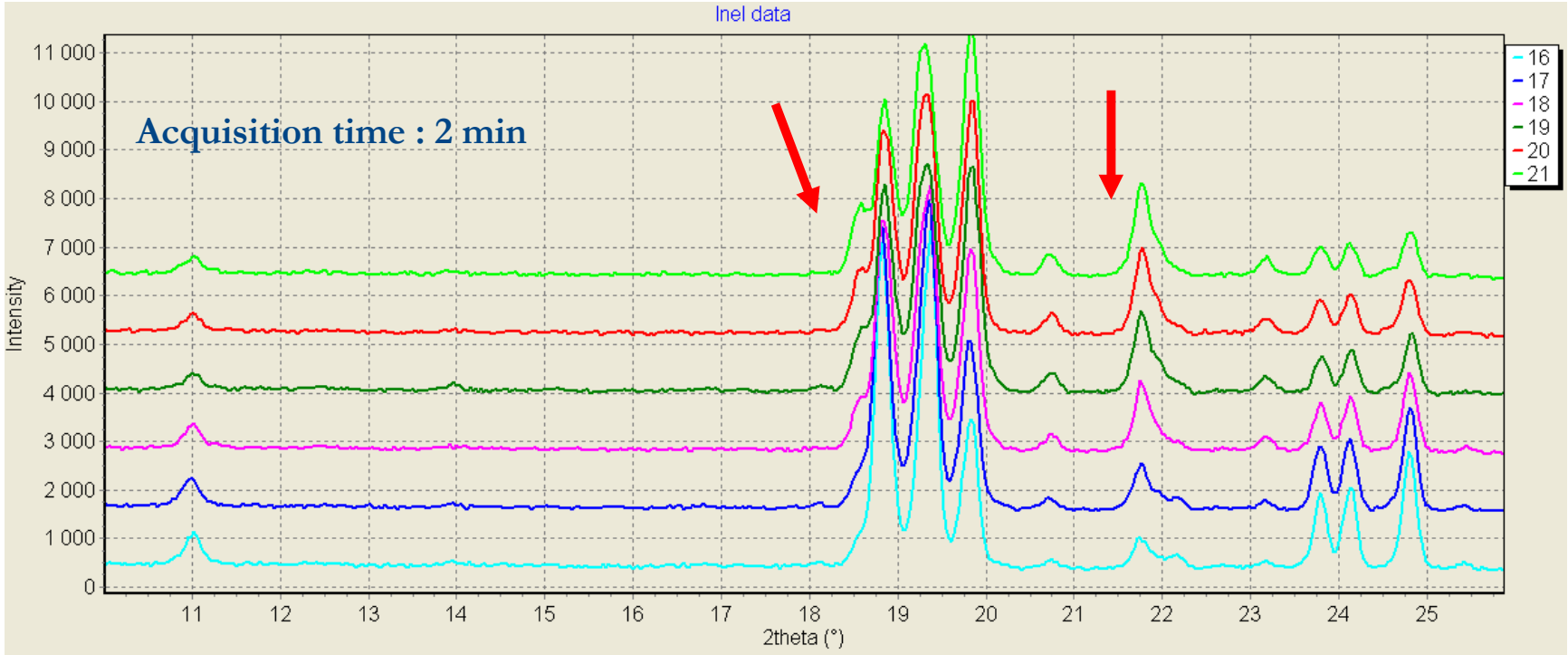
- Real time detection across 110°/2θ (CPS180)
- Monochromatic optics
- 3500 Watts generator
- External water cooling
- Working wavelength : Copper or Cobalt

Applications:

Qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation...

Quality control in detergent

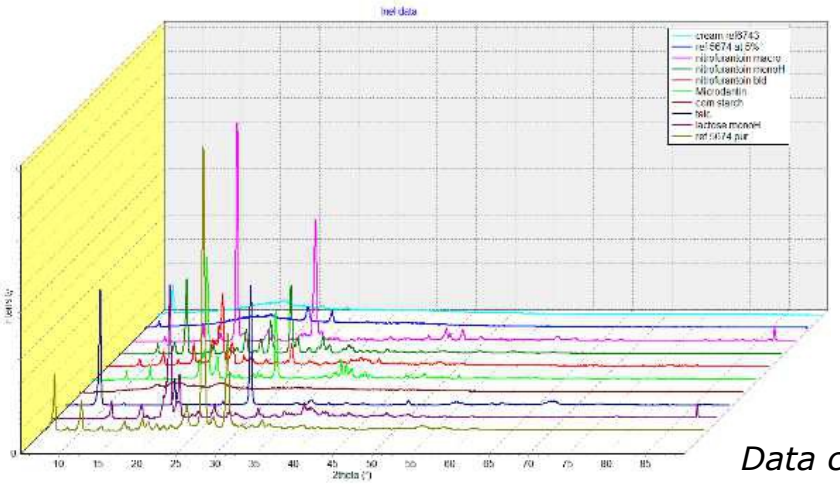
On the graph below, are represented diffractograms recorded for each sample. We can clearly evidence an increase of STPP 1 with the index (red arrows).



Sample	16	17	18	19	20	21
STPP I	17,67%	25,9%	40,9%	51,35%	51,17%	60,2%
STPP II	82,33%	70,7%	56,93%	45,23%	46,57%	37,93%
Other	0,0%	3,3%	2,17%	3,43%	2,27%	1,87%

Quantitative analysis has been performed by using the **Rietveld** method. Good reproducibility, and good agreement with other techniques (chemistry)

EQUINOX 2000, routine XRD



Data collection with sample changer

A routine diffractometer

with the EQUINOX 1000 performances and a bigger sample space, the EQUINOX 2000 enlarges your applications capabilities. You can now realize variable temperature and/or atmosphere measurements.

- Fast results
- Thermodiffraction (phases transitions, unstable compounds)
- Large sample space
- Real time detection across 110°/2θ (CPS180)
- Monochromatic optics
- 3500 Watts generator
- Working wavelength : Copper or Cobalt
- Environmental chambers (option)
- 30 positions auto-sampler (option)

Applications

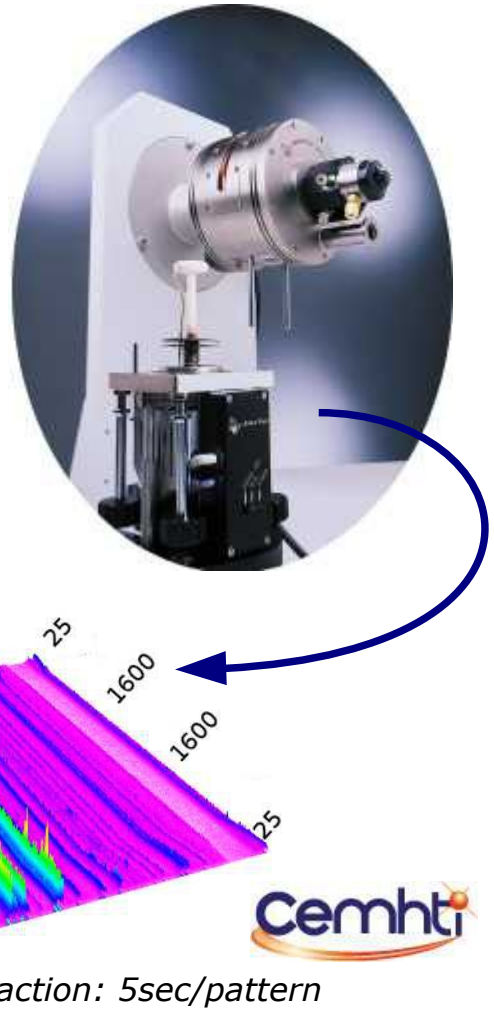
Qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation, phases transitions under variable environments, …

EQUINOX 3000, powder high resolution XRD

A fast, powerful and multi-purpose XRD

You are now able to realize variable temperature and/or atmosphere measurements, or even add a motorized sample holder to perform thin layer analysis.

