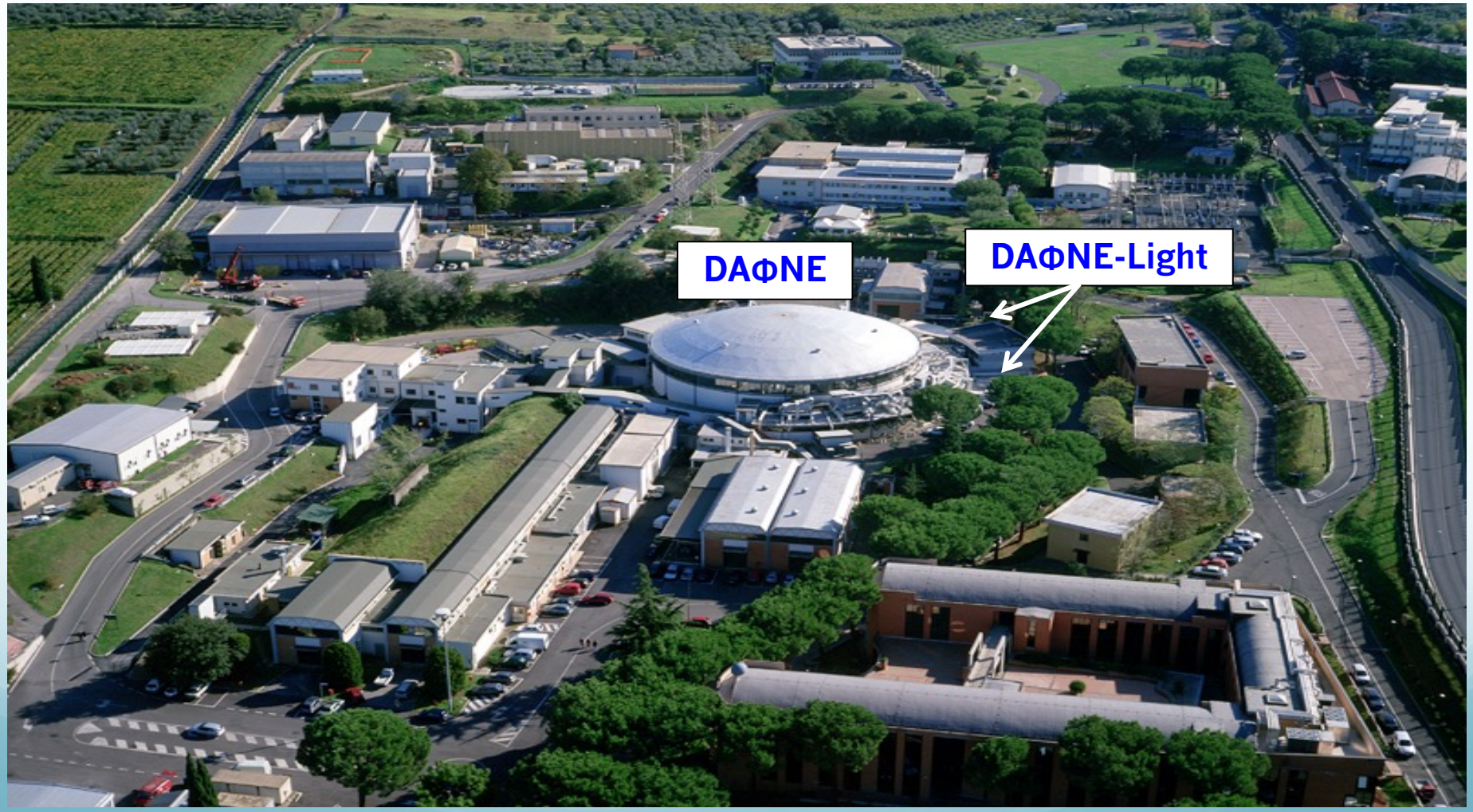
X-Ray Activities @ DAΦNE-Light

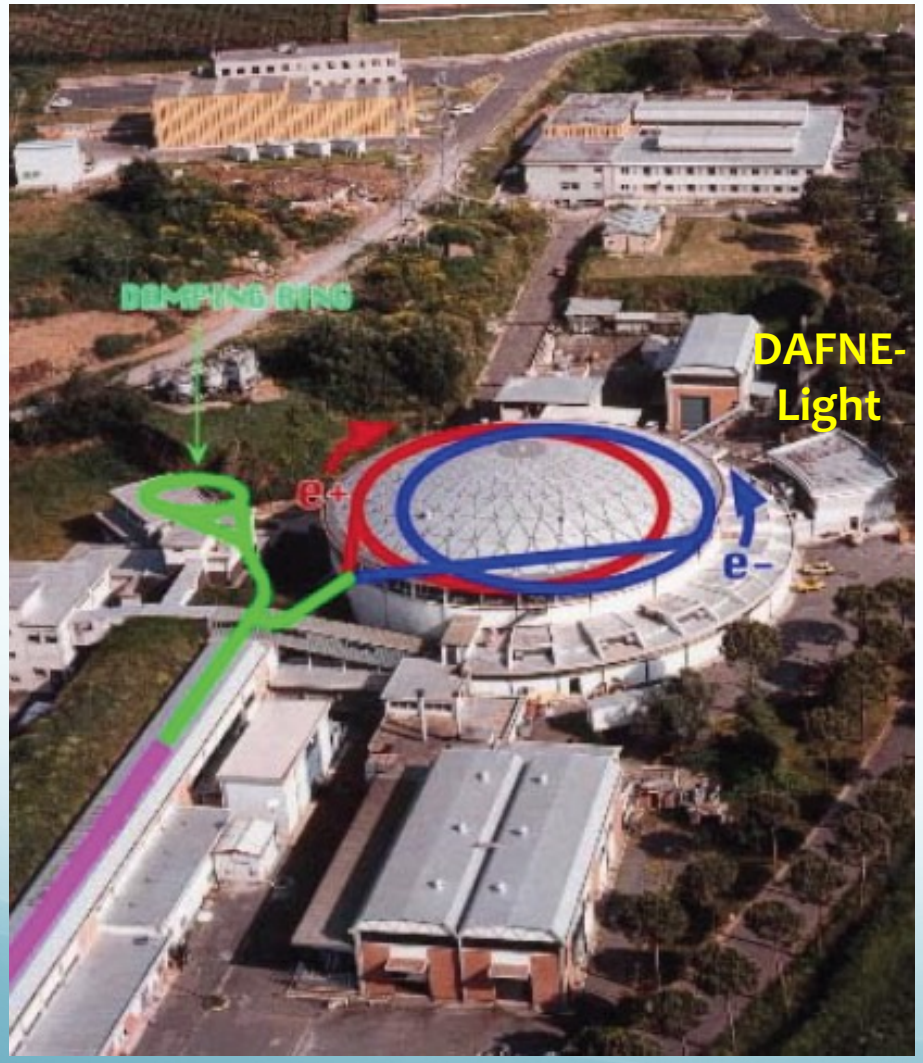
Antonella Balerna

INFN-LNF DAΦNE-Light Synchrotron Radiation Facility

DAΦNE-Light
INFN-LNF Synchrotron Radiation Facility



DAΦNE



Double Annular Φ factory for Nice Experiments

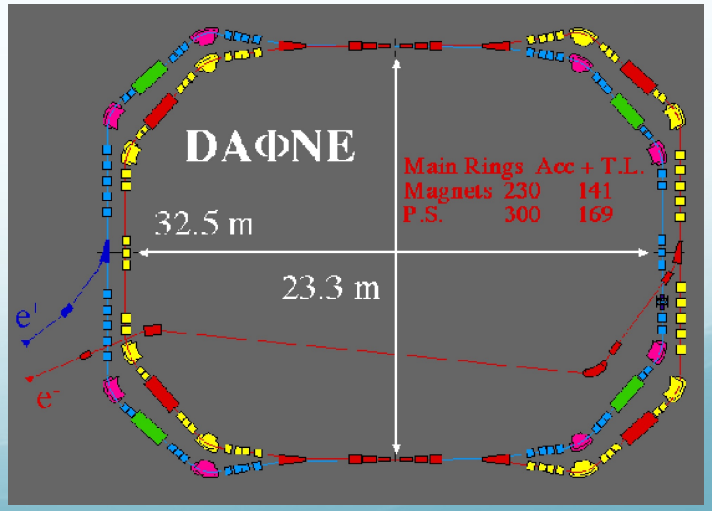
DAΦNE is a two rings e+/e- collider, with two interaction regions.

Energy = 0.51 GeV

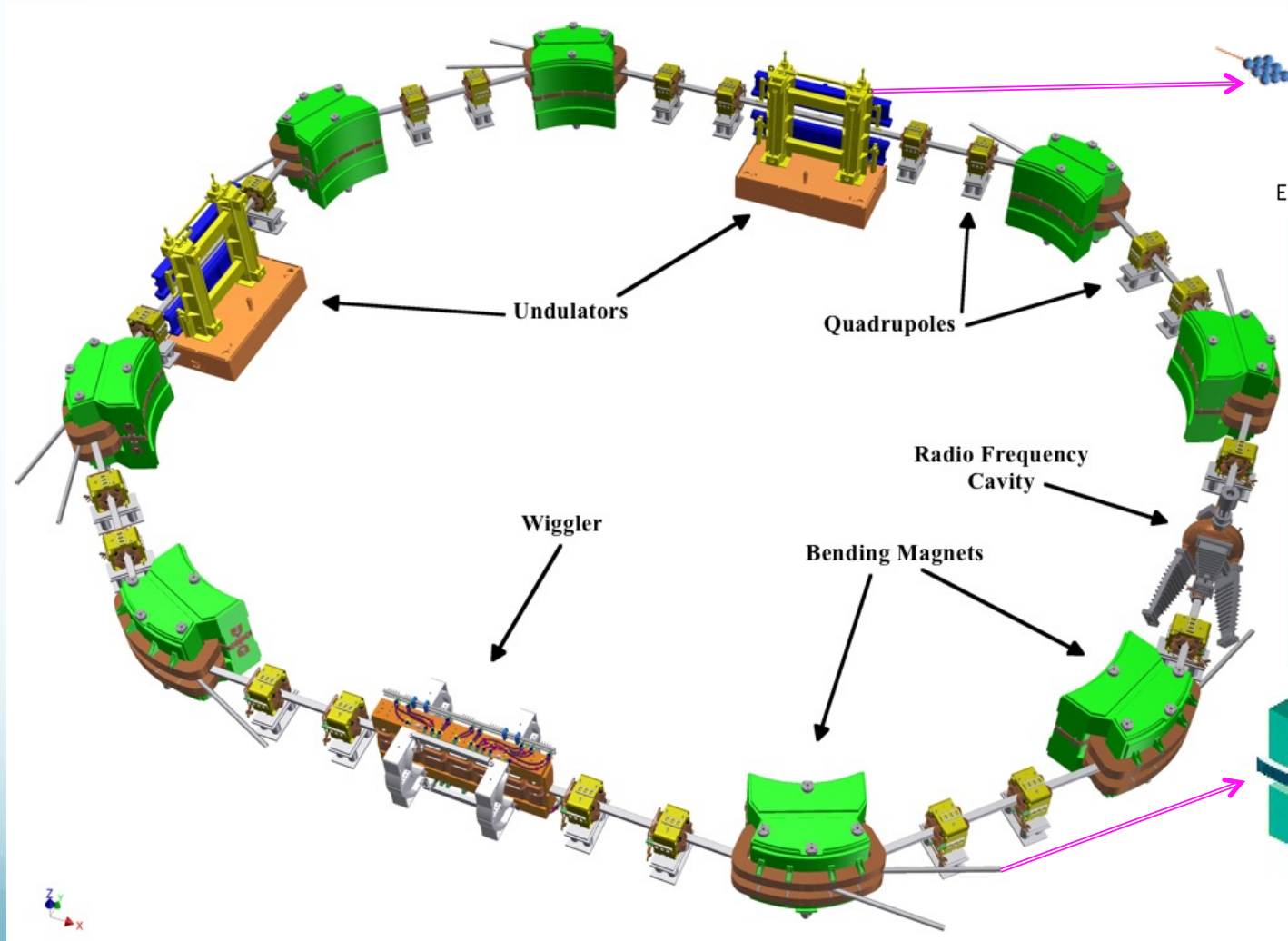
Circumference = 97.7 m

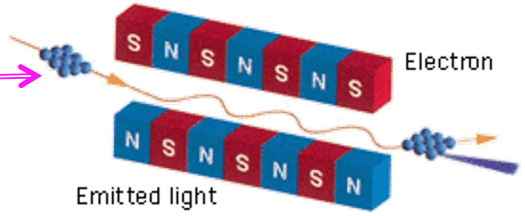
I > 1500 mA e-

I > 1000 mA e+



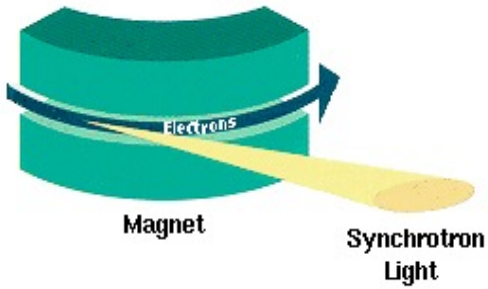
Synchrotron light and relativistic particles accelerated in circular orbits.





