

INFN-LABORATORI NAZIONALI DI FRASCATI
IR SYNCHROTRON BEAMLINE

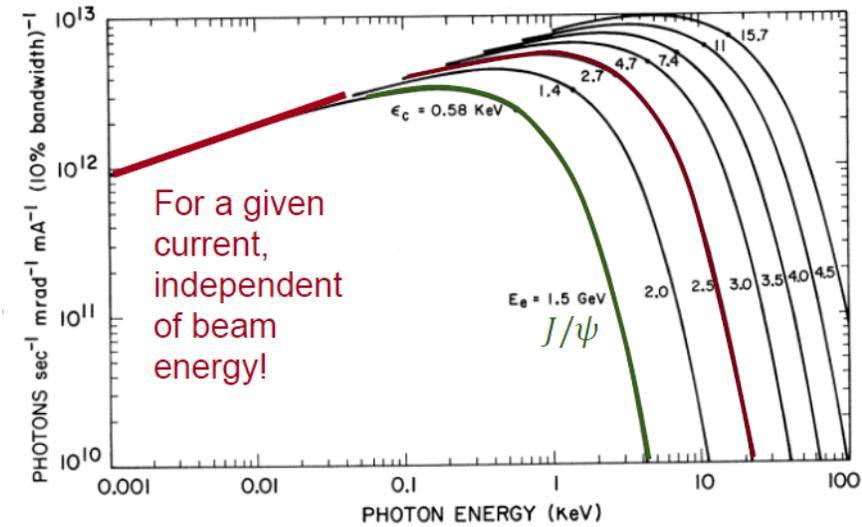
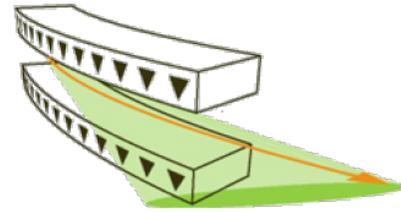
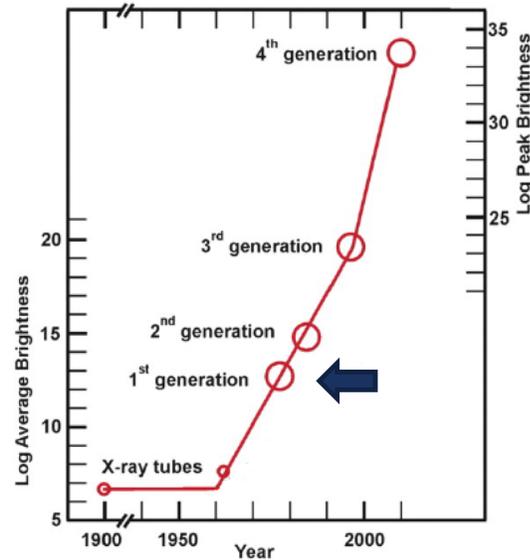
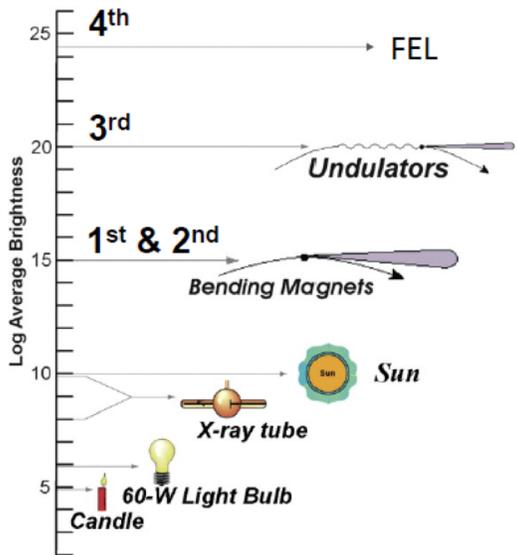
MARIANGELA CESTELLI GUIDI