- Evolutive depending on your needs
- Real time detection
  - CPS120 across 120°/2θ
  - CPS590 across 90°/2θ (High resolution)
- Monochromatic optics
- 30 positions autosampler (option)
- Environmental chambers (option)

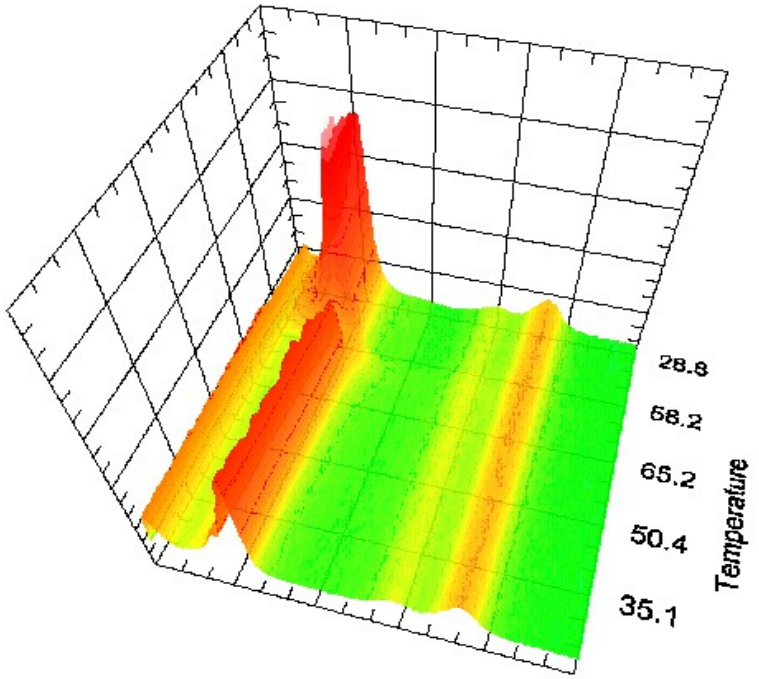


Thermal diffraction: 5sec/pattern

Applications

Qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation, phases transitions under variable environments, thin layer analysis, uniaxial stress analysis…

Phase transition at low 2θ



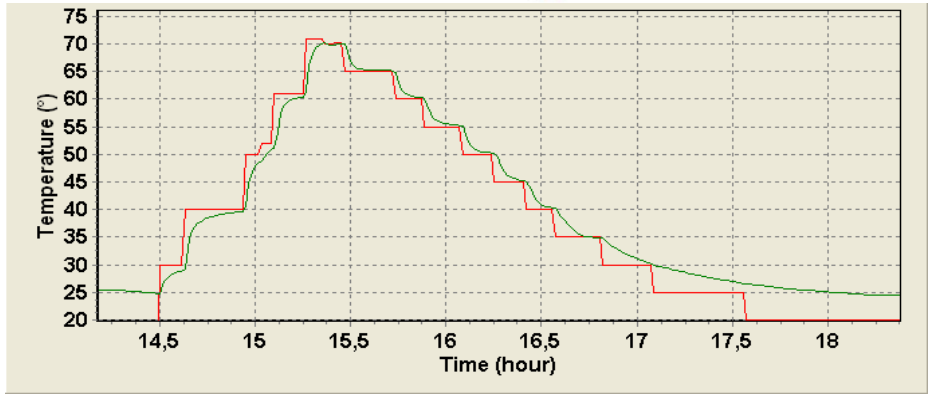
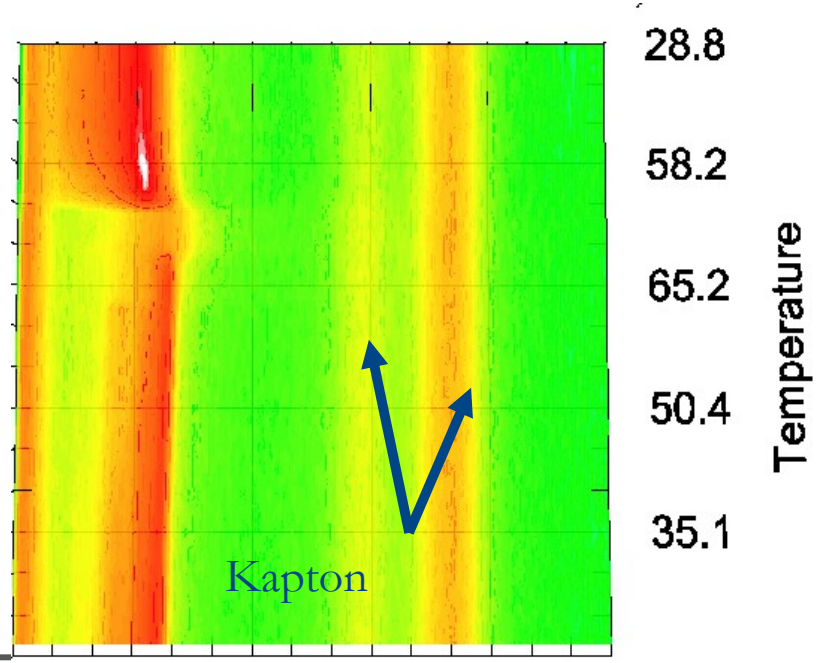


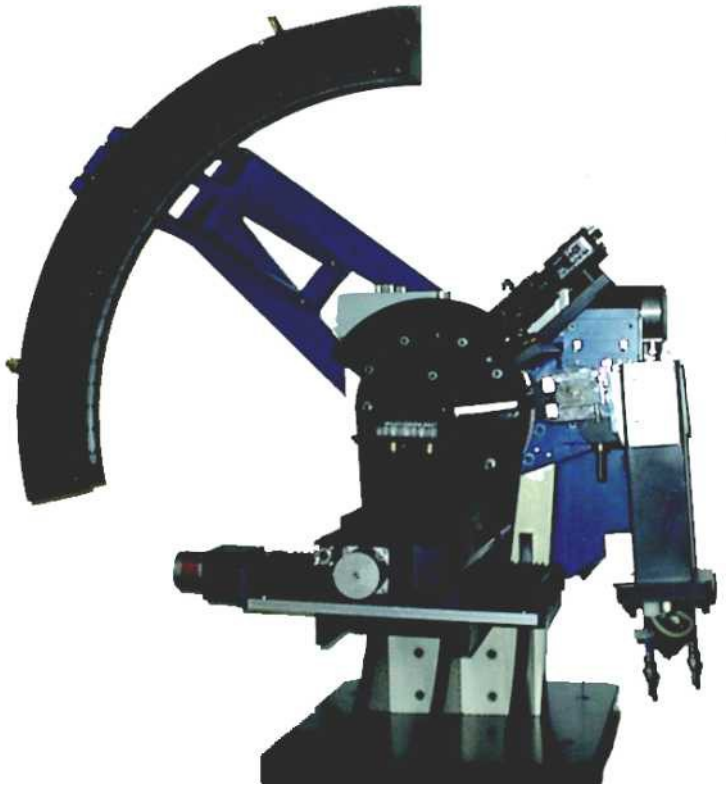
figure 1 : temperature profile : from RT to 70°C step 10°C and every 5°C while cooling down.

Source	: Copper
Generator	: 3,5 kW
Optique	: Parabolic mirror
Incidence	: Transmission (1mm capillary)
Sample holder	: non spinning furnace type FURCAP
Detector	: CPS120
power	: 35 kV – 35 mA
Acquisition time	: 3min
setting	: MPD