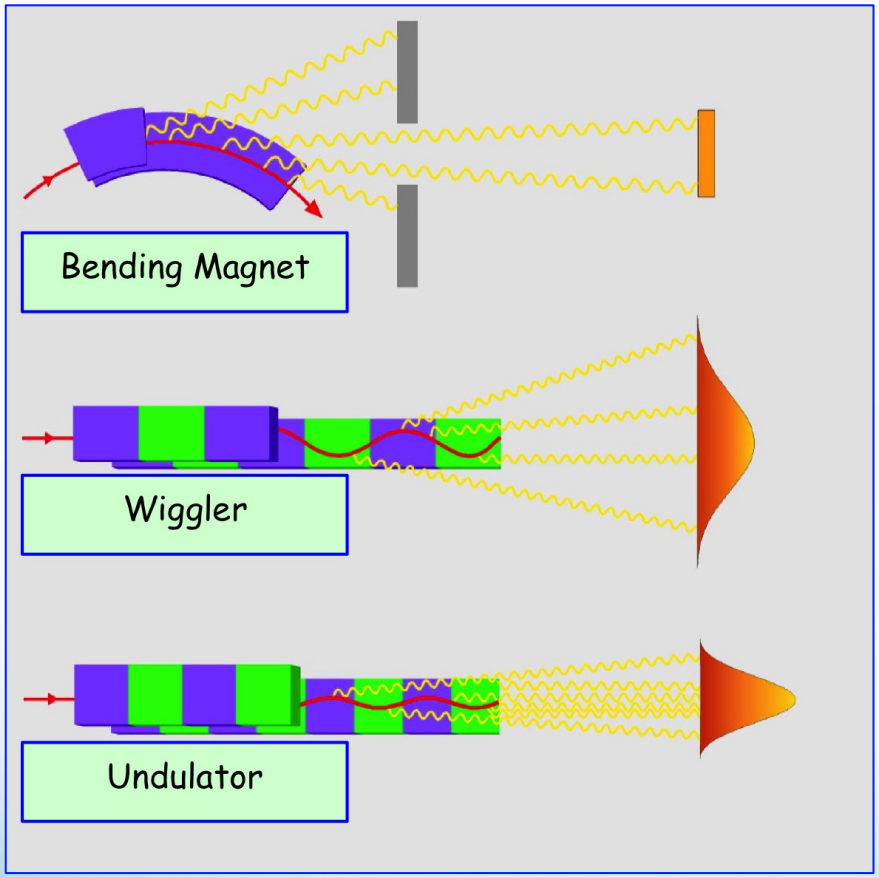
Insertion Devices : wigglers and undulators

Bending Magnet

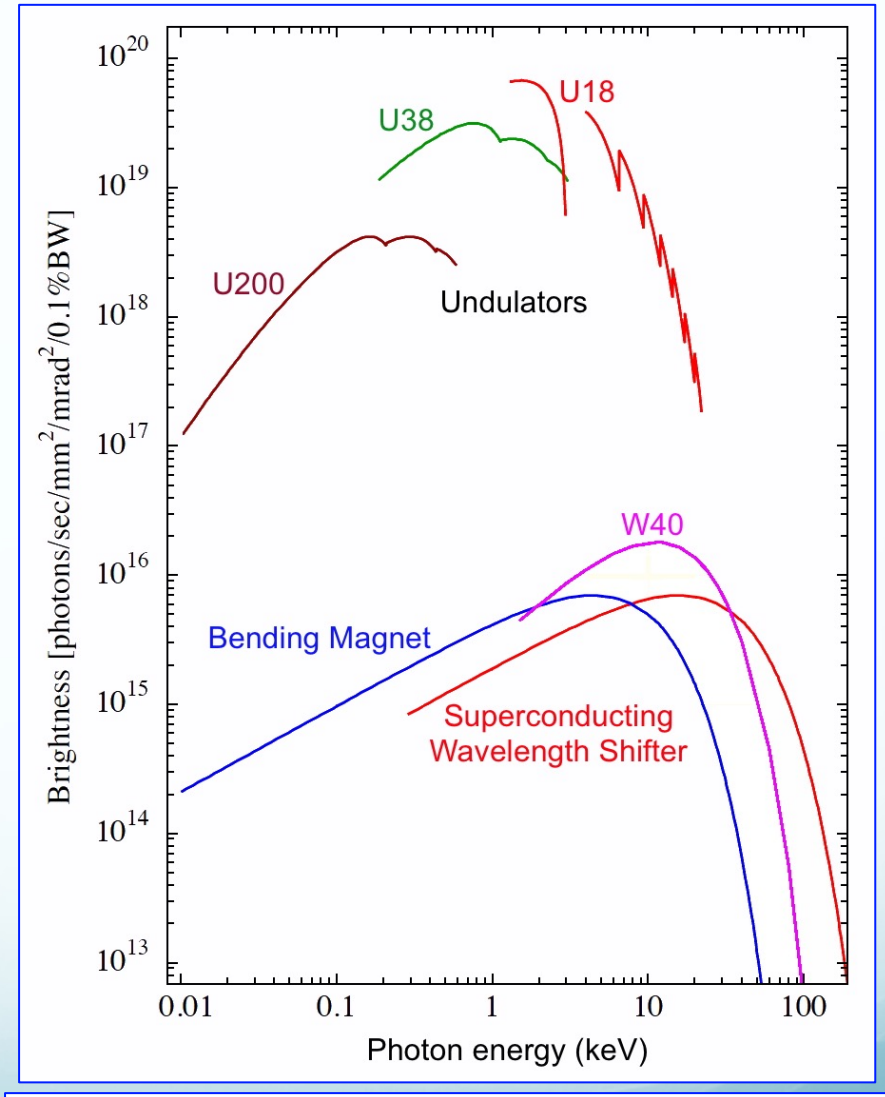


… and synchrotron radiation is also the coherent radiation emitted by the undulators of Free Electron Lasers (FELs) .

Comparing the achievable brightness



Courtesy DESY

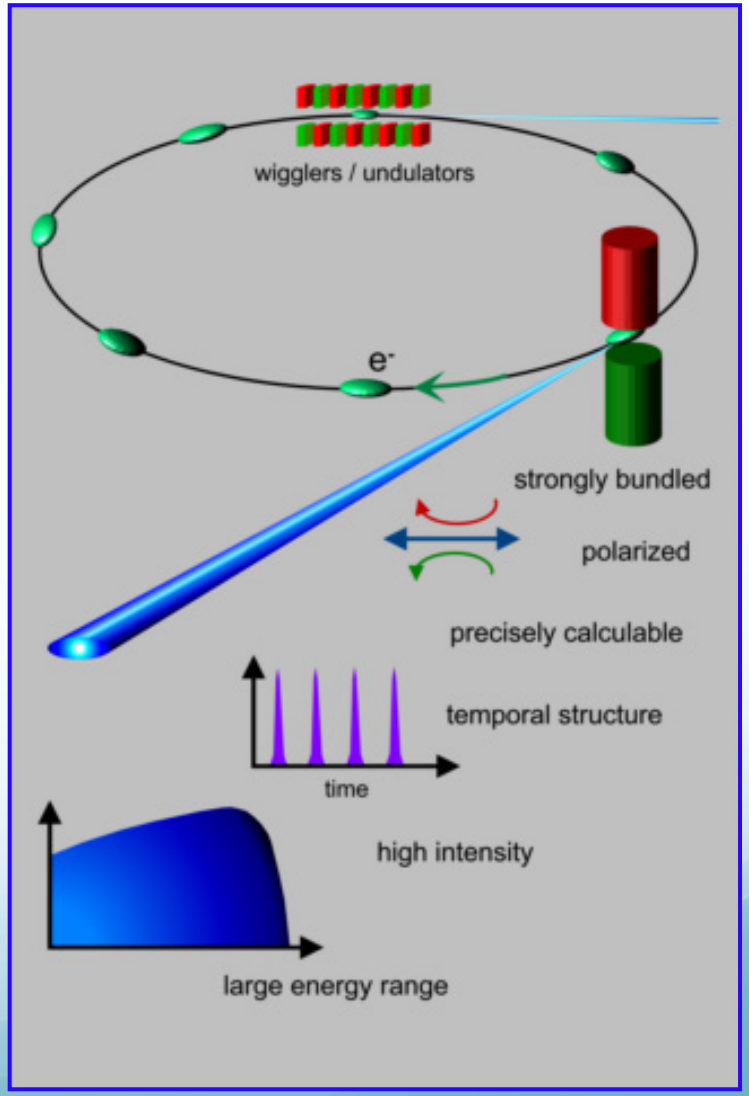


Calculated brightness of beams emitted by undulators (200 mm (L= 10 m), 38 mm (L= 4 m) and 18 mm (L= 2 m) periods), wigglers (wavelength shifter and 40 mm (L= 2 m) period) and bending magnets for a 2.4 GeV storage ring with 400 mA circulating current (**M. Boge** http://accelconf.web.cern.ch/Accelconf/e98/PAPERS/MOP28G.PDF)

Synchrotron Radiation Properties

What makes synchrotron radiation interesting and powerful?

- **Tunability or large energy range from IR to X-rays:** users can select the wavelength required for their experiments - **continuous** (Bending Magnet/Wiggler) - **quasi-monochromatic** (Undulator) **emission**
- **Source in a clean UHV environment**
- **Very high flux** and **brightness** (**with undulators**) highly **collimated photon beams** generated by a **small divergence** and **small size sources.**
- **Highly Polarized**
- **Pulsed time structure**
- **High stability** (**submicron source stability**)



Beamlines @ DAΦNE

Building 12

OPEN to USERS

1) SINBAD - IR beamline (1.24 meV - 1.24 eV)

2) DXR1- Soft x-ray beamline (900-3000 eV)

3) DXR2 – UV-VIS beamline (2-10 eV)

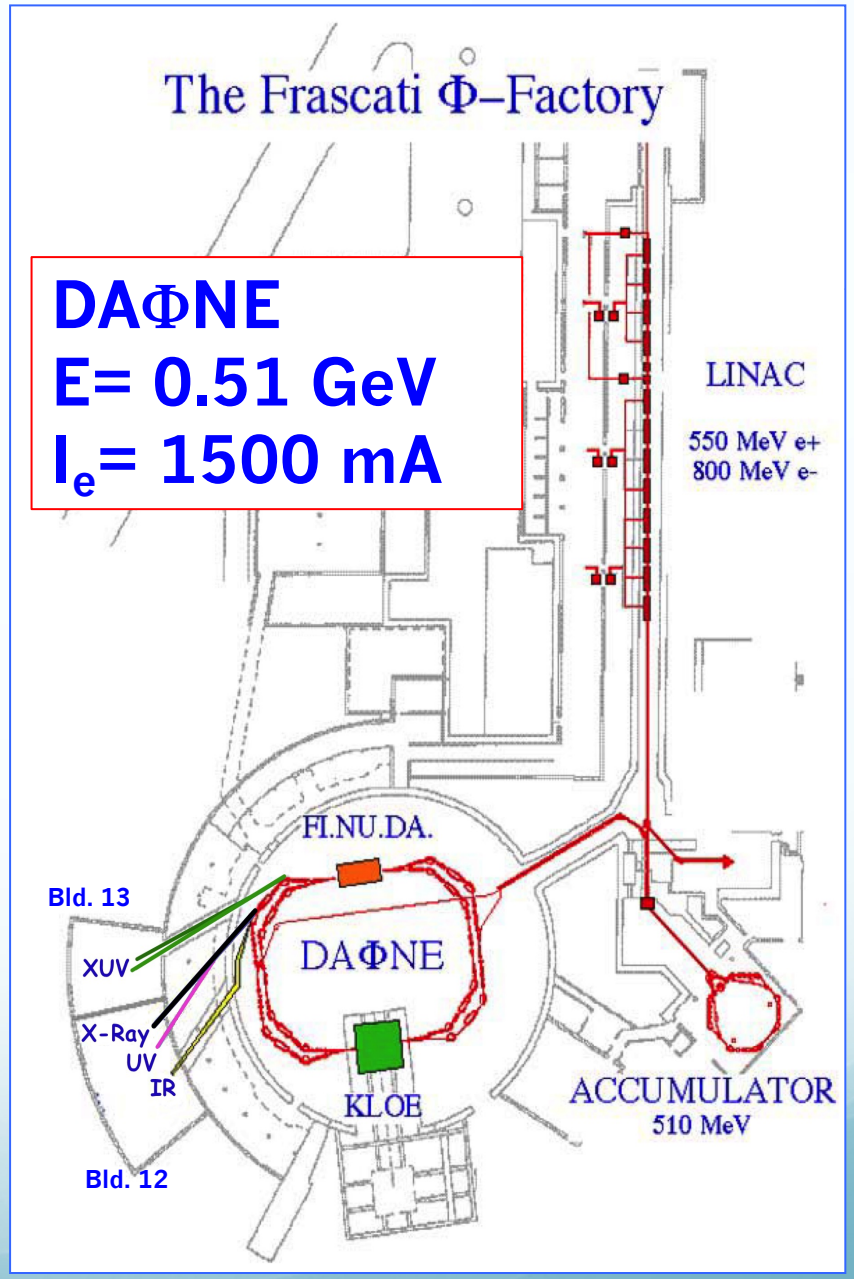
Building 13

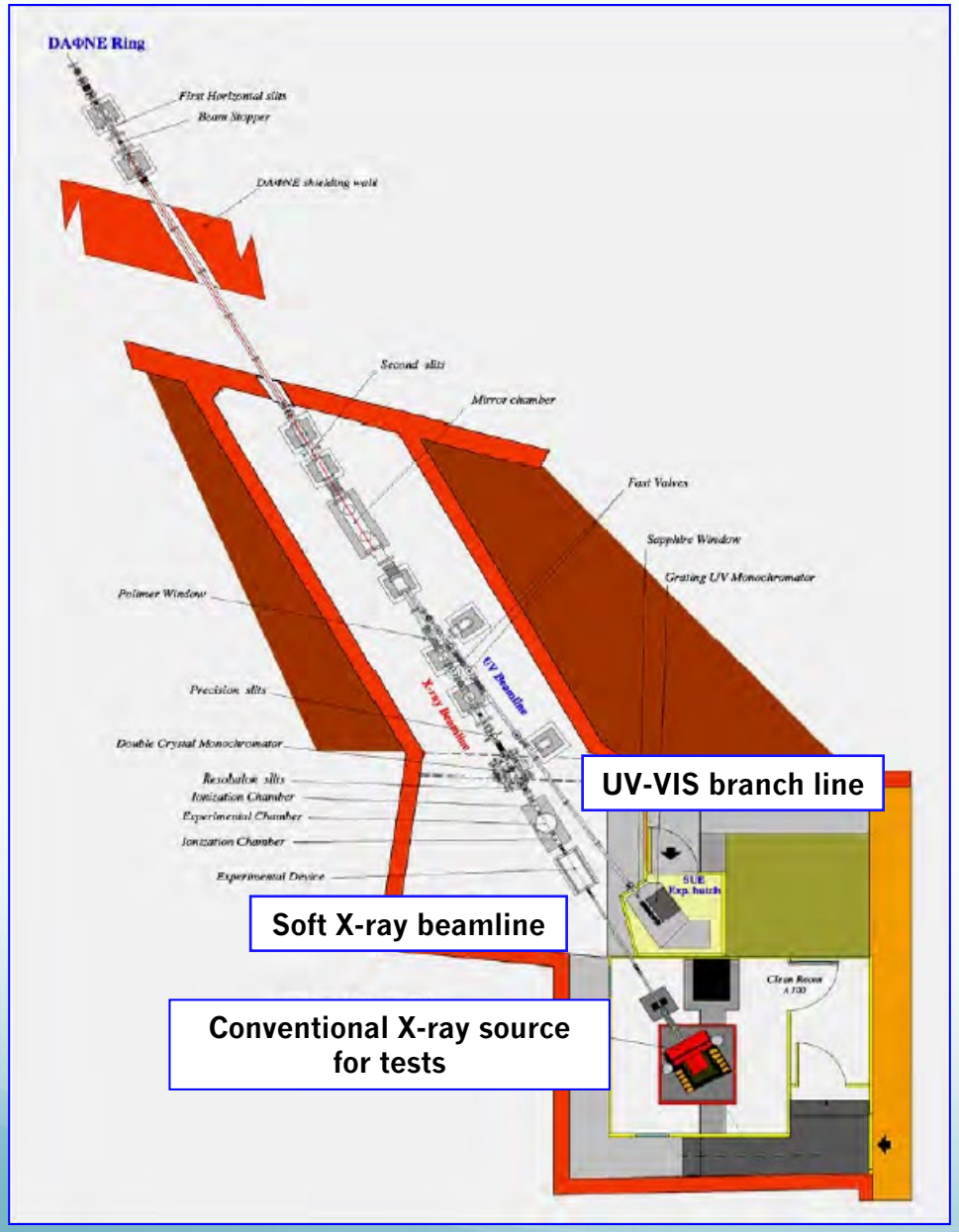
XUV beamlines

4) XUV1 - Low Energy Beamline (30-200 eV)