M. Romani, L. Pronti, F. Benetti

A. Raco, A. Grilli, M. Pietropaoli, G. Viviani

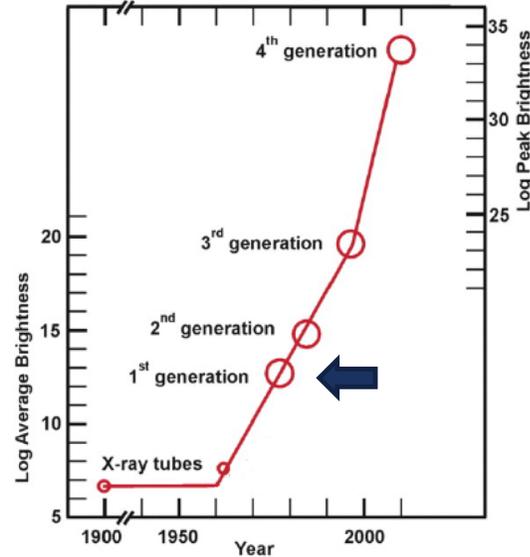
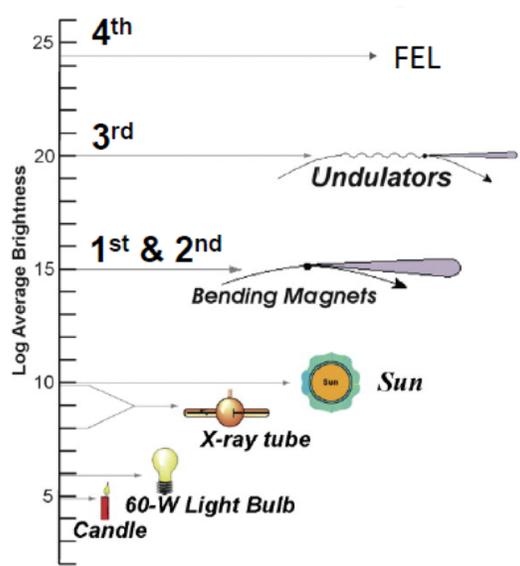


THE DAΦNE e⁺e⁻ COLLIDER: 1st GENERATION SYNCHROTRON RADIATION SOURCE

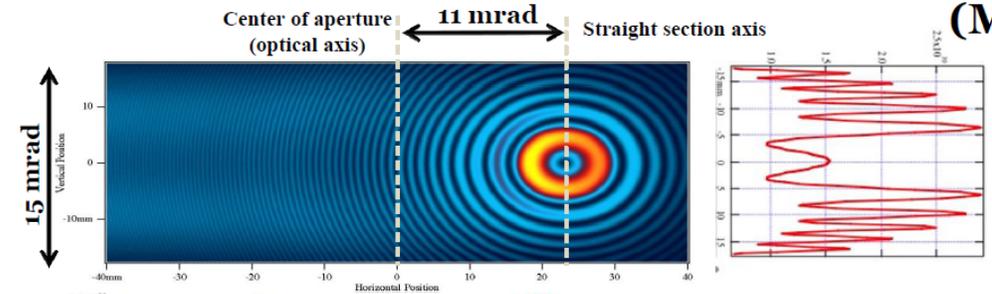


| Parameter | Description | Value |
|--------------|------------------|--------------|
| E | Electron Energy | 0.51 GeV |
| B | Magnetic field | 1.4 T |
| R | Bending radius | 1.2 m |
| I | Electron current | 1.5-2 A |
| E_c | Critical Energy | 208 eV |
| ϵ_X | Emittance | 0.3 mm. mrad |

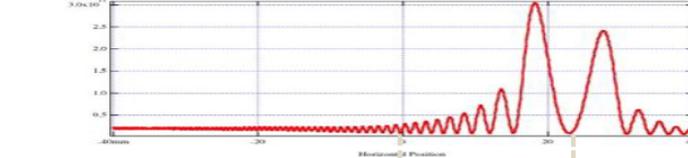
DAΦNE (e⁺e⁻ COLLIDER): SORGENTE DI RADIAZIONE DI SINCROTRONE DI 1^a GENERAZIONE