Transition at 70°C



EQUINOX 4000, DRX microdiffraction / cartographie

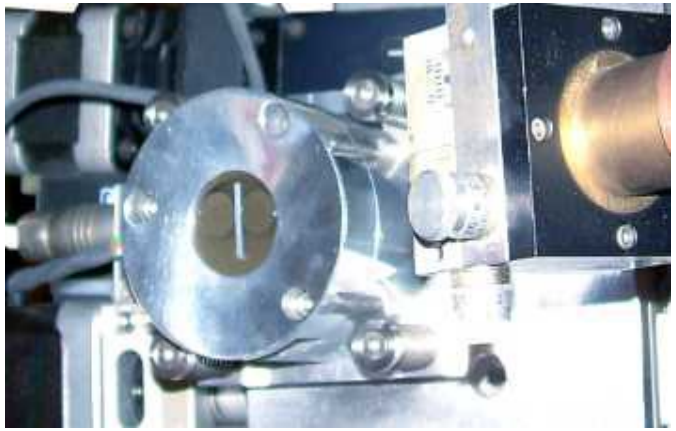


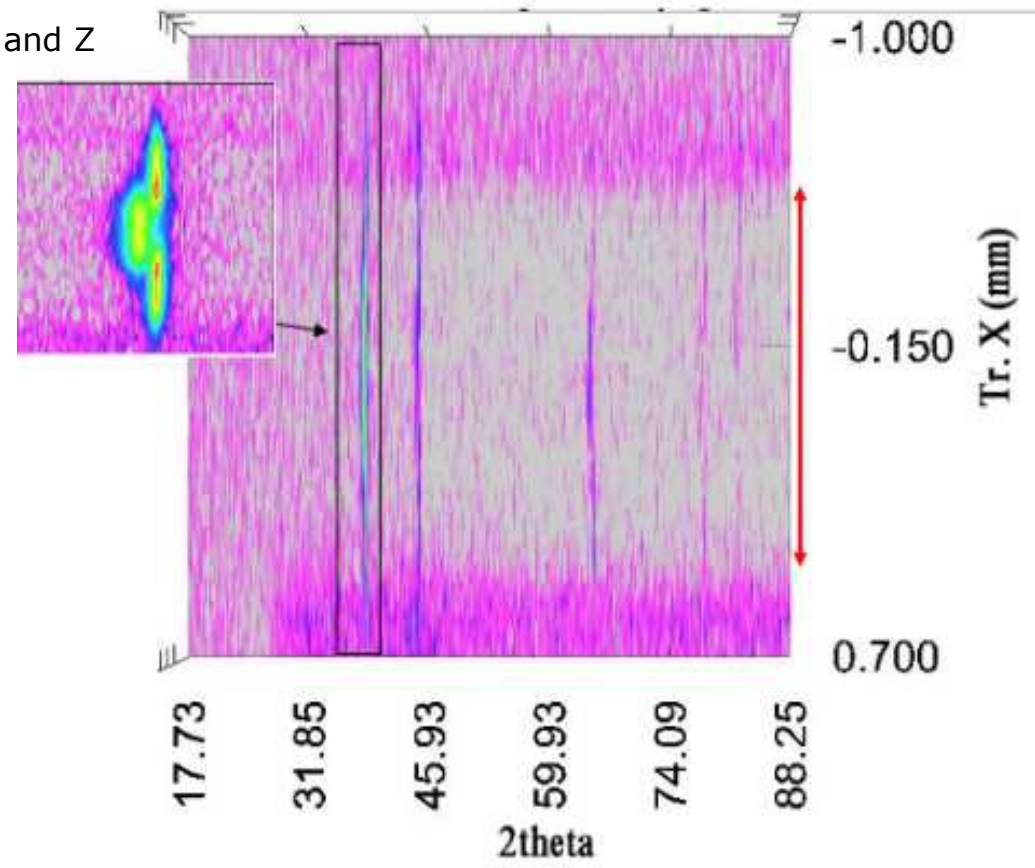
EQUINOX 4000 is designed for all your microdiffraction or mapping applications. The instrument uses X, Y and Z translation stages with strong travel.

- Real time detector (CPS 120)
- θ / 2θ goniometer with large stages X, Y and Z
- Working wavelength : Copper or Cobalt

Applications

Microdiffraction, mapping...





Microdiffraction on the edge of an aluminum plate

Experimental: Beam size: 20mic, Power : 1200W
Acquisition : 120sec/pattern

EQUINOX 5000, high resolution XRD

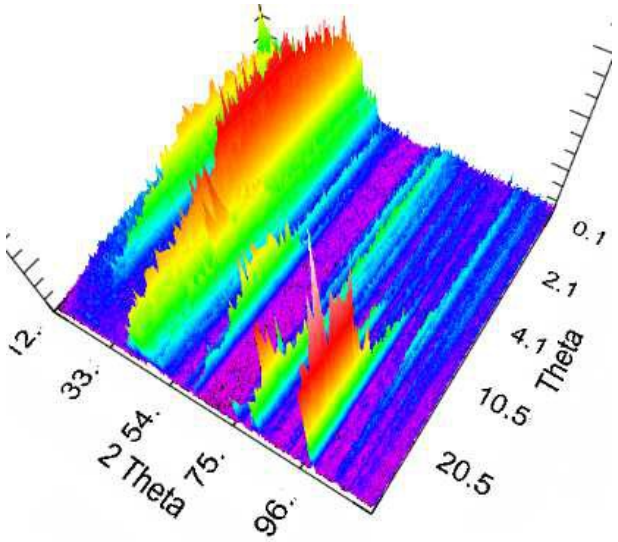
A high resolution diffractometer

for all your powder analysis under variable temperature and/or atmosphere that require a very high resolution.

- θ/θ or θ/2θ 2 circles goniometer
- High resolution detection (CPS 590)
- Environmental chambers (option)

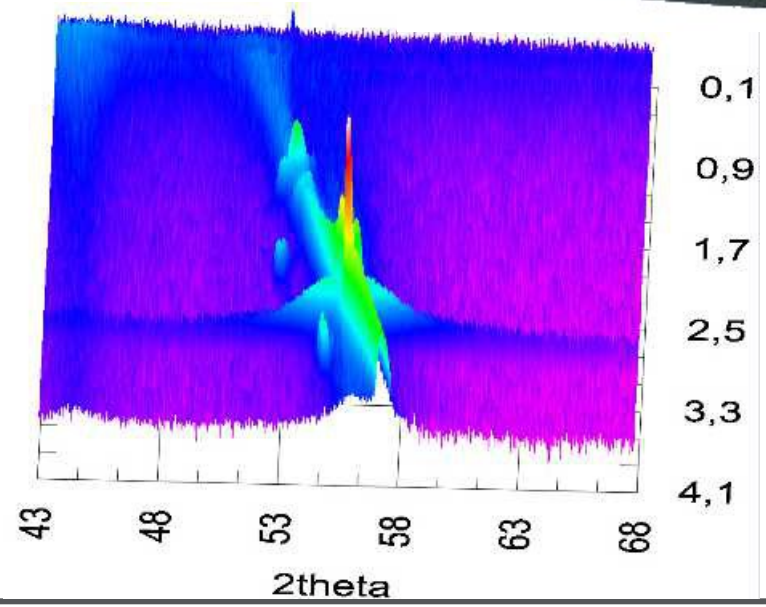
Applications

Qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation, phases transitions under variable environments, thin layer analysis, uniaxial stress analysis…



Coating on stainless steel

Thin film analysis



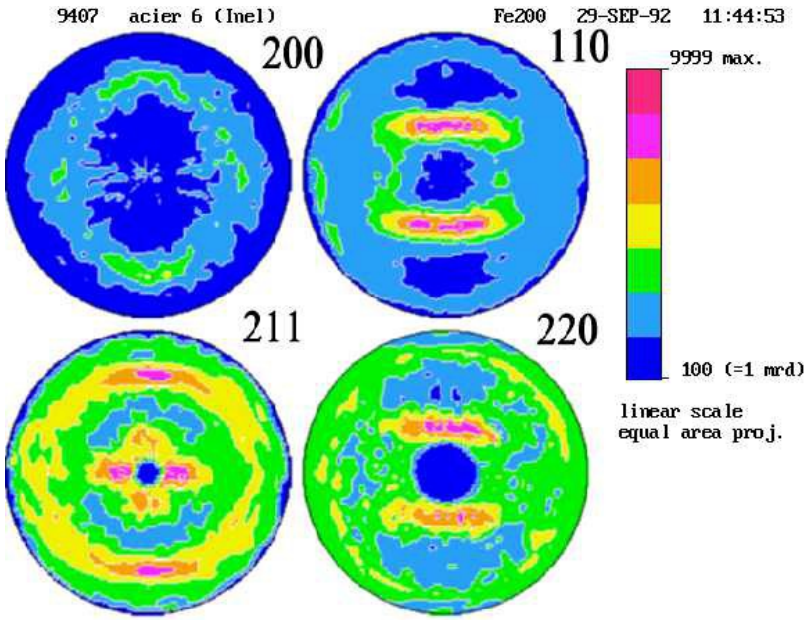
ThermoFisher SCIENTIFIC

EQUINOX 6000, 4 circles texture/stress XRD

4 circles X-ray diffractometer

Ideal for all your 4 circles goniometer X-ray diffraction applications.

- Robust and multi-purpose goniometer
- Heavy loads accepted on every movements
- Large sample space
- Real time detection (CPS590)
- 4 circles goniometer (θ, 2θ, χ, ϕ)
- Collimating monochromatic optics
- 3500 Watts generator
- Variable working wavelength
- Temperature chambers (option)



Texture analysis on stainless steel foil

Applications

Texture, stress, thin layer, qualitative & quantitative analysis, phases identification, structure determination, crystallites orientation, phases transitions under variable environments, microdiffraction…

SWAXS, SAXS WAXS instrumentation

- Evolutive mounting
- Variable sample/detector distance
- Specific supports and chambers available
- 1D or 2D detection with dedicated software

Applications

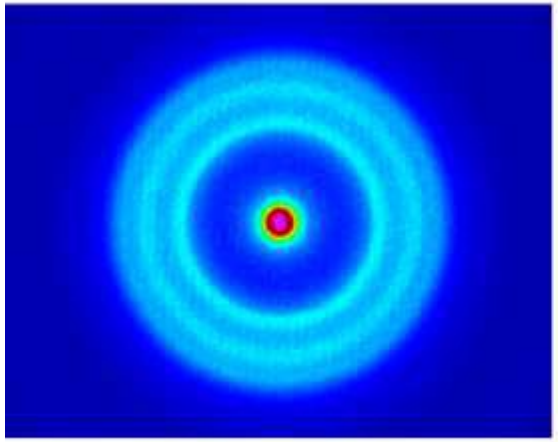
Colloids, metals, cement, clays, oil, polymer, plastics, proteins, pharmaceutical industry...