5) XUV2 - High Energy Beamline (60-1000 eV)

6) New XUV2 Branch White Line





DAΦNE Soft X-ray DXR1 Beamline

-Wiggler (5 poles +2 (1/2) poles) soft x-ray beam line

- Critical energy E_c = 284 eV

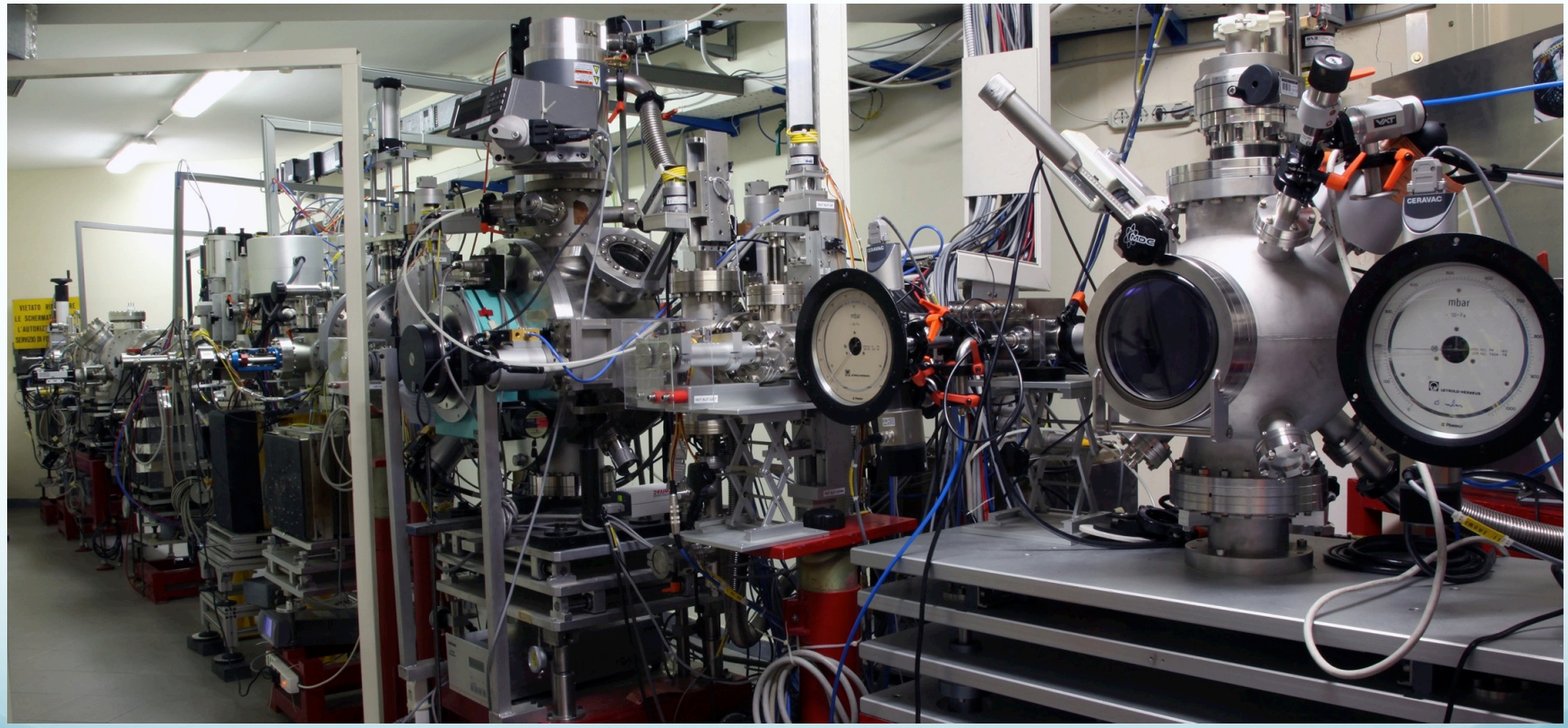
- Working range 0.9 - 3.0 keV

- TOYAMA double crystal monochromator with KTP (011), Ge (111), Si (111), InSb (111) and Beryl (10-10) crystals

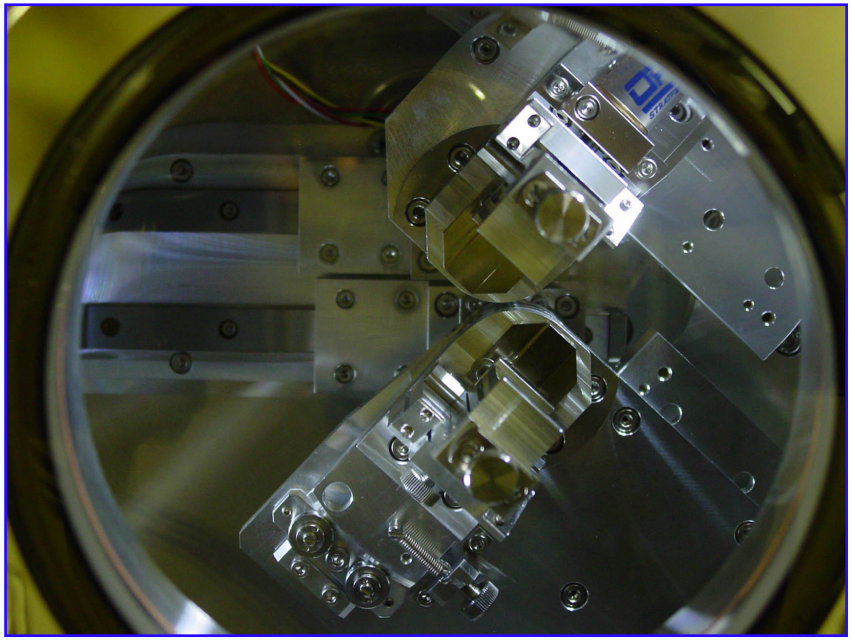
- Cryostat LNT

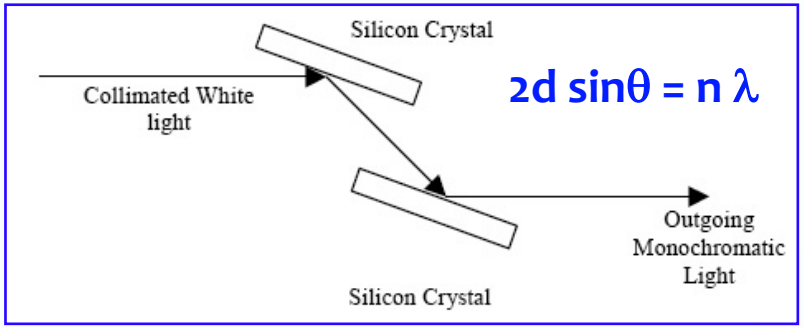
- Soft X-ray Absorption Spectroscopy and tests of Soft x-ray optics and detectors.

DXR1 Soft X-ray Beamline



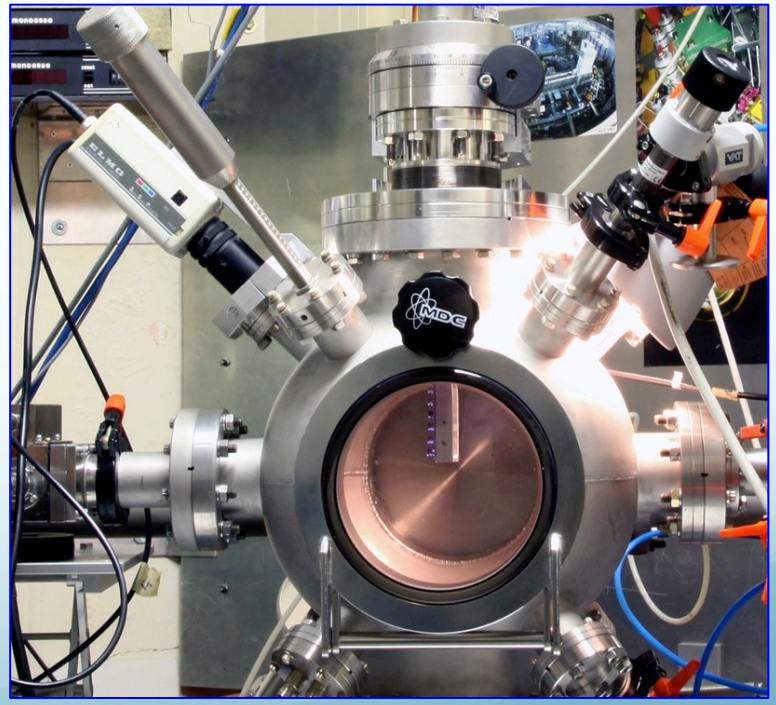
DXR1 Soft X-ray Beamline





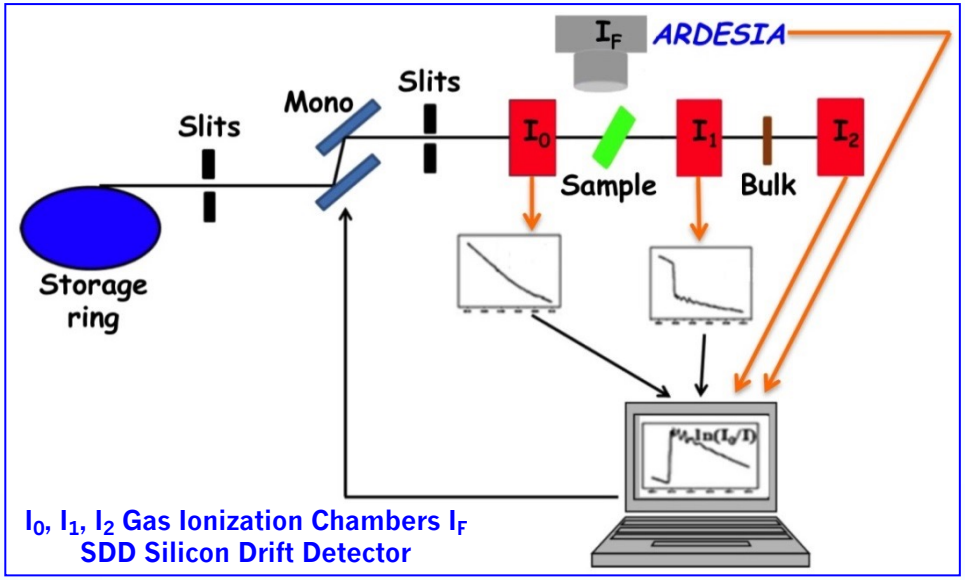
Double crystal monochromator with fixed exit boomerang mechanism.

Crystal type	2d spacing (Å)	Energy range (eV)	Absorption edges
Beryl (10-10)	15.954	1000 - 1560	Na K, Mg K, Cu L
KTP (011)	10.950	1200 - 2200	Mg K, Al K
InSb (111)	7.481	1800 - 3100	Si K, P K, S K, Cl K
Ge (111)	6.532	2100 - 3100	P K, S K, Cl K



Experimental Chamber

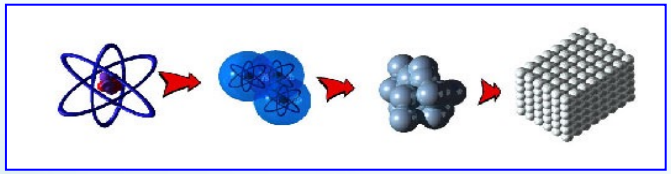
Soft X-ray spectroscopy -XAFS

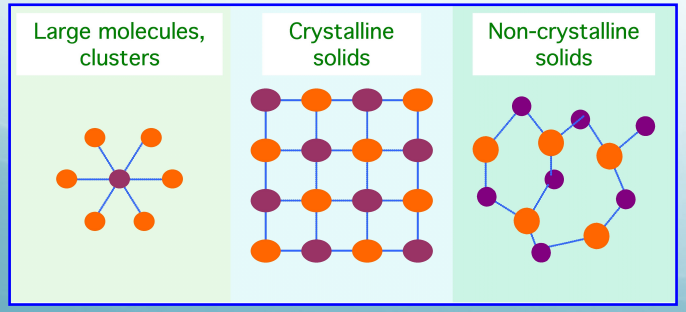


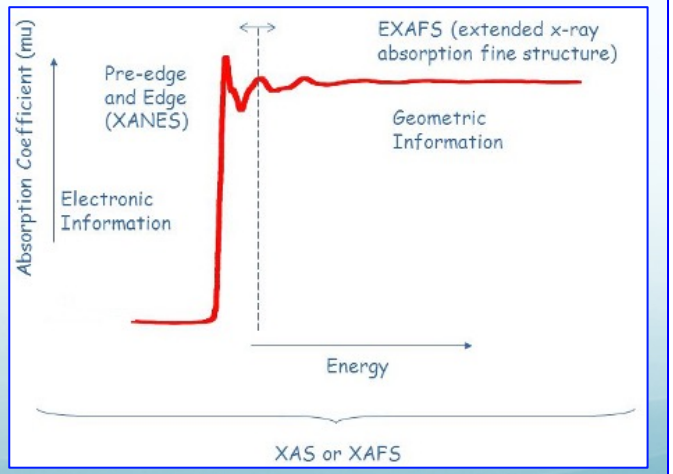
X-ray Absorption Fine Structure or XAFS spectroscopy

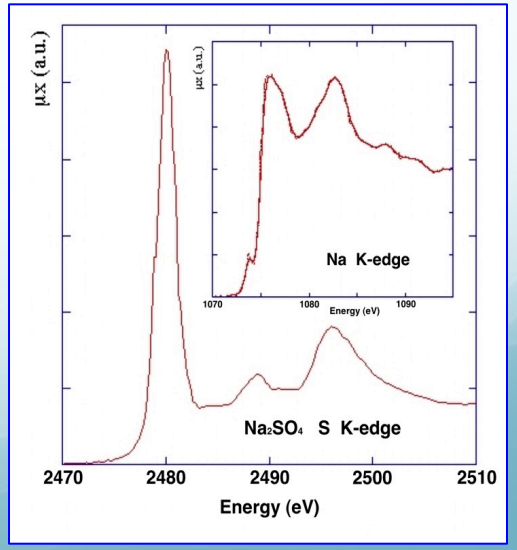
Particularly useful for investigating the electronic structure and local environment of atoms in quite different samples (solids, liquids and gasses).

At the DXR1 beamline the K absorption edges of all light elements from Na to Cl can be studied.