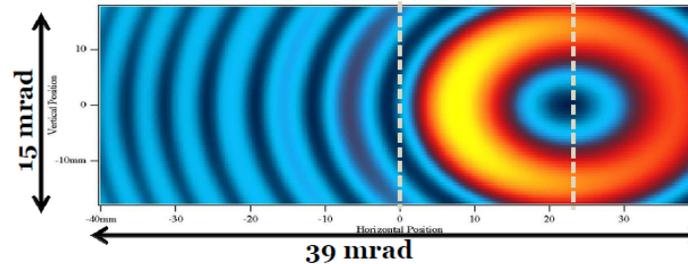
Initial Wavefront Profile



10 microns
(Mid-IR)



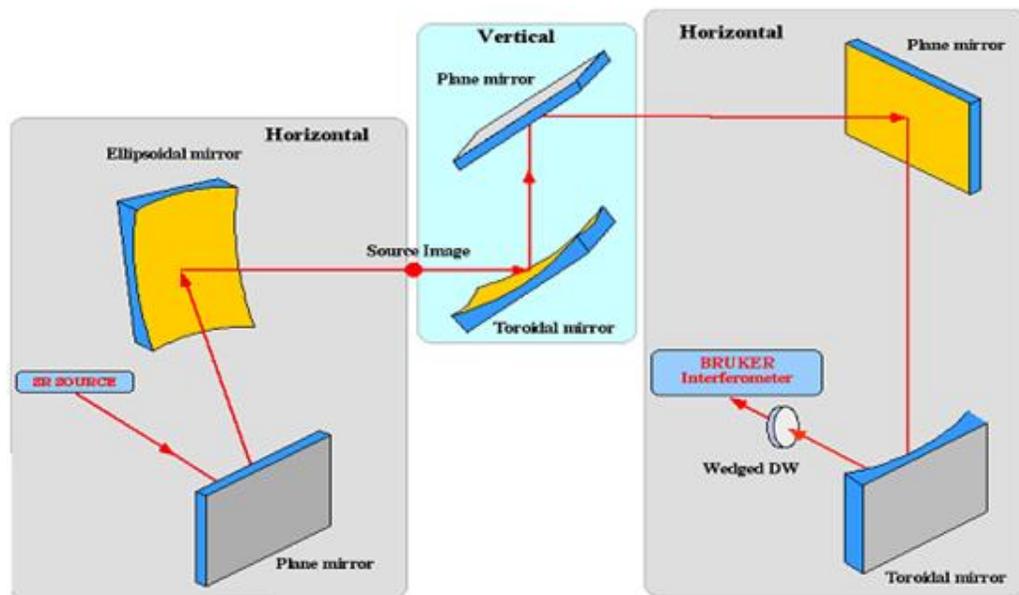
100 microns²
(Far-IR)