Small Angles X-ray Scattering

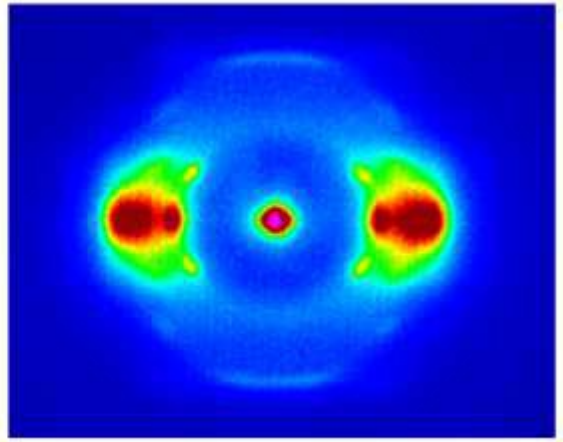
To better answer its customers needs, Inel designed a flexible SAXS line to make textured samples analysis or small angles scattering.

This technique is used to determine particles structure at nanometric range (size, form, distribution...). Studied materials can be solid, liquid or gas. This non-destructive method is accurate and requires usually only a minimal sample preparation.

It can be used as well for research as for QA/QC.



PET semicristallin (30%)



PET semicristallin (30%) déformation 1,4

Laüe back reflection diffractometer

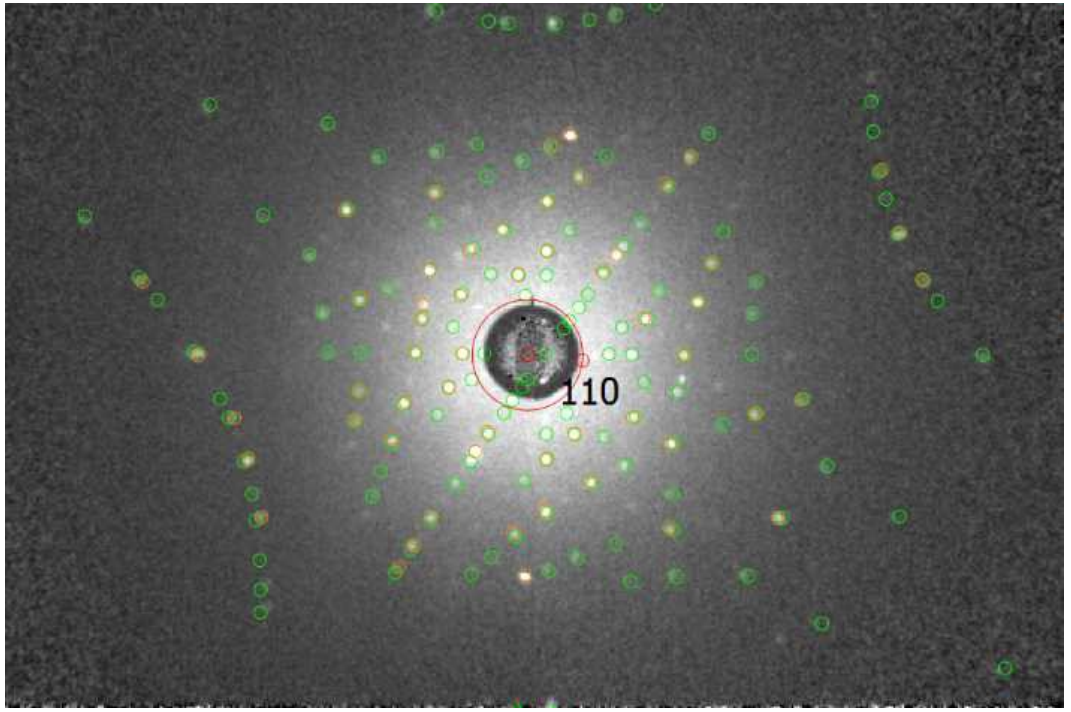
A fast tool for cristal orientation

Easy sample positionning

Fast acquisition

Fast orientation determination

Sample holder can be customized according to cristal



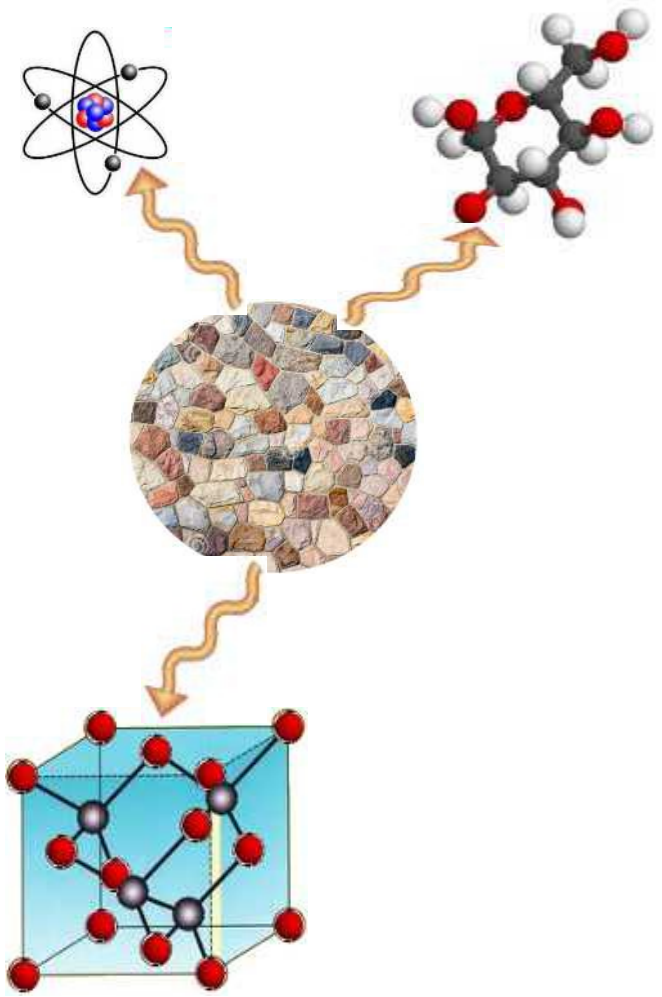
Si220 orientation

Instruments combination

Inel XRD flexibility

Combining X-ray diffraction with other techniques:

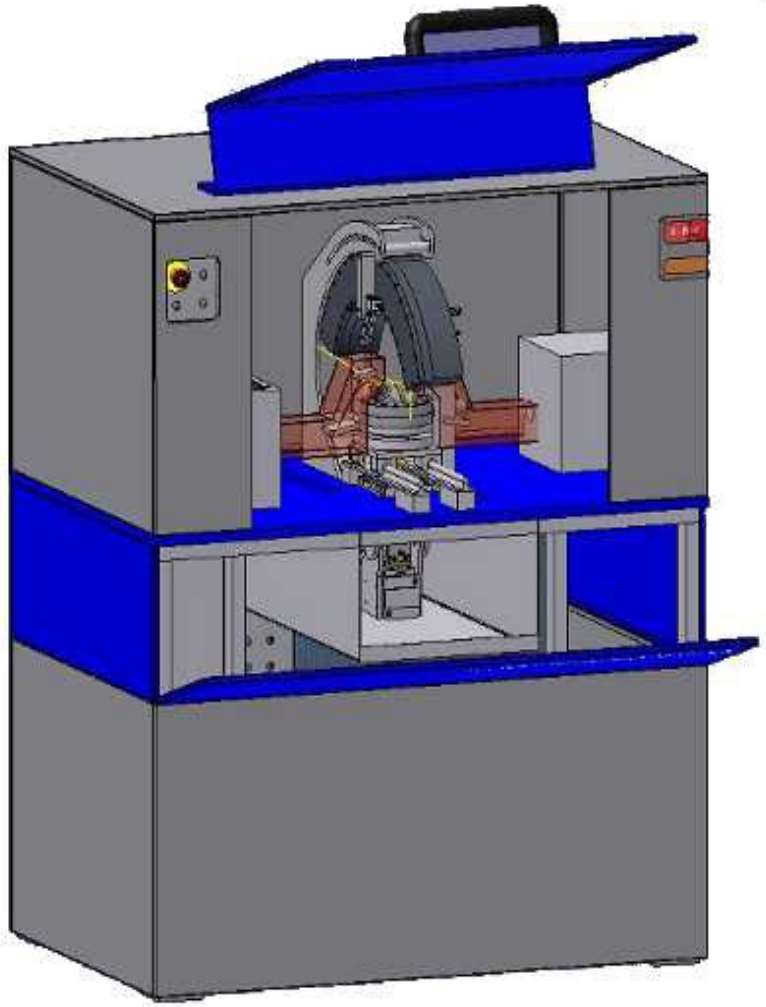
- One sample and several datas
- Real time analysis
- XRD comes to sample
- XRD for on line industrial control