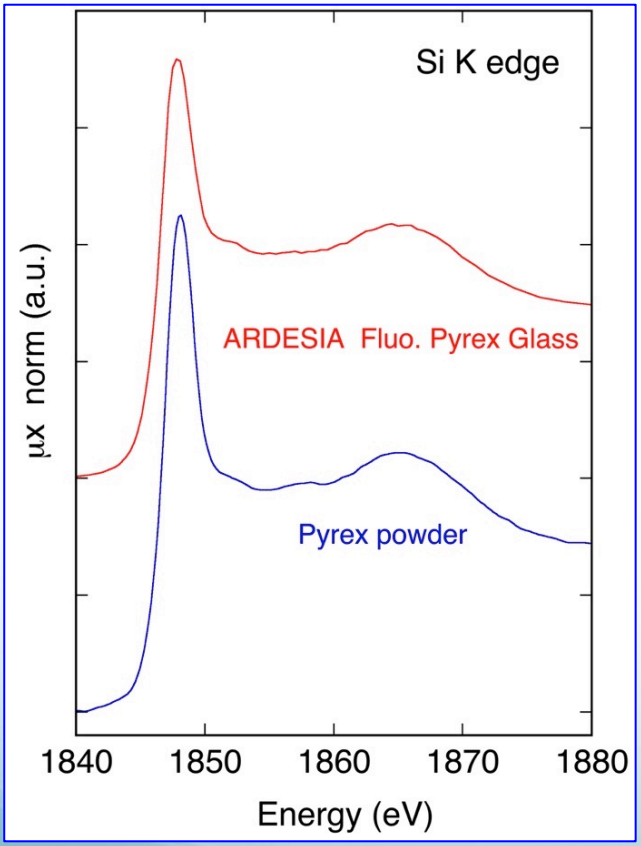


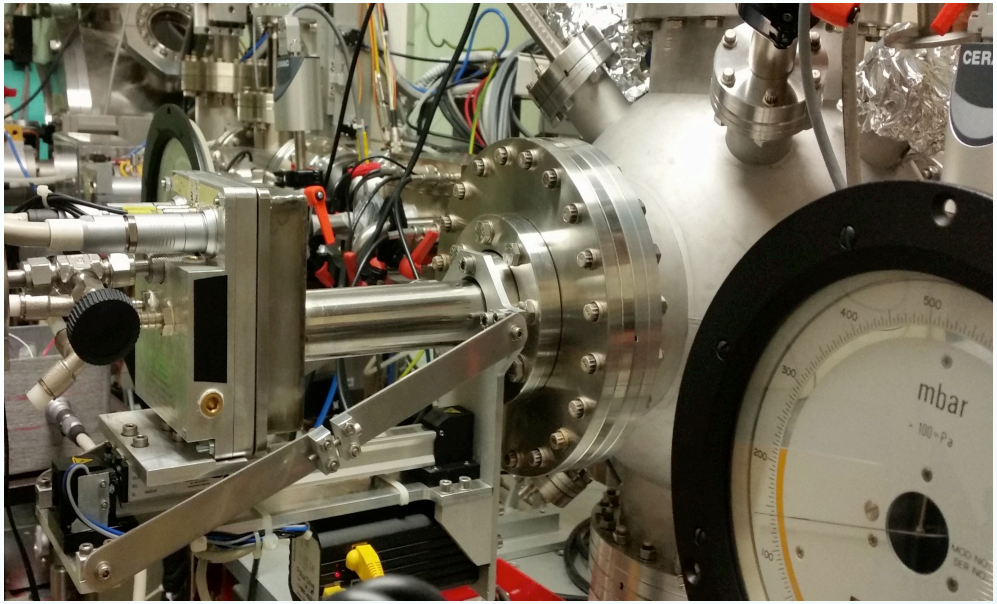




ARDESIA SDD detector

ARDESIA 4-channel X-ray XRF detector



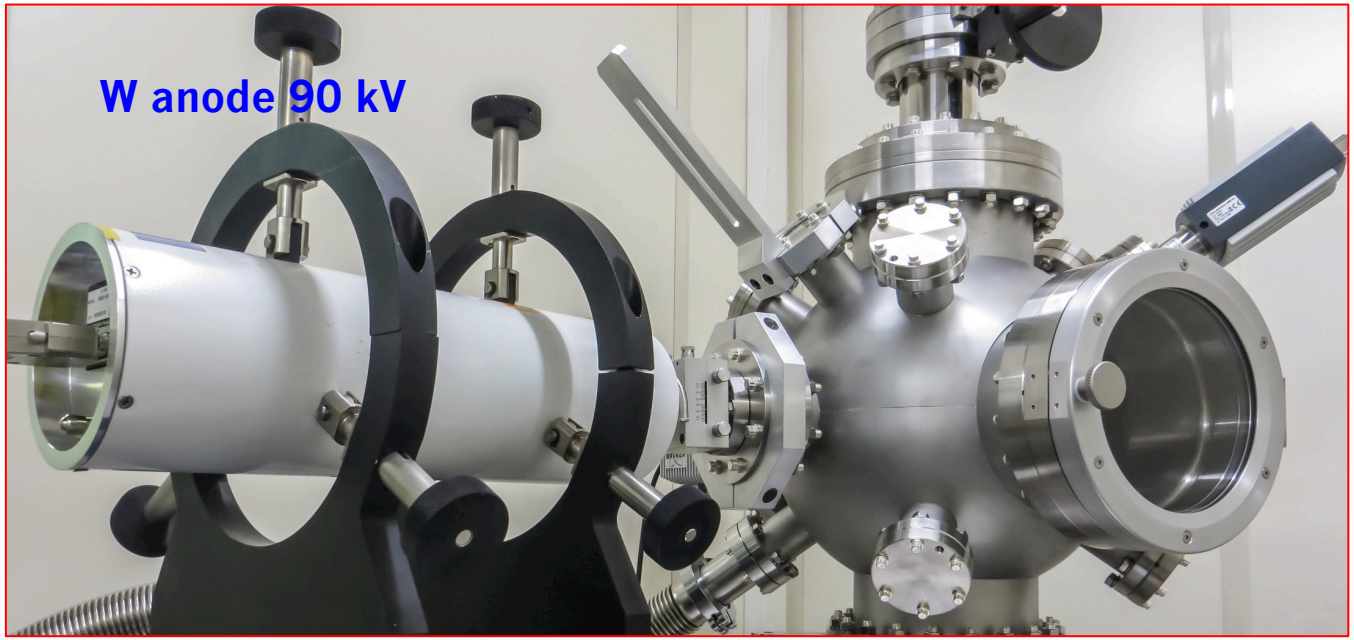


Developed thanks to a collaboration between **DAFNE-Light** and the **Politecnico di Milano.** Financed by **INFN through a CSN5** (INFN **National Scientific Committee 5** for technological research experiments) **ARDESIA** project.

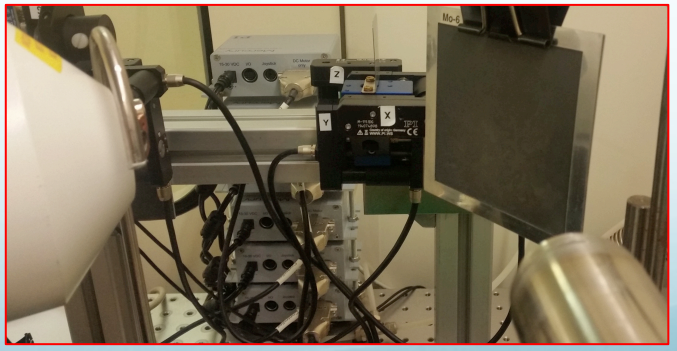
XAFS-XRF studies of thin and supported samples.

First XRF-XAFS @ DXR1 beamline - February 2018

Test chamber and x-ray conventional source



Testing crystals

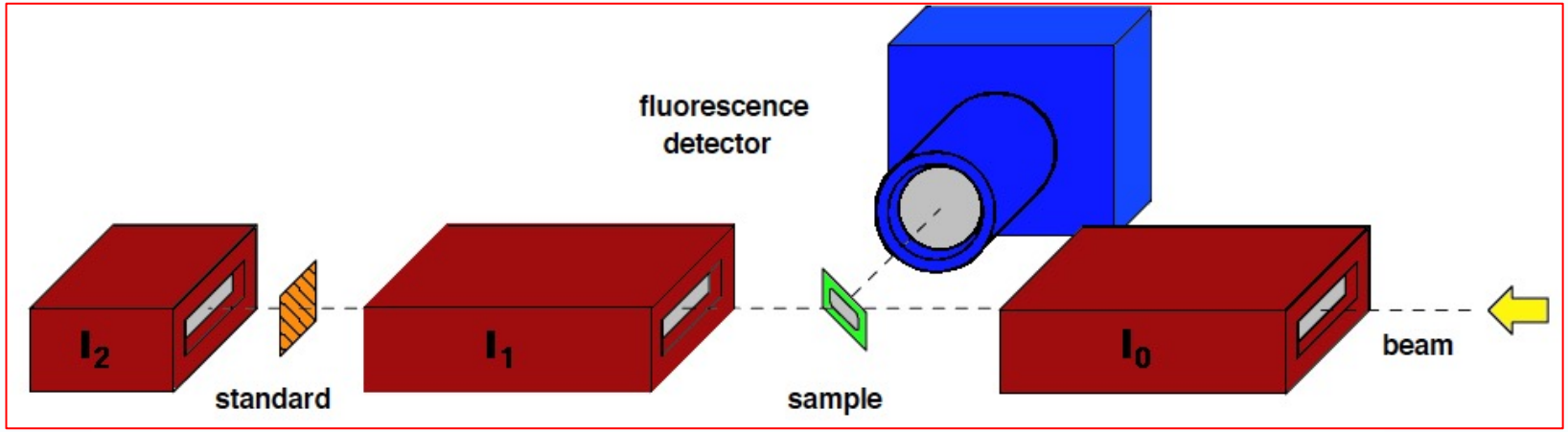


Testing detectors

Dispersive XAFS under development

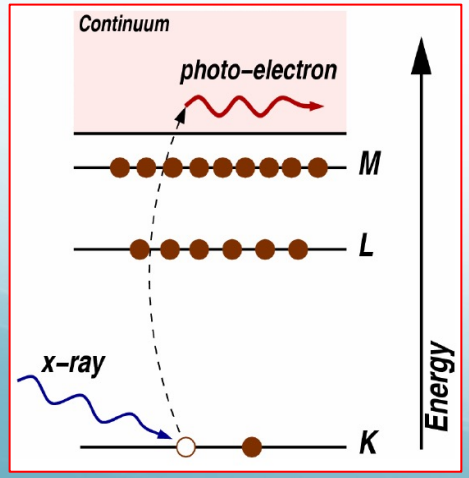
Material Science and XAFS spectroscopy

XAFS Spectroscopy

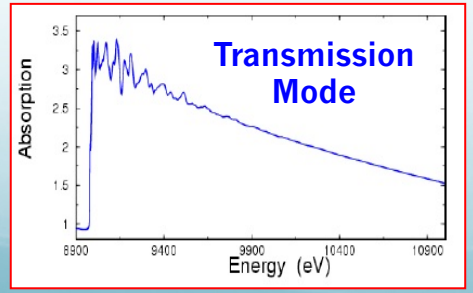


XAFS can be measured either in Transmission or Fluorescence mode.

X-ray absorption

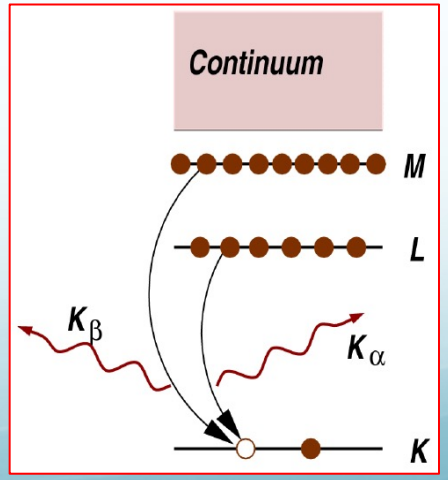


$$\mu(E)x = ln\left(\frac{I_0}{I_1}\right)$$

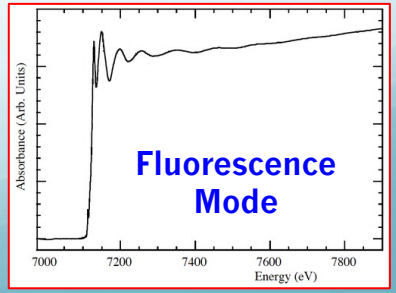


The probability of fluorescence emission is directly proportional to the absorption probability.

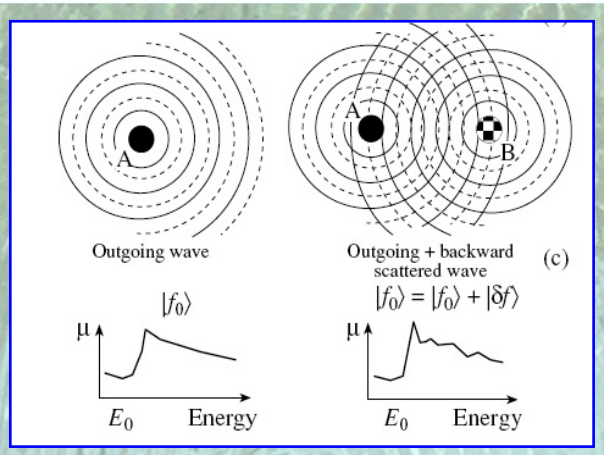
X-ray fluorescence

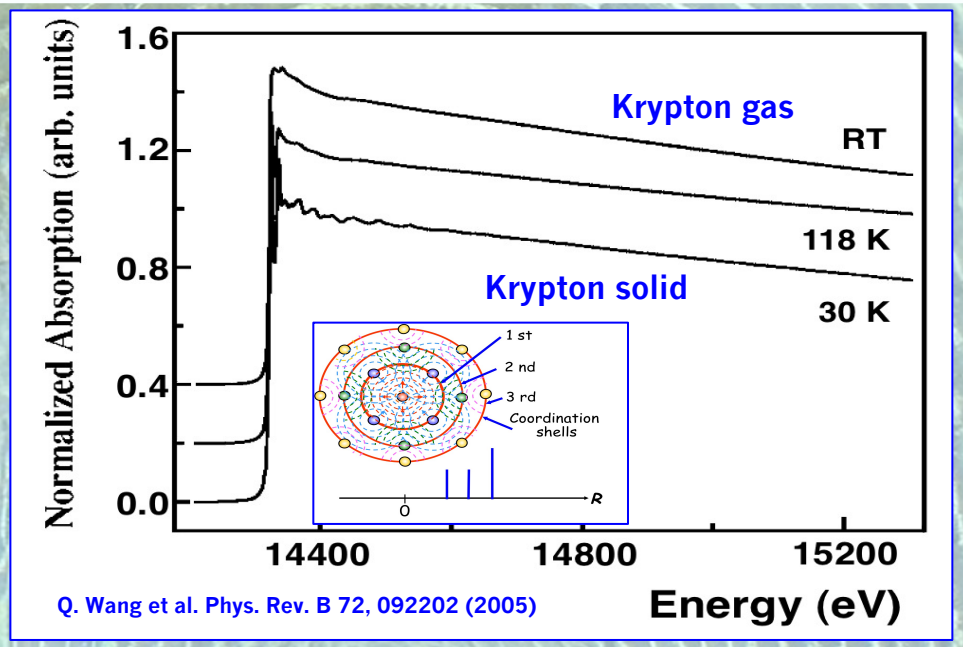


$$\mu(E)x = \left(\frac{I_F}{I_0}\right)$$



XAFS spectroscopy



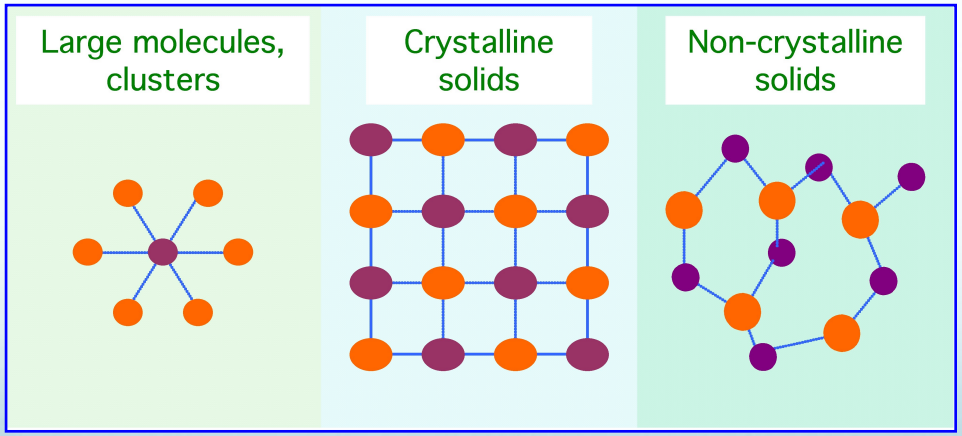


Q. Wang et al. Phys. Rev. B 72, 092202 (2005)

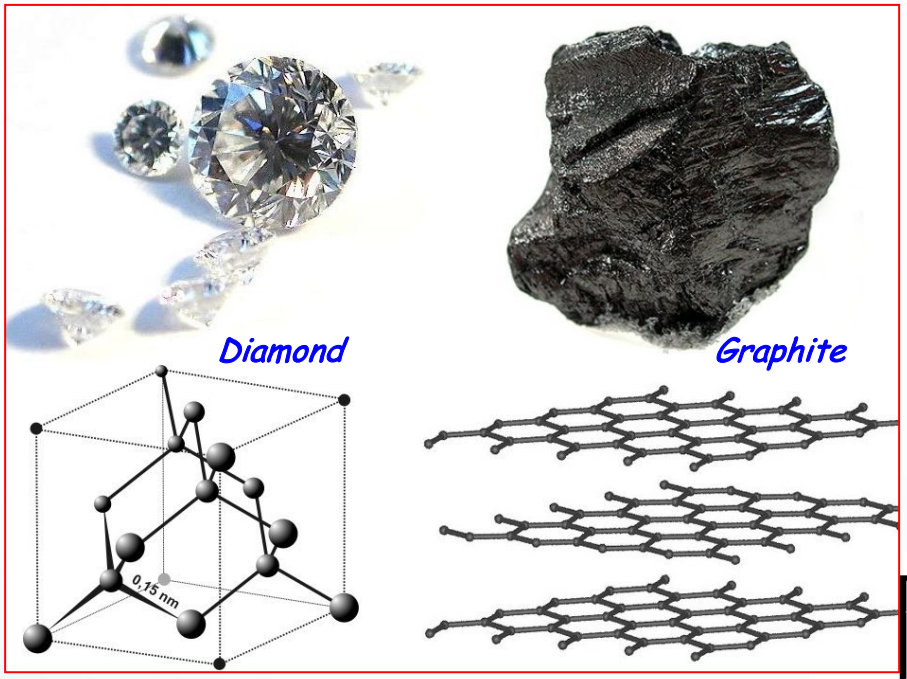
$$\chi(k) = -\frac{S_0^2}{k}\sum_s N_s \frac{\left|f_s(\pi,k)\right|}{R_s^2} e^{-k^2/\sigma_s^2} e^{-2R_s/\lambda_s} \sin\left(2kR_s + \phi_s(k)\right)$$

EXAFS — **Coordination number** — **Debye Waller factor** — **Interatomic distance**

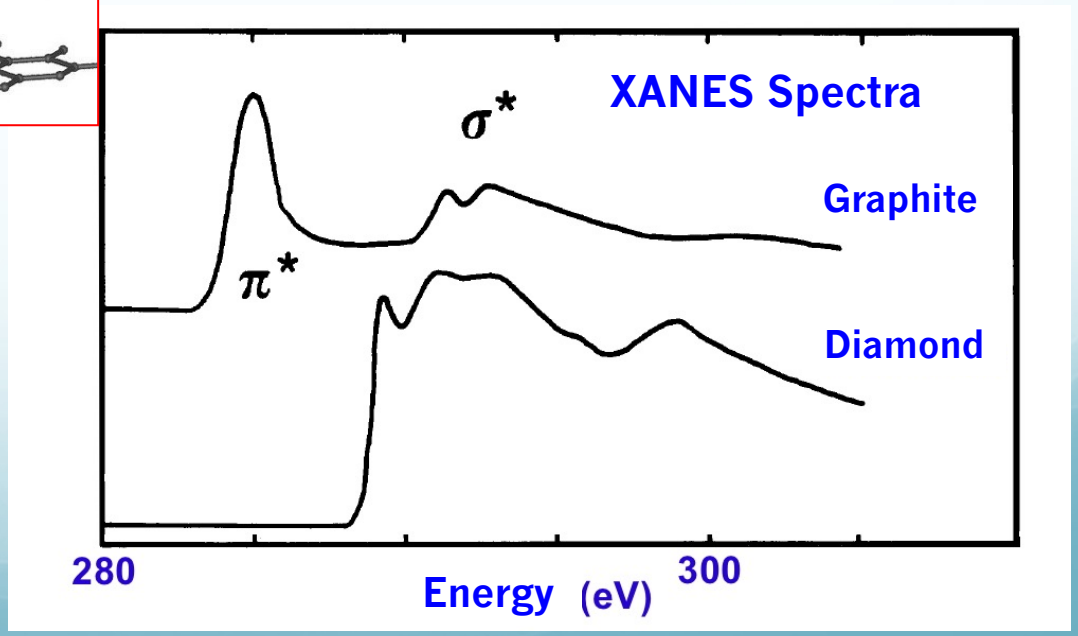
XAFS spectroscopy as a very powerful tool



XAFS - Carbon K edge

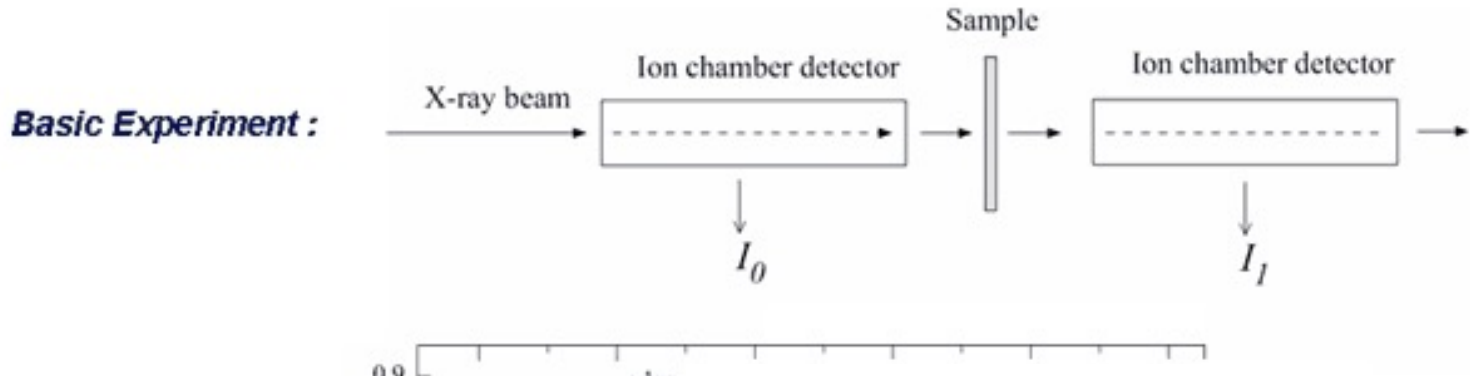


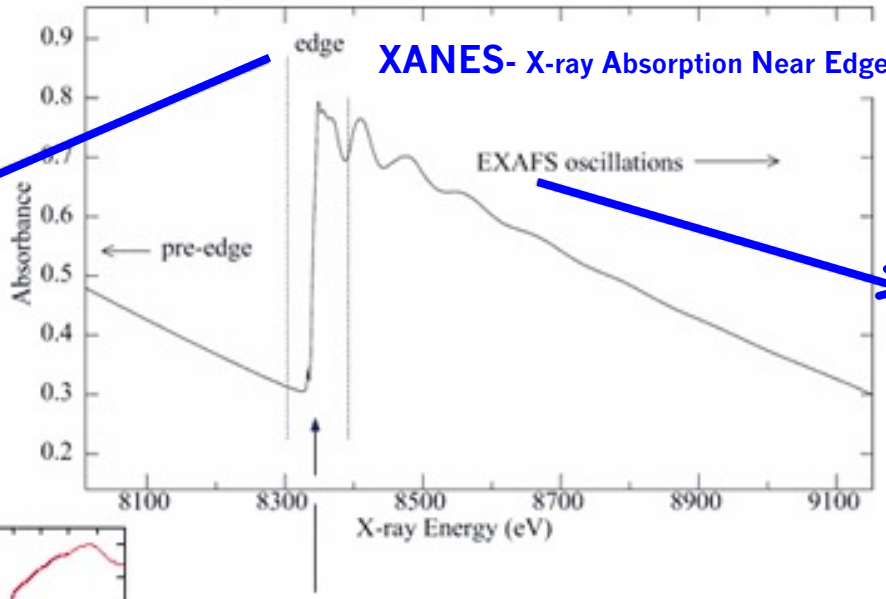
The quite different XANES spectra for Graphite and Diamond due to their different atomic structures.



J. Robertson, Prog Solid St. Chem 21, 199 (1991)

XAFS information

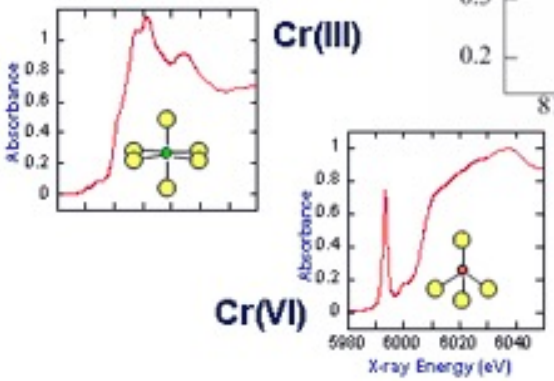




XANES- X-ray Absorption Near Edge Structure

XANES

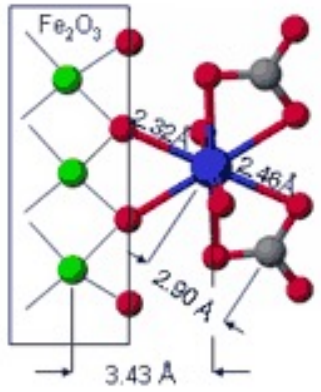
Oxidation state, Molecular composition, structure.



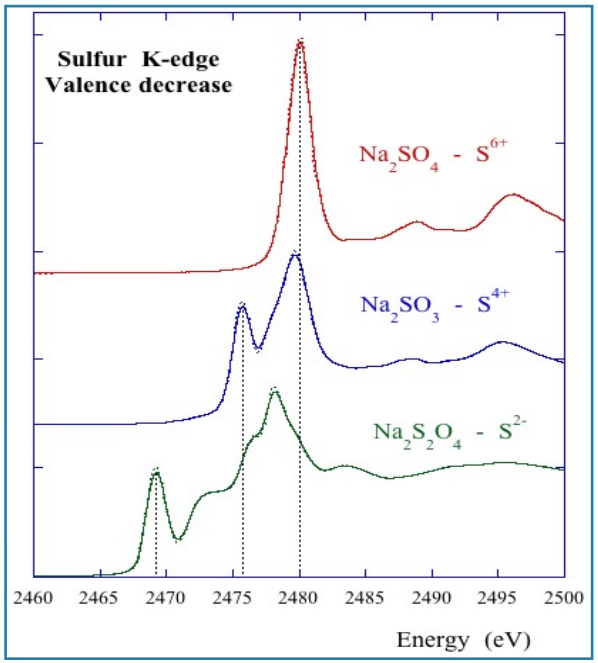
EXAFS- Extended X-ray Absorption Fine Structure

EXAFS

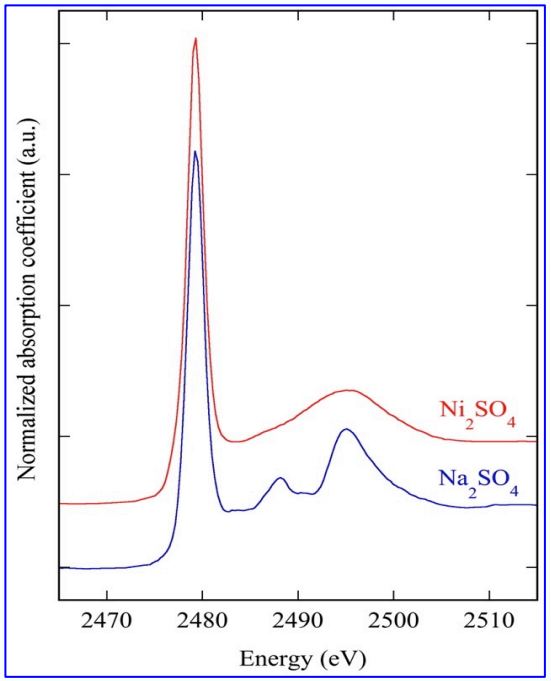
Quantitative Local Structure.