Inel portable XRD systems:

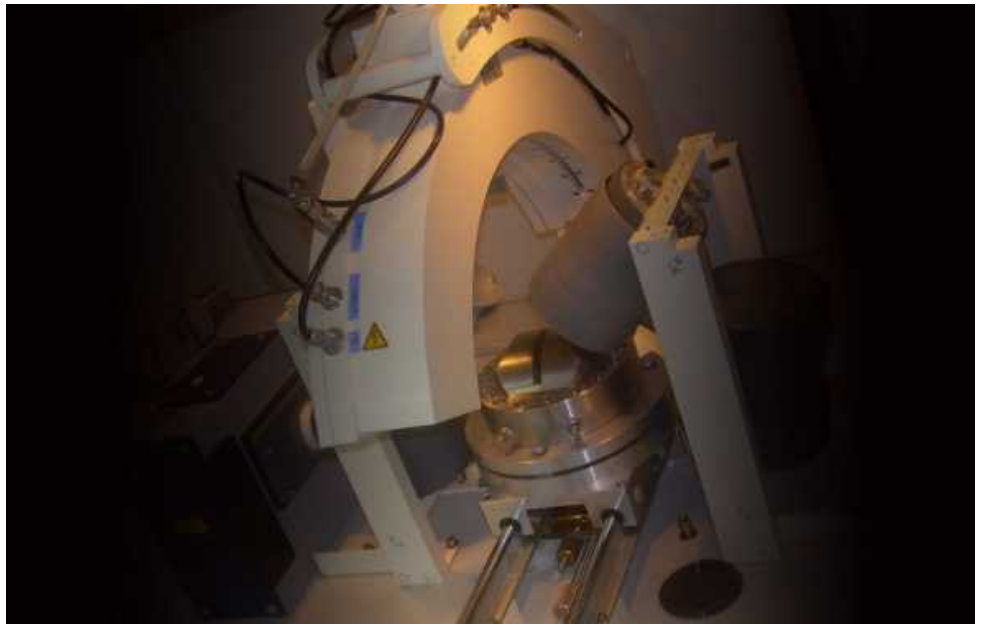
EQUIRAM	Combination of XRD and Raman spectrometer
XRD/DRIFT	Combination of XRD and DRIFT spectrometer
STRESS/WAXS	Combination of WAXS and stress analysis
SWAXS	SAXS WAXS diffractometer
COSMA	On-line production control XRD
PRECIX	Robotics for XRD residual stress measures

XRD/DRIFT combination

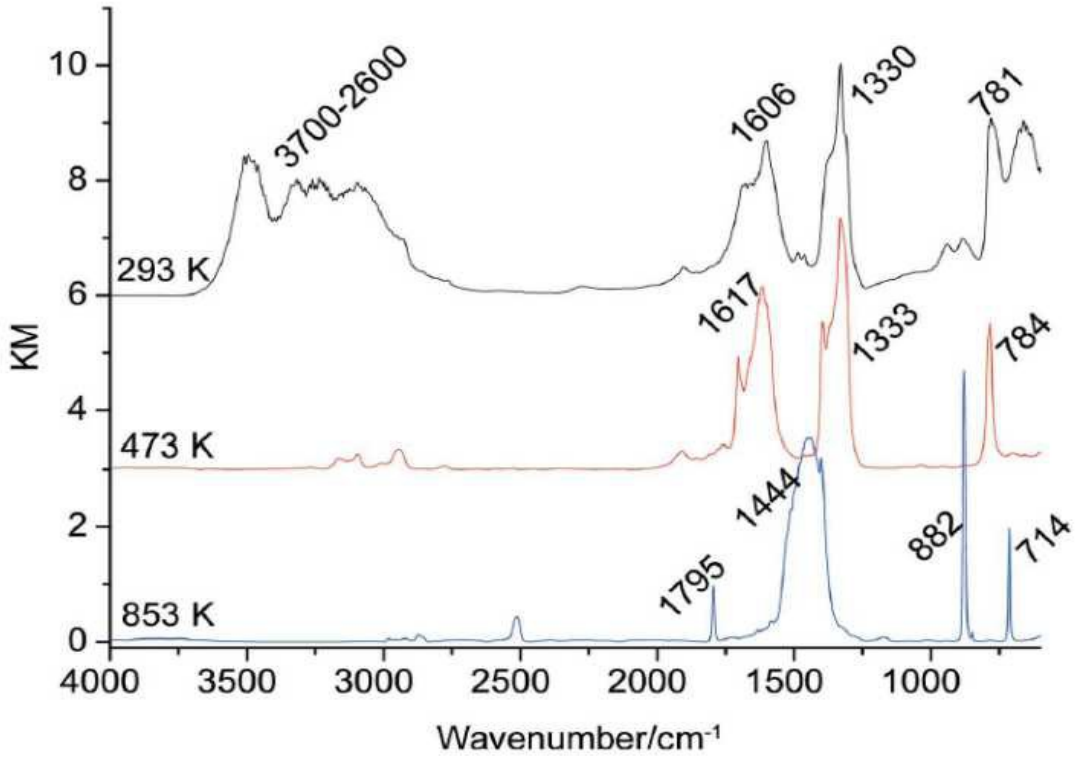


Phase transitions observation

- Development of a laboratory system, combining XRD and DRIFT, to perform in-situ measurement
- Development of an adapted environmental cell pressure-temperature
- Concept of instrumented system, with an appropriate expert software
- XRD in transmission with Mo radiation
- IR spectrometer in reflection (DRIFT)
- Sample cell with pressure/temperature, and gas mixing.



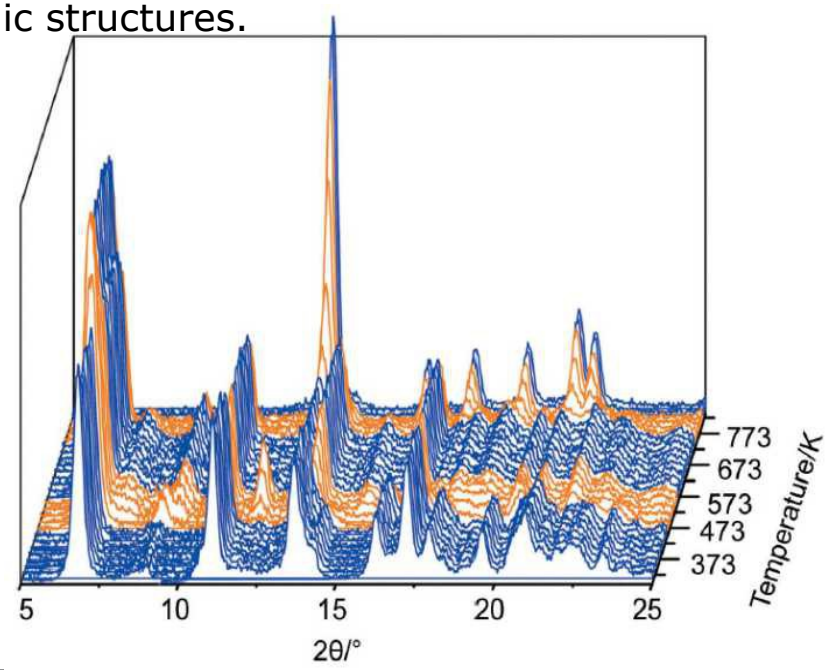
XRD/DRIFT combination



"*An X-ray diffractometer coupled with diffuse reflectance infrared Fourier transform spectroscopy and gas chromatography for in situ and in operando characterization: an innovative analytical laboratory instrument*", L. Braconnier, I. Clemencon, C.Legens, V.Moizan, F.Diehl, H. Pilliere, P. Echegut, D. De Sousa Meneses and Y. Schuurman, J. Appl. Cryst. (2013). 46, 262–266

DRIFT spectra recorded during thermal decomposition of calcium oxalate (50 mg, 5 Kmin1).

X-ray diffraction patterns recorded during the thermal decomposition of calcium oxalate (50 mg, 5 K min1) Blue traces represent stable crystallographic phases and orange diffraction traces indicate intermediate crystallographic structures.



Some developments

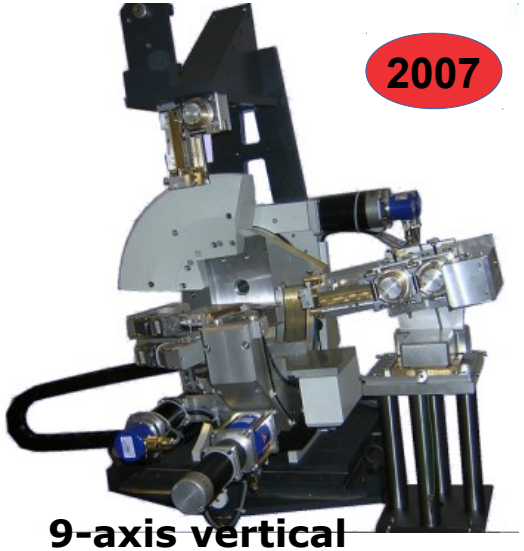
1997

COSMA, on-line XRD control of cement

2006

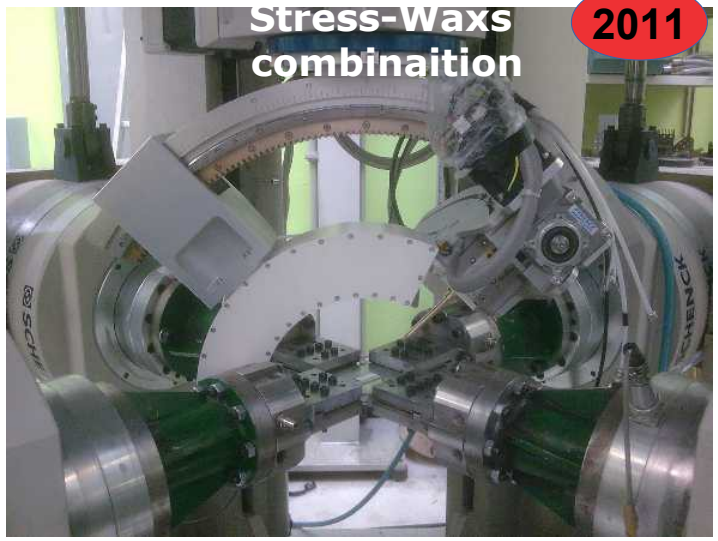
PRECIX for in-situ stress measurement

2007

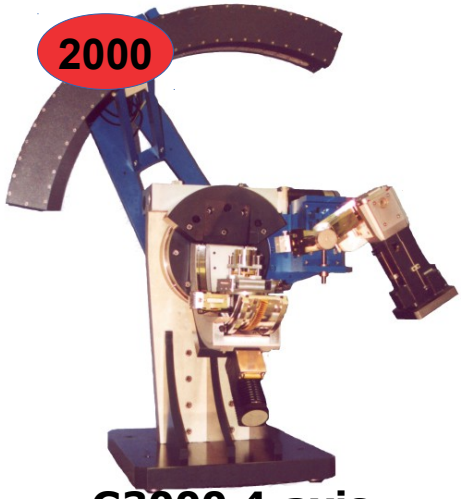


9-axis vertical goniometer for Epitaxy

2011

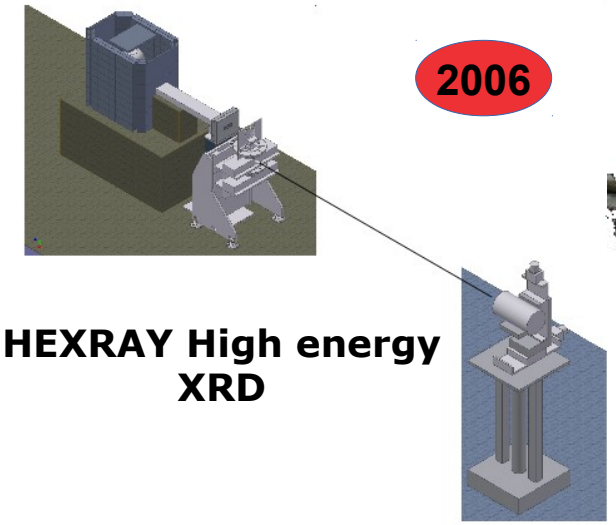


2000



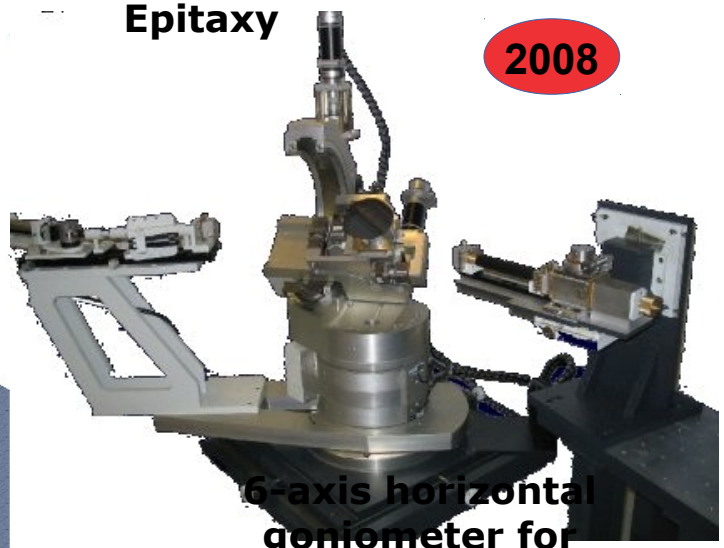
G3000 4-axis goniometer

2006



HEXRAY High energy XRD

2008



6-axis horizontal goniometer for Epitaxy

2010

ThermoFisher SCIENTIFIC

XRD combining

Interest of combining

- sample is a complicate mixture : XRD+XRF, XRD + Raman

- complementarity to observe phase transition: XRD + IR, XRD + Raman, XRD + DSC

- relationship between mecanical properties and structure : texture + stress

- many other combinations …

Advantages

- 1 sample for several measurements, but 1 result

- eliminating non possibilities (XRF prefiltering before search match)

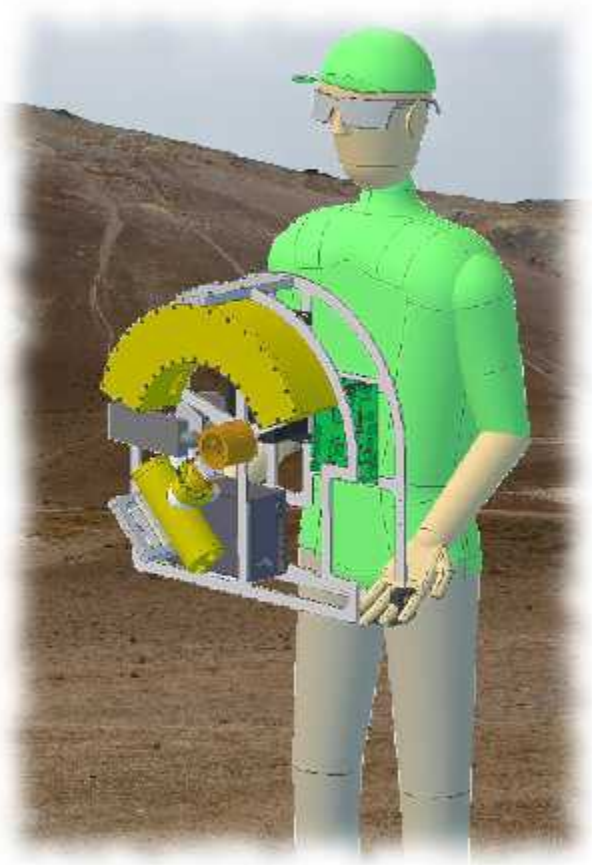
- ...

Since 2010, wedlock between PSD detector and X-ray minisource

XRD « escapes » from laboratories

Combining X-ray minisource and CPS detector:

- Low consumption XRD
- Robust instrument
- No external water cooling
- Works on standard power supply



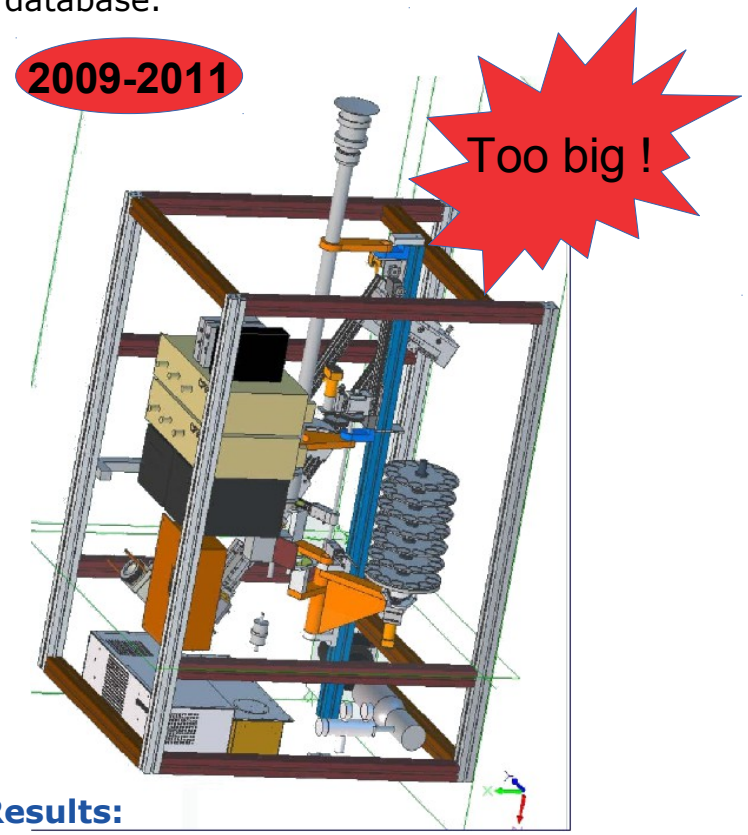
Inel portable XRD systems:

EQUINOX 100	Stand alone benchtop XRD
Enviromonitor	Aerosol quantification expert system
XSOLO	Nomadic Stress System
Equinox Trail	Rackable XRD
SOLXPERT	Portable XRD/XRF system for in field applications

Granted projects to develop ideas

Nanoair Project: (FP7 222333). Design of a prototype, composed by a combination WAXS/SAXS XRD device. Birth of FPSM software (deviation of MAUD), for automatic phases identification and quantification by using the Rietveld method and the COD database.