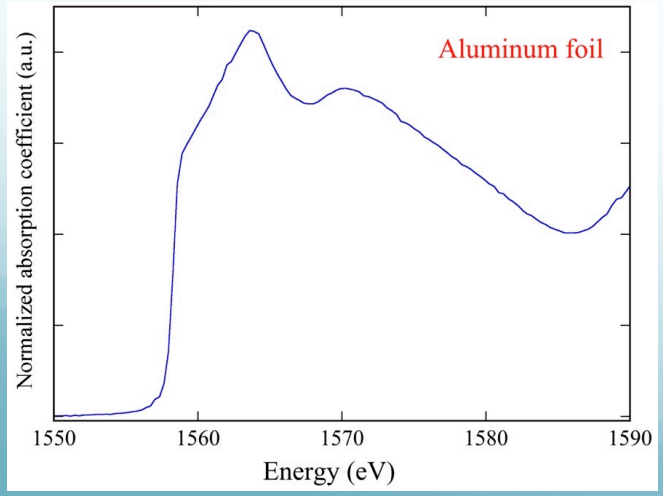
XANES DXR1

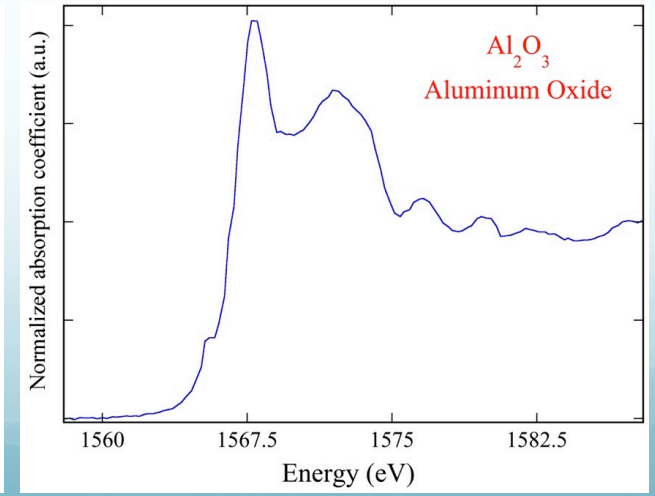


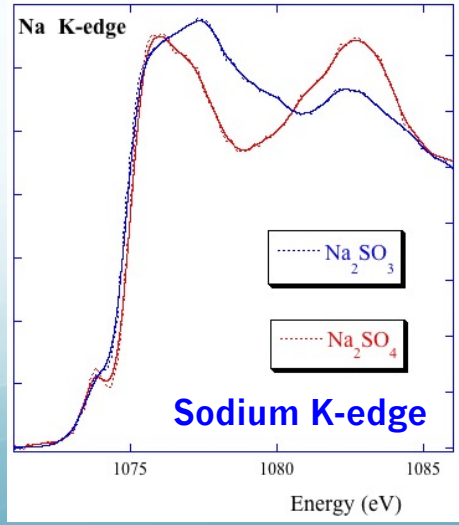
Sulfur K-edge



Aluminum K-edge

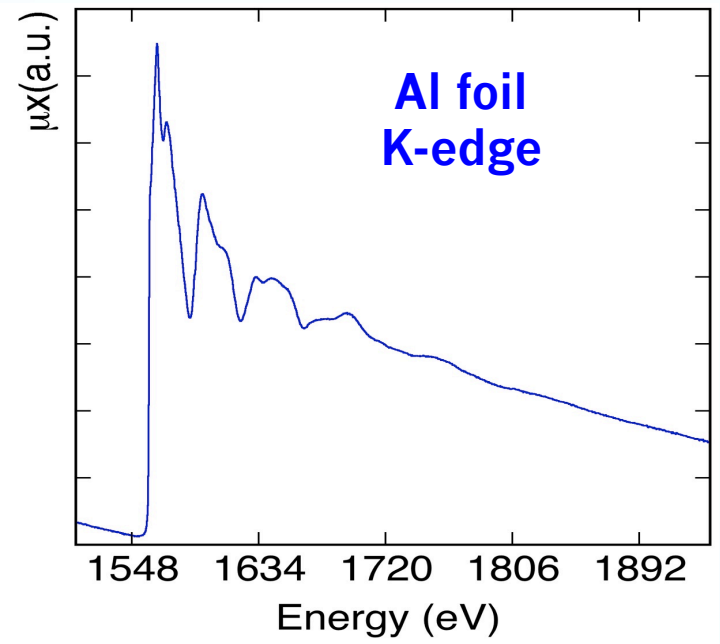


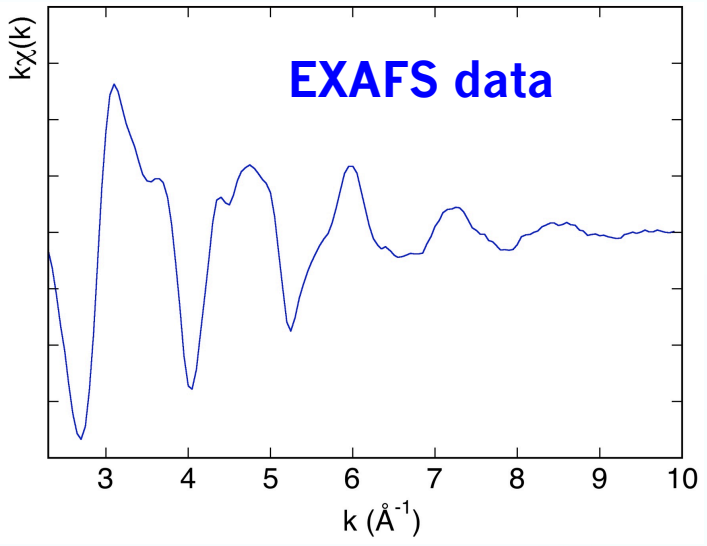


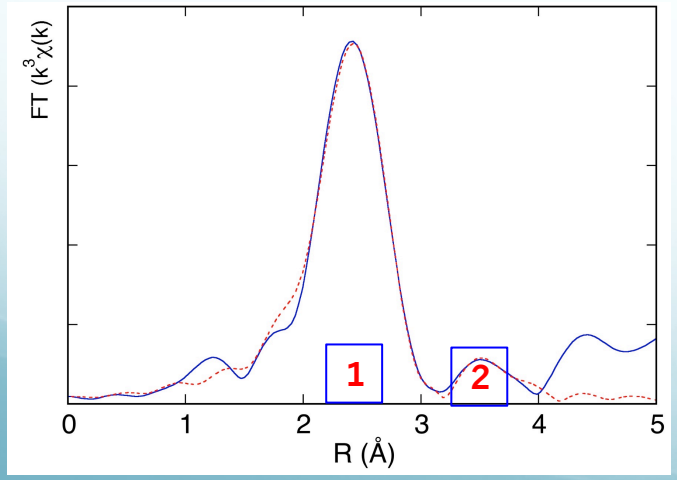


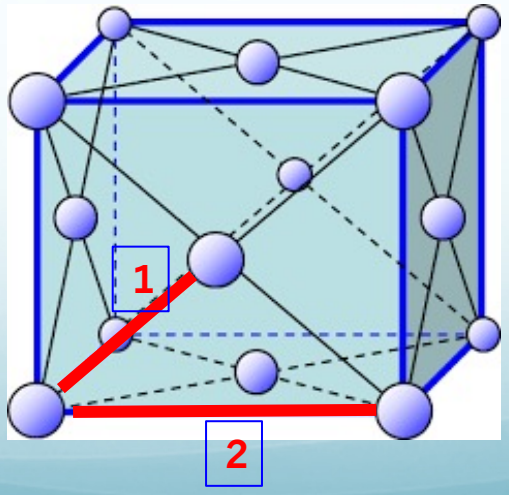
Sodium K-edge

EXAFS DXR1









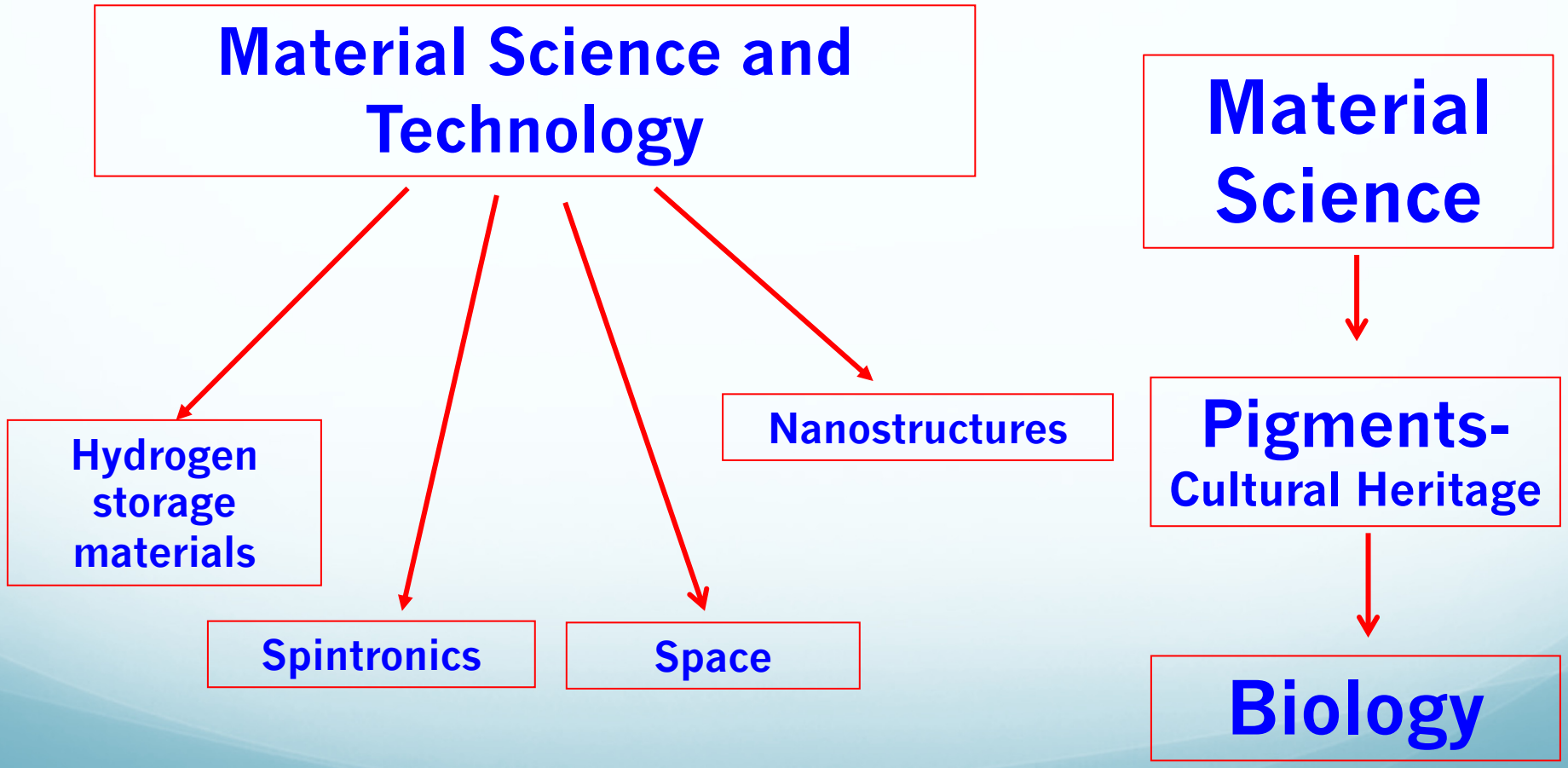
N_{1Al}= 12
R_{1Al}= 2.85 Å
$\sigma_1^2{}_{Al}$=0.014 Å^2

First shell

N_{2Al}= 6
R_{2Al}= 4.04 Å
$\sigma_2^2{}_{Al}$=0.027 Å^2

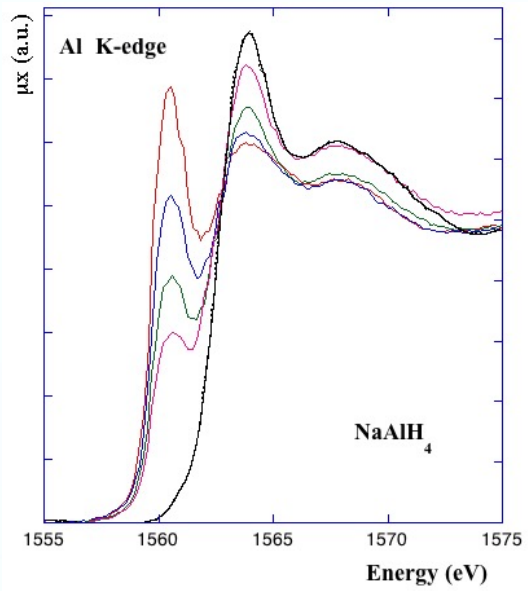
Second shell

Some DXR1 XAFS Applications



Technology

Hydrogen storage materials



Al K-edge XANES study of alkali aluminium hydrides

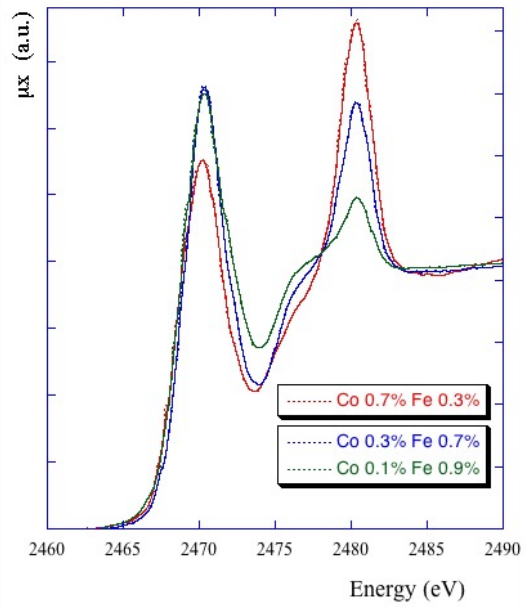
Development of higher-efficiency hydrogen storage materials

The aim of the experiments is to investigate the local structure around Al atoms in nanoscale hydrogen storage materials, **studying the alanate phase at different stages of the reaction when the material is cycled under hydrogen**.

This study shows the structural changes of the alanate structure upon cycling under hydrogen.

A. Leon et al. - KIT

Spintronics



Near-edge X-ray Absorption spectroscopic investigations: Fe doped CoS_2

Conventional electronics is based on the **transport of charges**. **Spintronics** or **spin-based electronics** is an **emergent technology** which **exploits the quantum spin states of electrons**. The electron spin itself is manifested as a two-state magnetic energy system. The structural investigation around the S K-edge of **Fe doped CoS_2 samples** gives information on the **electronic structural changes** induced by **doping of 3d transition metal ion**, **Fe** of **$Co_{1-x}Fe_xS_2$**.

I. Zuburtikudis - Dept. of Engineering, GREECE

Technology

Space

Characterization of thermal filters as a function of temperature

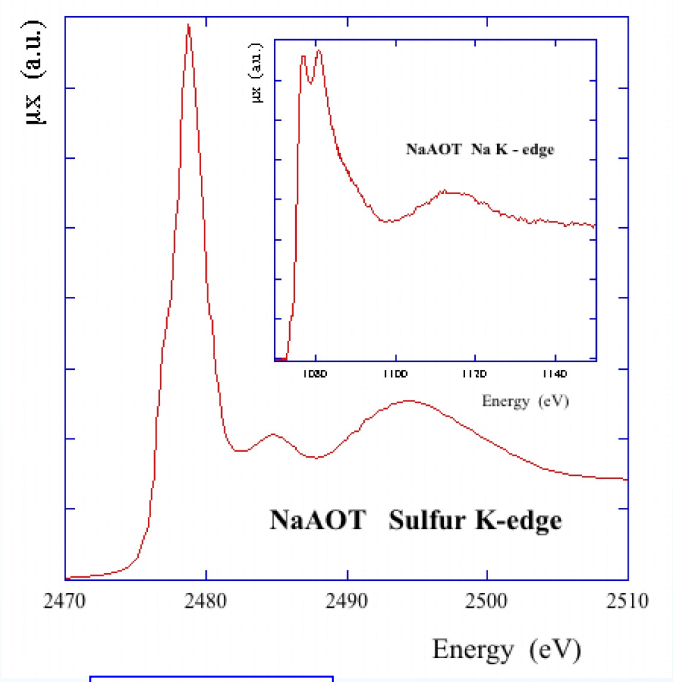
ATHENA is a large astrophysics space mission approved by the European Space Agency (launch scheduled in 2028) to address the science theme "**Hot and Energetic Universe**". The main instrument on-board ATHENA is the **X-ray Integral Field Unit (X-IFU)**, an x-ray detector with spectral, imaging and timing capabilities in the energy range 0.2÷12 keV. **Thermal filters need to be mounted to protect the detector**.