2009-2011



Results:
Partial feasibility
New automatic software for data treatment

Enviromonitor project: (FP7 SME-2011-3 CP grant agreement N° 286570) for the realization and miniaturization of a mobile system for aerosol sampling and analysis.

2012-2014

Results:
Feasibility in certain conditions
Performance in miniaturization
Target market not clearly visible

Equinox 100: Bench top XRD

Secondary results:
Optimization of a low power bench top XRD

Granted projects to develop ideas

XRD integration in mobile lab

Mobile lab start to be developed, in order to improve the reactivity in the decision.

- Compact instrumental part
- 19” electronic part

Applications

Environment, geology, police, industry...

SolXpert, innovation to serve field expertise

Combining XRD-XRF for in-field measurements

Total power : 200 W

Applications

Environment, geology, police, industry...

Goal of software,

Driving instruments

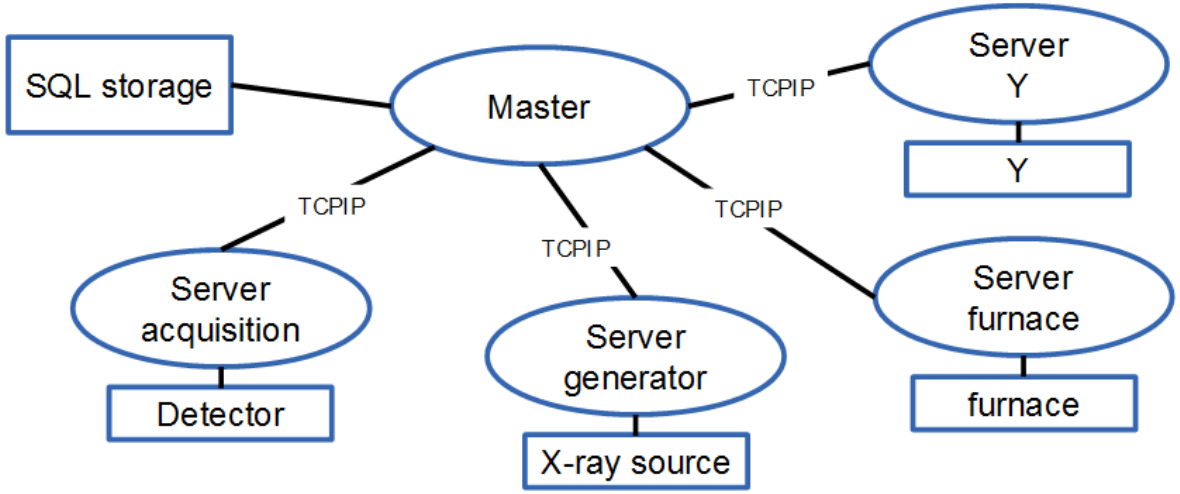
And

Assistance in methodology

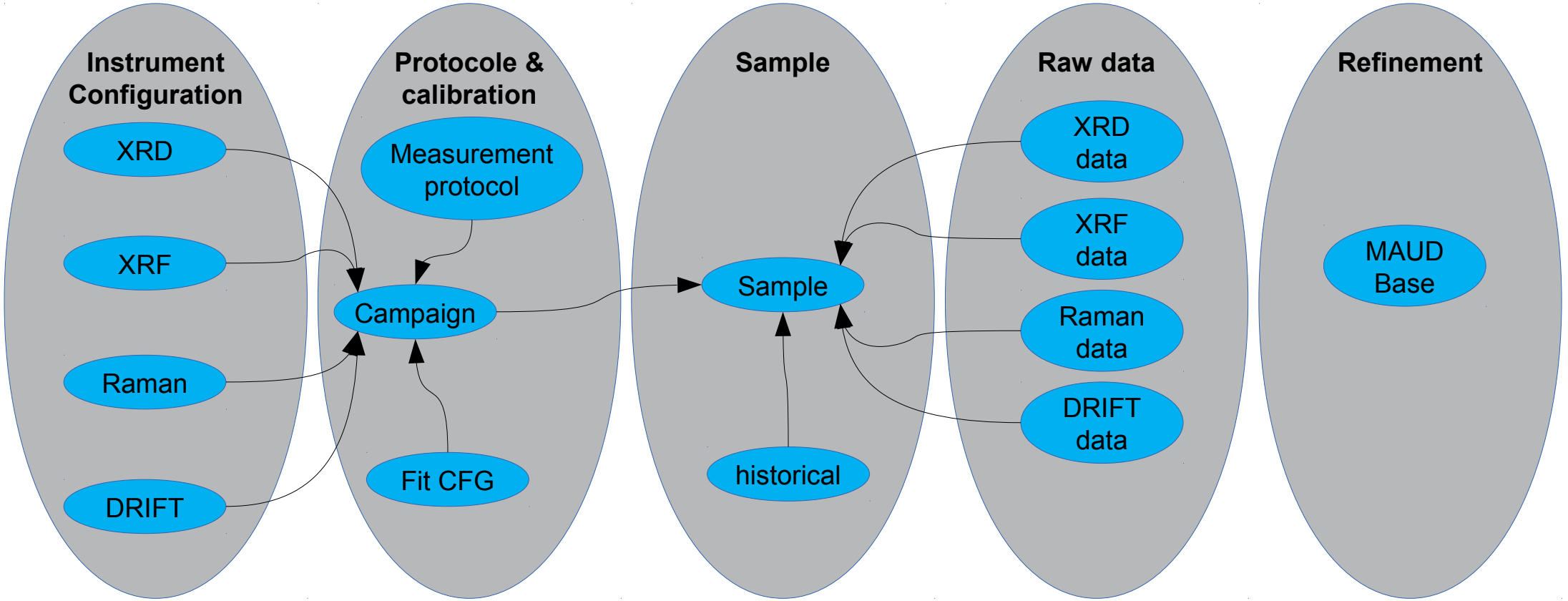
Software in the future

Development of instrument control software

UNIVERS : from 2013, transition to more universal software :
- data storage (configuration, sample description, raw data and refined data in a unique SQL database)
- sub-programs drive components (servers)
- Master communicates with servers in TCPIP



Development of instrument control software



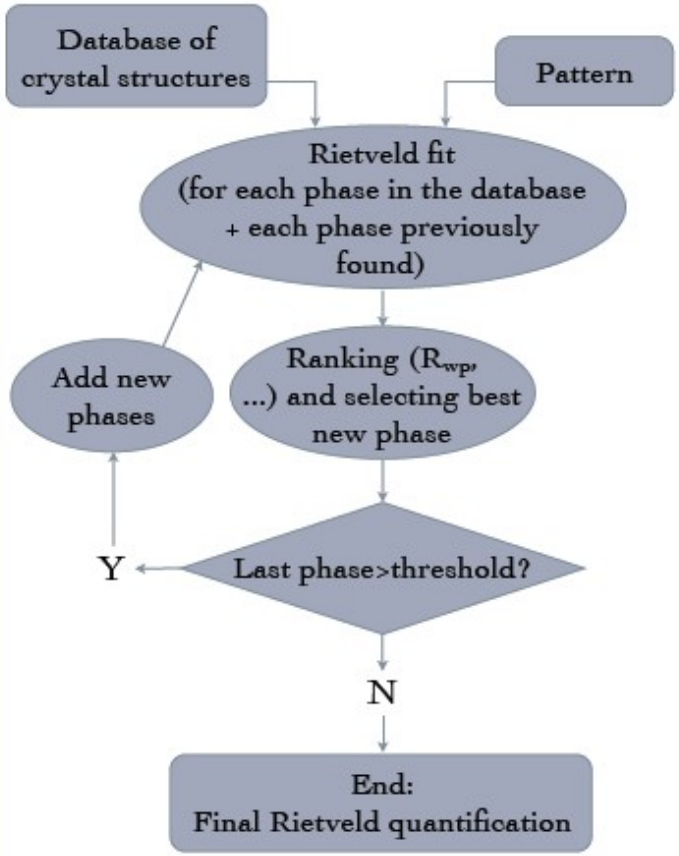
UNIVERS : from 2013, transition to more universal software :
- data storage (configuration, sample description, raw data and refined data in a unique SQL database)
- sub-programs drive components (servers)
- Master communicates with servers in TCPIP

Innovative software for search-match

Not yet launched.