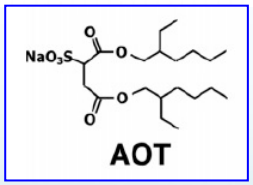
1. Measuring the **X-ray transmission curves in the energy range 1500-1750 eV** should map the regions around the absorption edges of aluminum with an energy resolution like that of the X-IFU.

2. **Monitoring the temperature dependence of the Absorption Fine Structures as a function of temperature** from room temperature to LN temperature

M. Barbera and L. Sciortino, Univ. Palermo

Liquid crystals





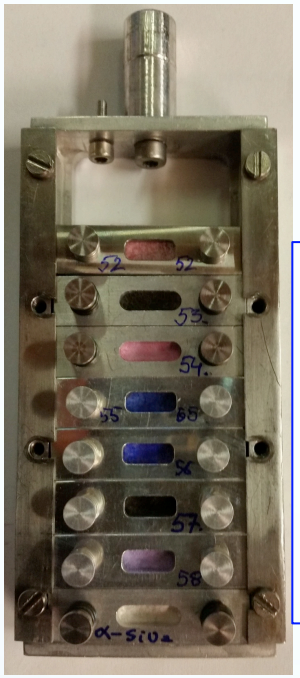
Sodium bis (2-ethylhexyl) sulfosuccinate -**NaAOT**

Structural investigation of water-soluble inorganic salts within reversed micelles or liquid crystals used as good templates in which nanoparticles can be trapped and stabilized.
System studied: Co, Yb and Er in NaAOT

V. Turco Liveri, Univ. Palermo

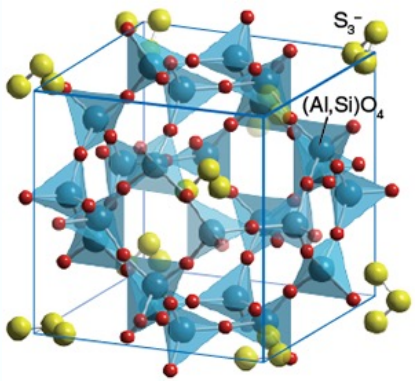
Study of Pigments

possible applications in the Cultural Heritage field



XAFS RT sample holder

Revisiting properties of $CaCoSi_nO2_{n+2}$. Crystal and electronic structure
M. Szubka et al.
Journal of Magnetism and Magnetic Materials (2022)



Extra framework molecules in lazurite: a combined XAS/FTIR study

Lapis lazuli is a rare and precious pigment exploited and prized for its deep blue color since, at least, the 5th century B.C.
Lapis lazuli is indeed a complex rock characterized by the **abundance of the mineral lazurite** $(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$, which is responsible for its overall blue hue. **Lazurite belongs to the sodalite group of minerals**, which includes, along with sodalite, also nosean and hauyne.
A series of sodalite-group minerals spanning a large range of colors, have been studied as a function of T using Raman spectroscopy observing changes probably related to the S sites.
Following these results, it was proposed to study using XANES spectroscopy at the S K-edge a set of samples treated at different T and for different time durations.

Della Ventura G. Univ. Roma Tre

Silicon K Edge XAS study of Silicate Pigments

Silicon pigments have been known since millennia. Their properties were first investigated at the beginning of the XIX century but the **exact structure** and composition of $BaCuSi_2O_6$ (Han purple), $BaCuSi_4O_{10}$ (Han blue) and $CaCuSi_4O_{10}$ (Egyptian blue) **were established over 100 years later.**
Contemporary, $CaCoSi_2O_6$ is used in industry as pigment varying in colors from blue to pink.

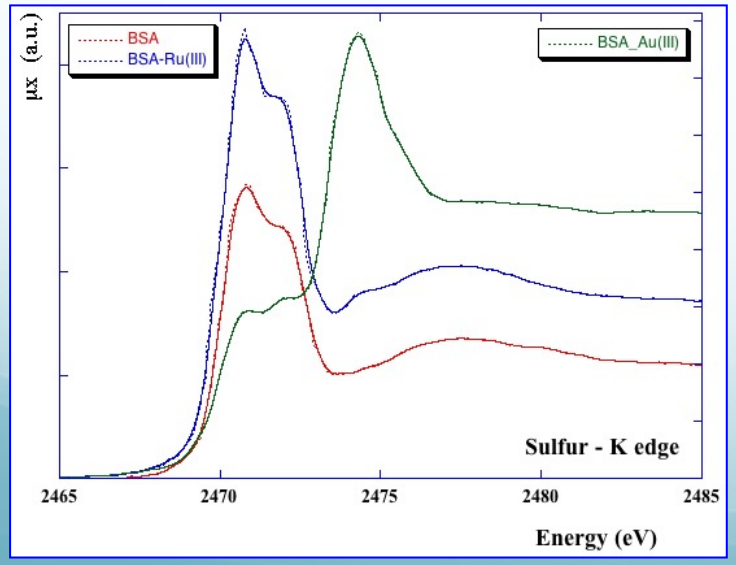
Zajdel P. et al. Univ. Of Silesia, Poland.

Biology

X-Ray Absorption Spectroscopy to Characterize Metallodrug/Protein Interactions

Interactions of metal-based drugs with serum proteins have biological and pharmacological implications.
Specifically, **great attention has been given to ruthenium and gold complexes that seem to be very promising**. The mechanisms through which the **metal complexes produce their biological and pharmacological effects** are still largely unexplored and it seems that **gold and ruthenium complexes act on different targets, most likely on protein targets.**

I. Ascone et al.



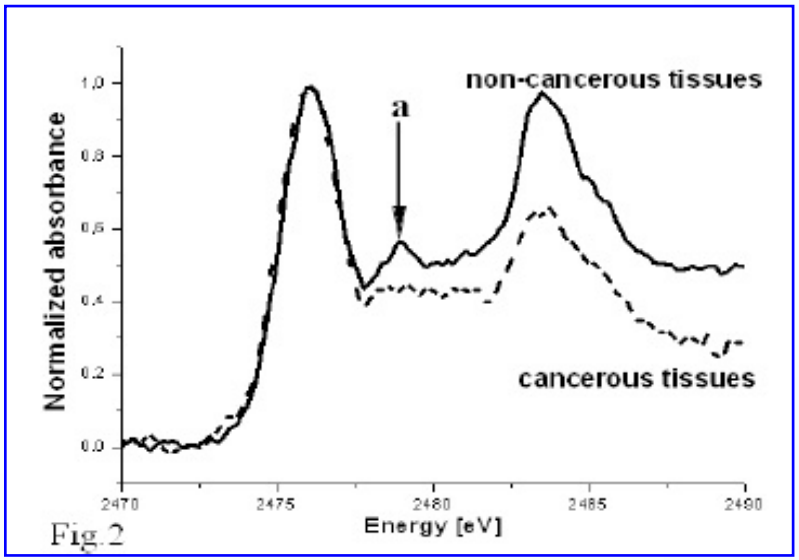


Fig. 2

Preliminary Study on Chemical Speciation of Sulfur in Cancerous Tissues

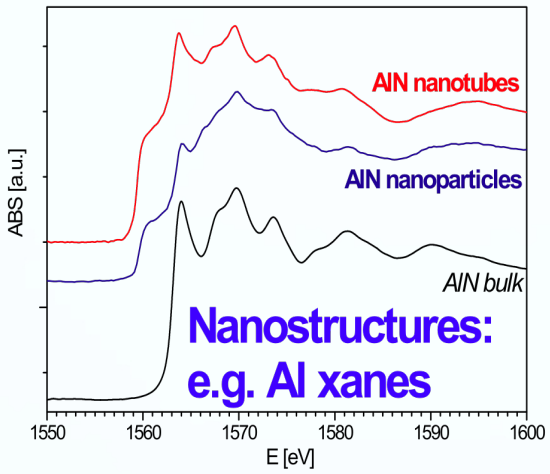
Urological cancers comprise approximately one-third of all cancers diagnosed in men worldwide and out of these, prostate cancer is the most common one.

Out of many relevant factors, it is believed that **sulfur can take an important part in cancer transformations**. Prostate cancer tissues along with selected organic and inorganic compounds used as references have been investigated.

W.M. Kwiatek et al., Division of Inter. Res. IFJ PAN, Poland

Nanomaterial Science

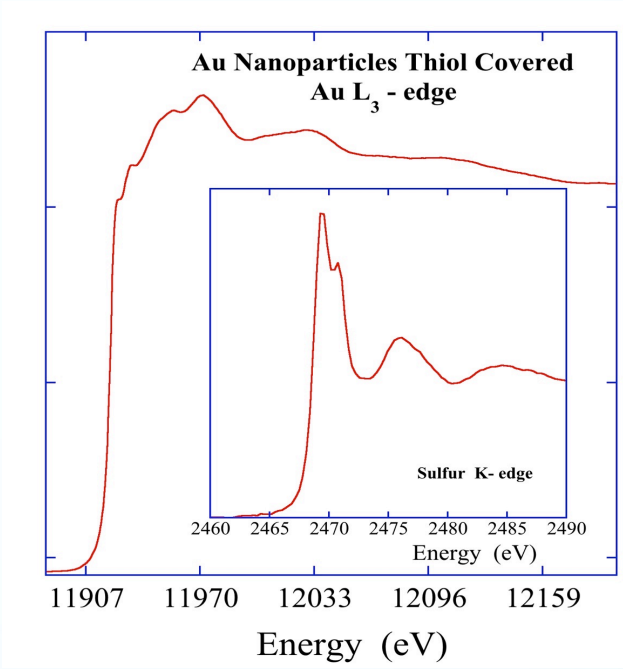
Nanostructures



Characterization of Aluminum Nitride Nanostructures by XANES, XRD, FTIR

The atomic structure of nanotubes or particles is normally different to that in the bulk due to the reduced symmetry. **Both hexagonal (wurtzite-AlN) and cubic phases (zincblende-AlN) of aluminum nitride have found applications in a variety of technologies, ranging from cutting/grinding to corrosion or in exotic devices such as electro-acoustic systems.** The main result obtained from the analysis of the XANES is **the high sensitivity to the presence of both symmetries: hexagonal and cubic**. Indeed, all spectra are characterized by the **same features whose intensity scales proportionally with the content of the wurtzite AlN phase.**

C. Balasubramanian et al.



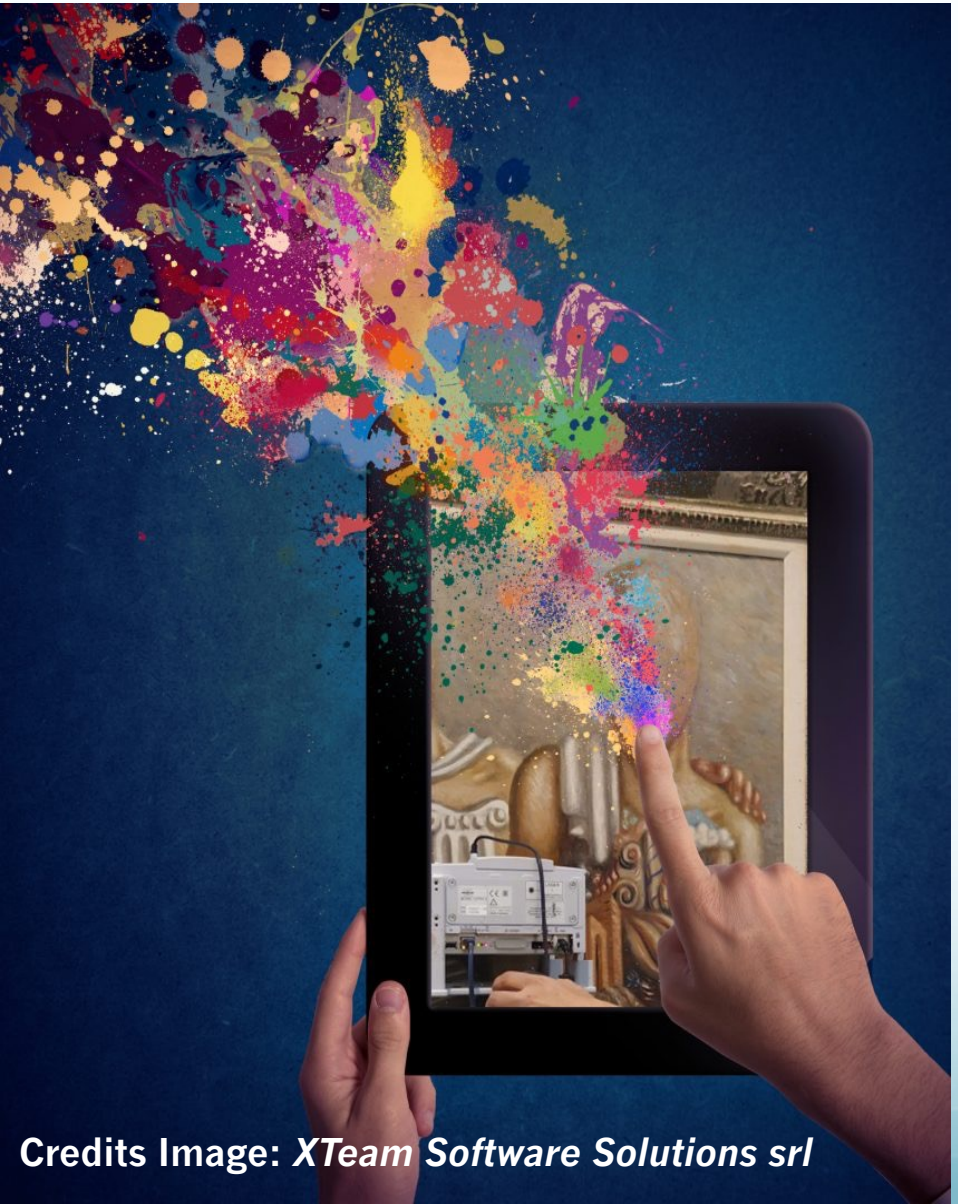
Structural investigation of thiol-capped gold nanoparticles

The use of **multithiolated species improves the stability of gold nanoparticle**.
Sulfur K-edge XANES spectroscopy as an attractive approach for characterizing **multithiolated or disulfide species adsorbed on gold surface nanoparticles**.

T. Comaschi et al.

From synchrotron radiation to a conventional X-ray source

ARTEMISIA Project



ARTEMISIA

ARTificial intelligence **E**xtended-**M**ultispectral **I**maging **S**canner for **I**n-situ **A**rtwork analysis

A. Balerna [1], M. Cestelli Guidi [1*], E. Gorga [1], L. Pronti [1], M. Romani [1], G. Viviani [1], V. Sciarra [1], G. Verona Rinati [2], G. Bonifazi [3], G. Capobianco [3], S. Serranti [3], F. Aramini [4], E. Giani [4], M. Ioele [4], B. Lavorini [4], S. Brandalesi [5], A. Mantoan [5], S. Tamascelli [5], M. Simeone [6]

1 INFN Frascati National Laboratory, Frascati (RM)
2 INFN Sezione di Roma II
3 DICMA Sapienza University of Rome
4 Central Institute of Restoration, Rome
5 XTeam Software Solutions s.r.l., Rovigo RO
6 Vianet slr, Rome.

5 and 6 COMPANIES OPERATING IN THE FIELD OF CULTURAL HERITAGE

* email: mariangela.cestelliguidi@lnf.infn.it

ARTEMISIA Project

ARTEMISIA is an Experimental project for the in-situ identification of pictorial materials through **an integrated multi-modal approach for assessing the state of conservation of pictorial artworks.**

GOALS OF THE PROJECT:

- **The enhancement of imaging diagnostics through the extension of the spectral range of analysis**
- **The development of artificial intelligence algorithms dedicated to the automatic recognition and monitoring of the state of conservation of artwork's materials.**

THE DEVELOPED PROTOTYPE INVOLVES THE COMBINATION AND THE DATA FUSION OF TWO TECHNOLOGIES:

- **Hyperspectral imaging** (in the VIS-NIR spectral range)
- **FT-IR spectroscopy in reflection** (Medium IR spectral range)

FOUNDING

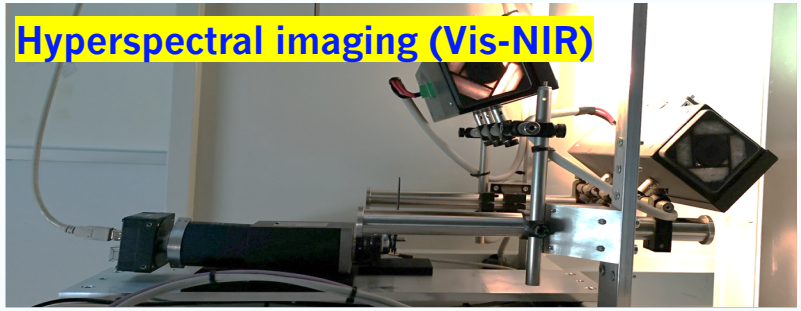
The project was among the winners of the public notice of LAZIO INNOVA
Financing entities: Lazio Region and MUR
Grant awarded: € 149,102.48

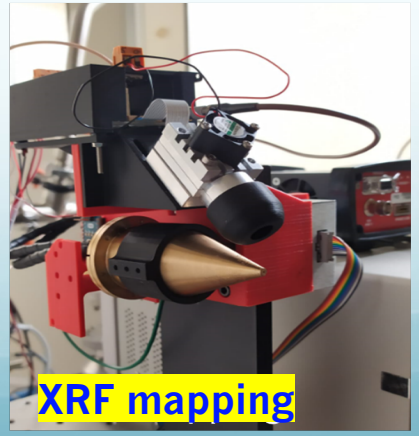
DURATION

22 June 2021 – 22 September 2023

TECHNOLOGICAL DEVELOPMENT

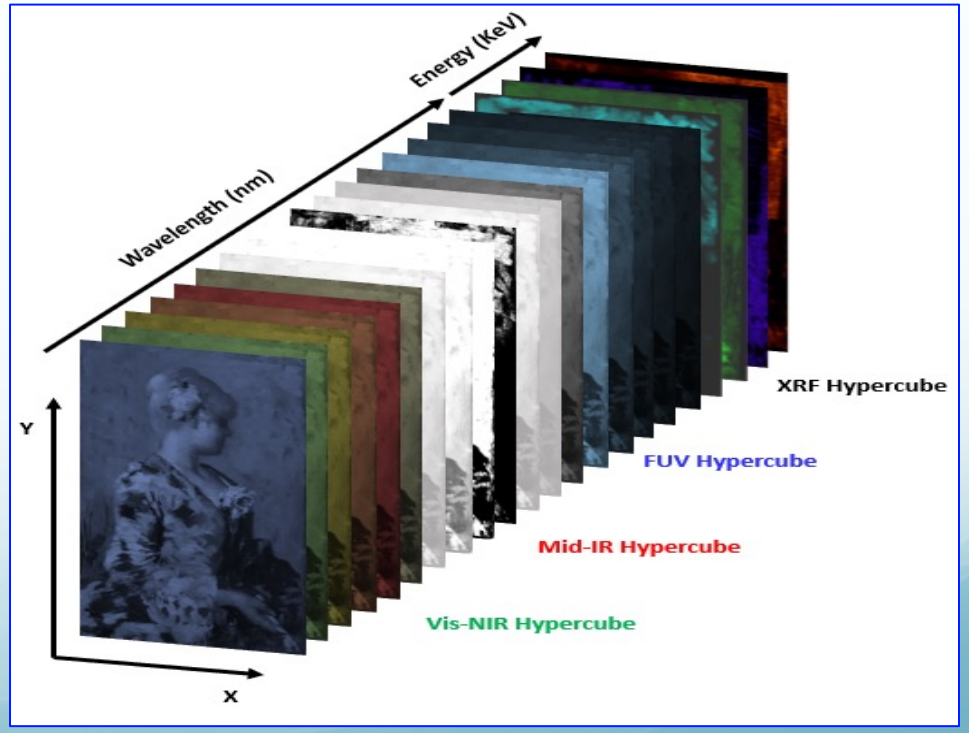
- Development of a scanning system to **motorized the FT-IR spectrometer** in order to perform **macro-FTIR mapping**.
- Integration of the macro-FTIR mapping with the **hyperspectral imaging (Vis-NIR)** technique to extend the spectral range from visible to mid-infrared range of the hyperspectral images acquired.
- **Feasibility study** for the integration in the mapping system of the **UV Fluorescence** and **XRF** spectroscopies (in **collaboration with CHNet LABEC-Fi**).



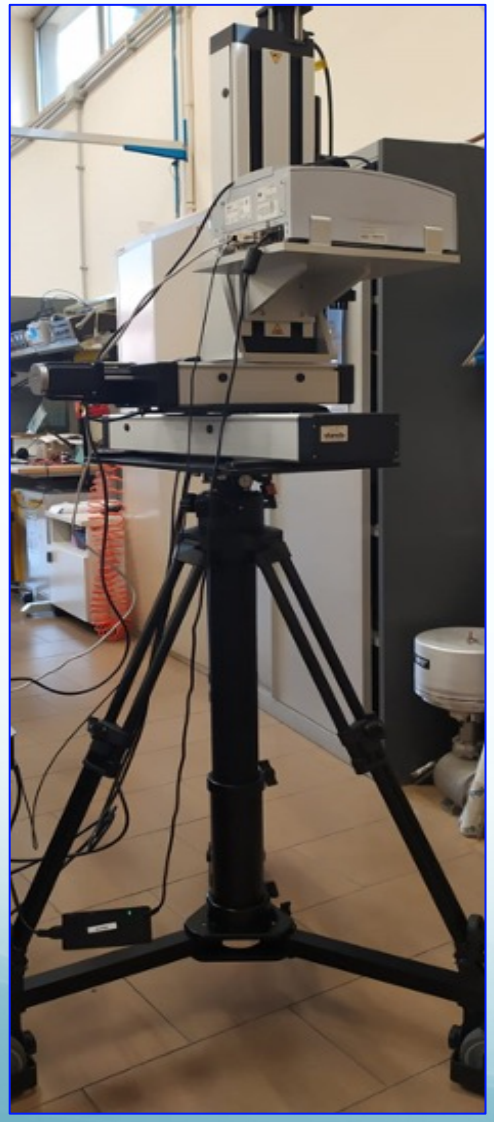


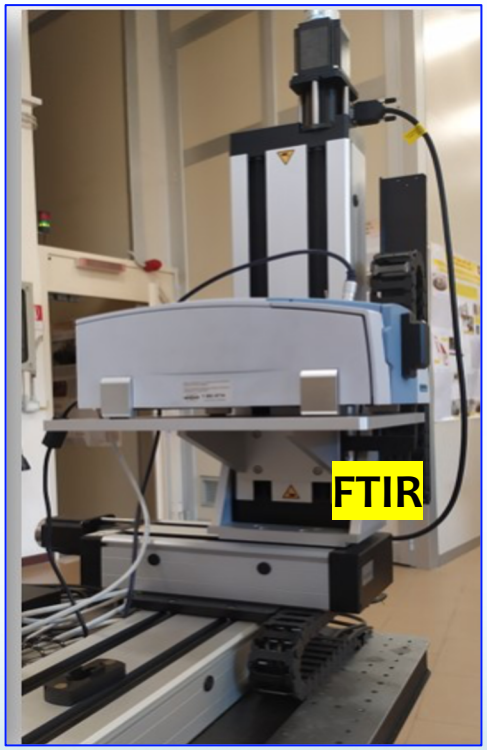
DATA FUSION AND MACHINE LEARNING

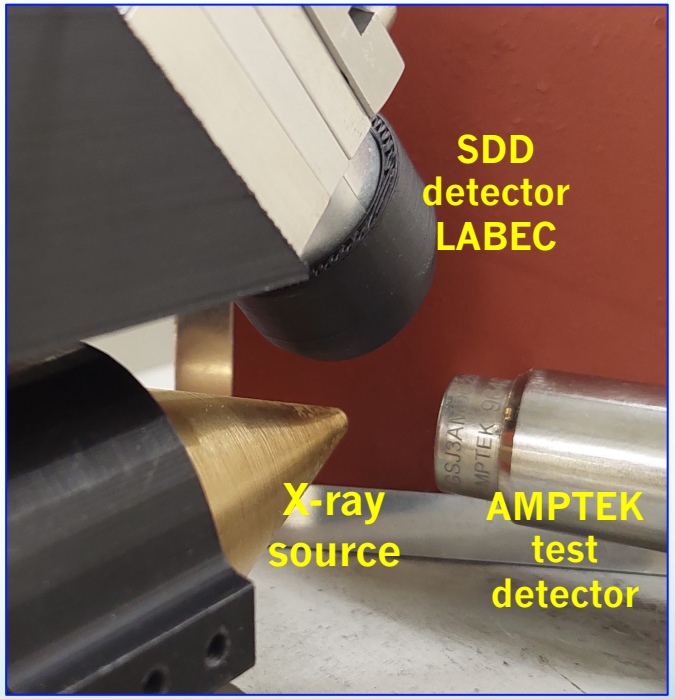
1. **Development of a dedicated software for the registration of the hyperspectral images** including the photographic image of the artwork and application of data fusion methods.
2. Creation of a **database of hyperspectral images of pictorial materials** and development of **machine learning methods for their automatic recognition on artworks**.
3. Development of a **User-Friendly graphical interface** to show the distribution of the constituting materials as multi-level information.



Present Status of ARTEMISIA



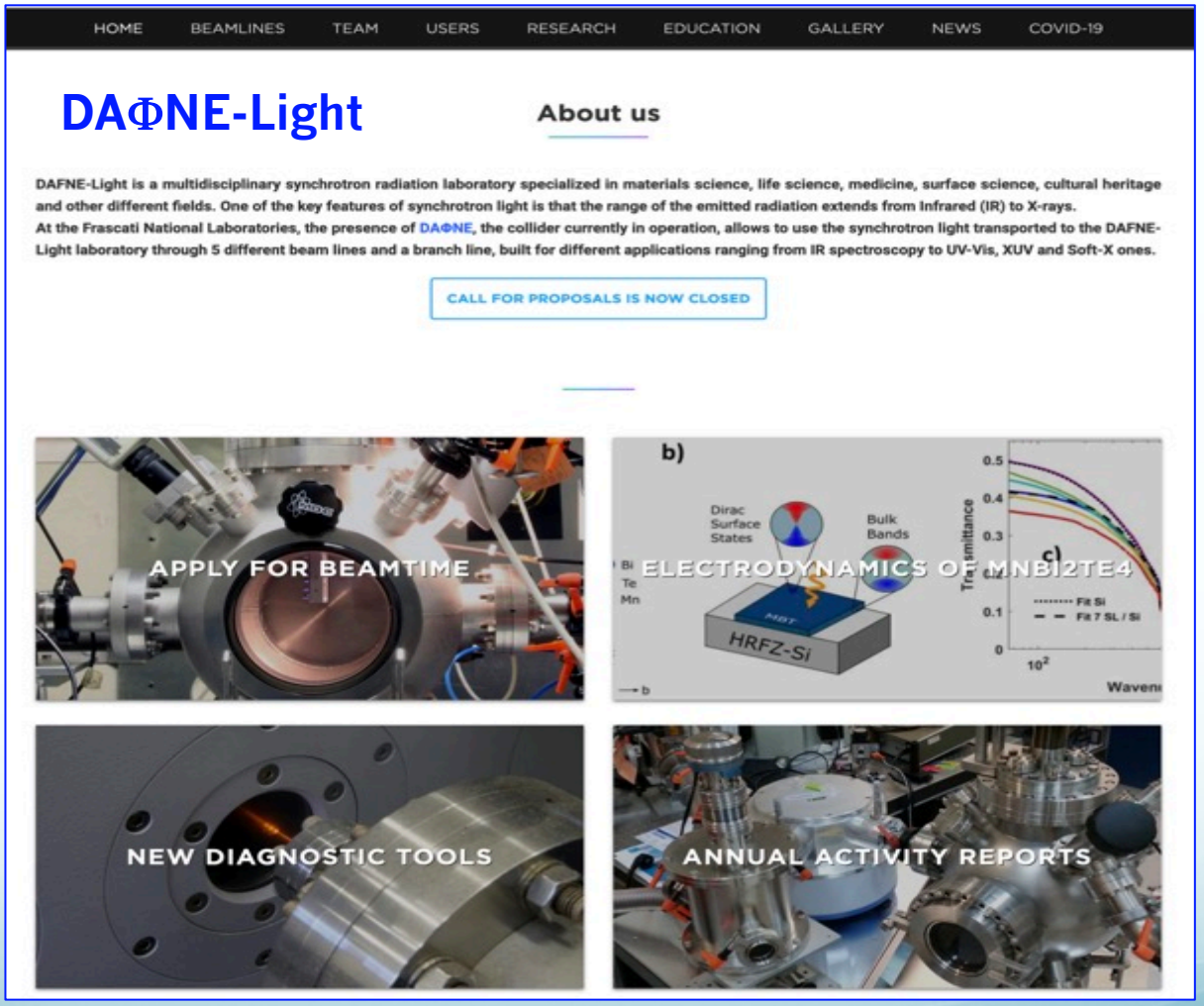




The Vis-NIR and FTIR XY mapping has been tested on artworks in a Museum: we are now working on the integration of the XRF and UVF systems.

DAΦNE-Light Facility and www

More information
https://dafne-light.lnf.infn.it/



Next Call for Proposals: 20 June 2023 – 20 August 2023

Thank you for your attention