The FPSM (Full Pattern Search-Match method)

Developed inside the Nanoair project for the portable instrument

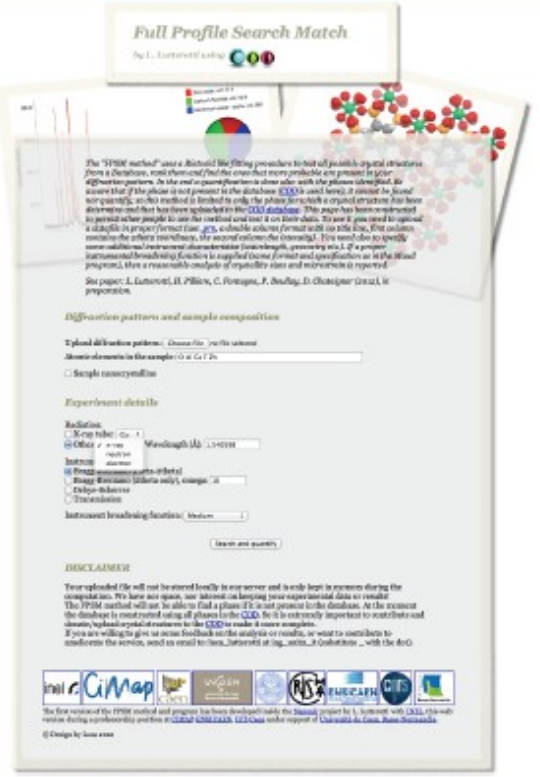


Pro:

- No user intervention, automatic analysis
- No peaks identification required (works with nano materials/particles
- Full Rietveld quantitative analysis provided
- Works for neutron and electron diffraction

Cons:

- Only phases with know crystal structure are ready to be used (unknown structures require a list of peaks and calibrated intensities, PONKS)
- Available databases are still uncompleted
- If no elemental composition provided → requires > 20 minutes on 12 cores computer
- Good ranking algorithm required for very small phase amount

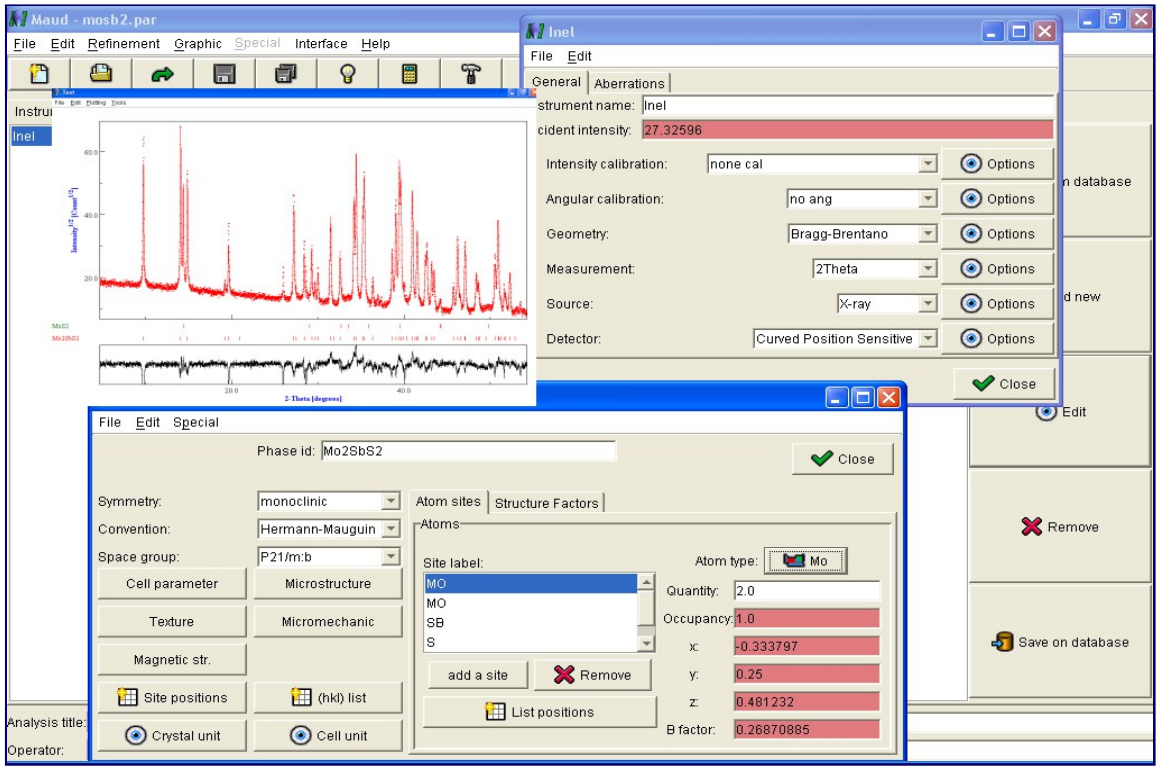


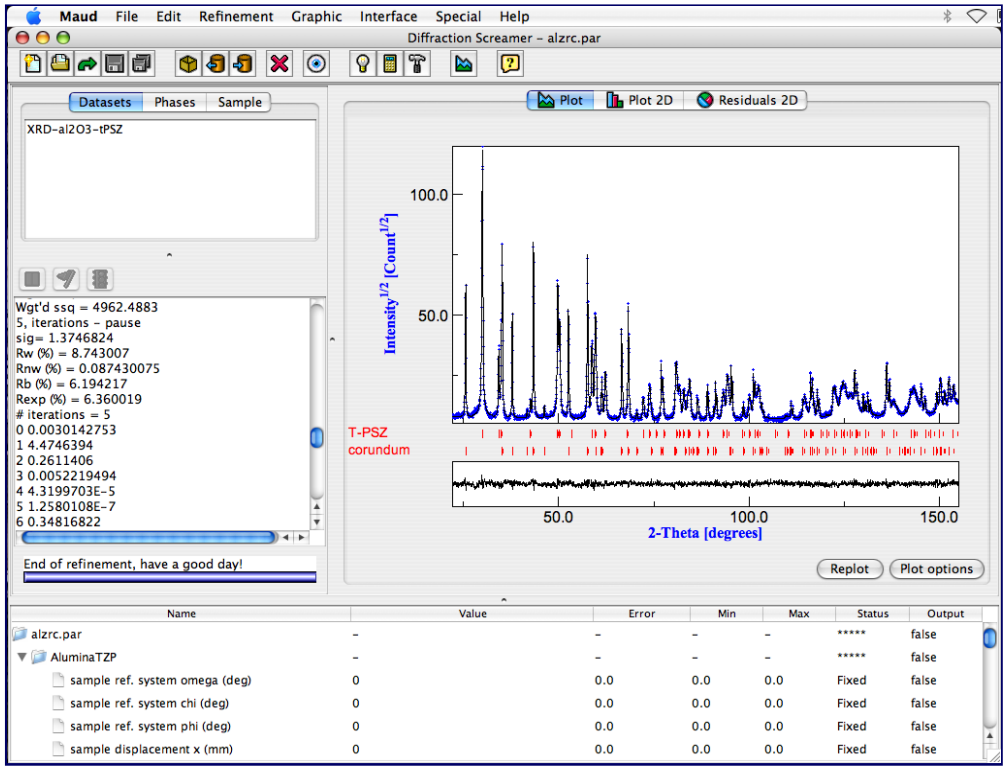
A demo version has been setup online at:
http://nanoair.ing.unitn.it:8080/sfpm
search and quantification is limited by the time required (or better server response time) so it should be used restricting the composition as much as possible to speed up computation. A limited number of concurrent connections are supported also. INEL SAS can be inquired for the full version.

See also the demo at the Software Fayre on tuesday afternoon

Innovative software for Rietveld refinement

Free software





Originalities :

- combined refinement with XRD method (powder, texture, stress, grazing …)
- combined refinement with other techniques (XRF)

New concepts for the future

- Light instruments
- Expert system because of measurement/modeling combination
- Low power
- Applications designs
- Technics combination
- Unique software for expertize : MAUD

Thank you for your attention

This presentation has been made using only opensource software, so if it didn't work as expected that's normal...