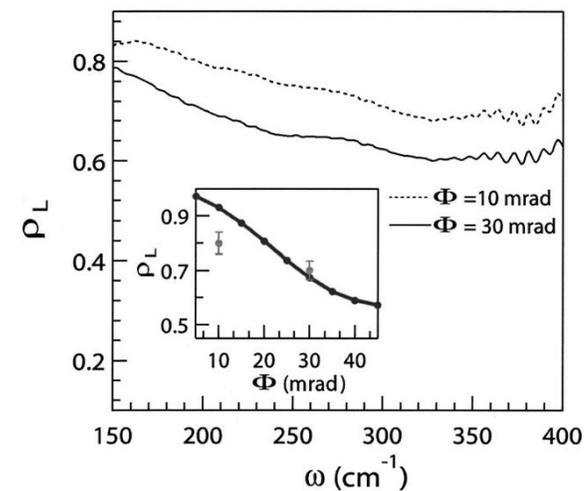
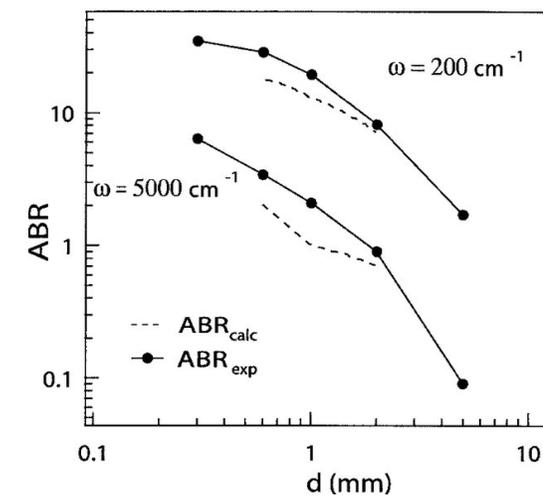
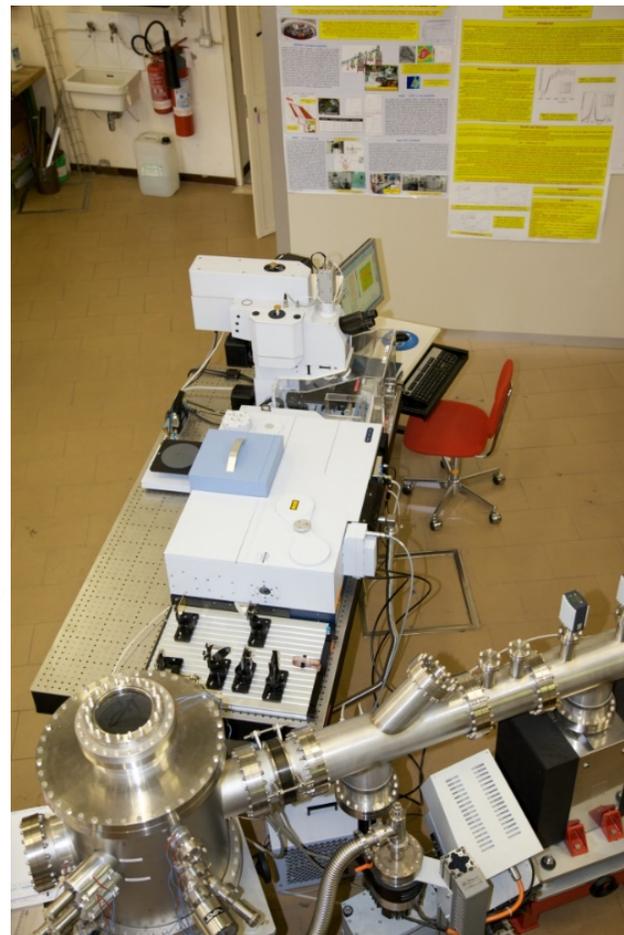
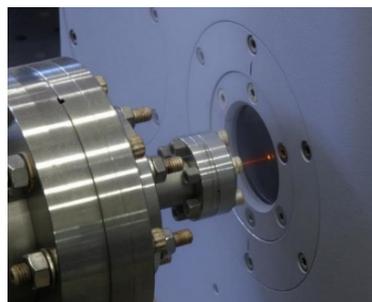
$$\theta_v \sim \lambda^{1/3}$$

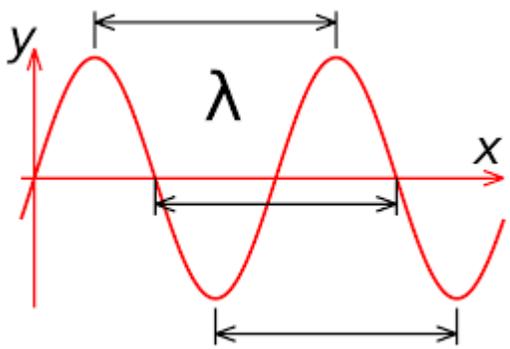
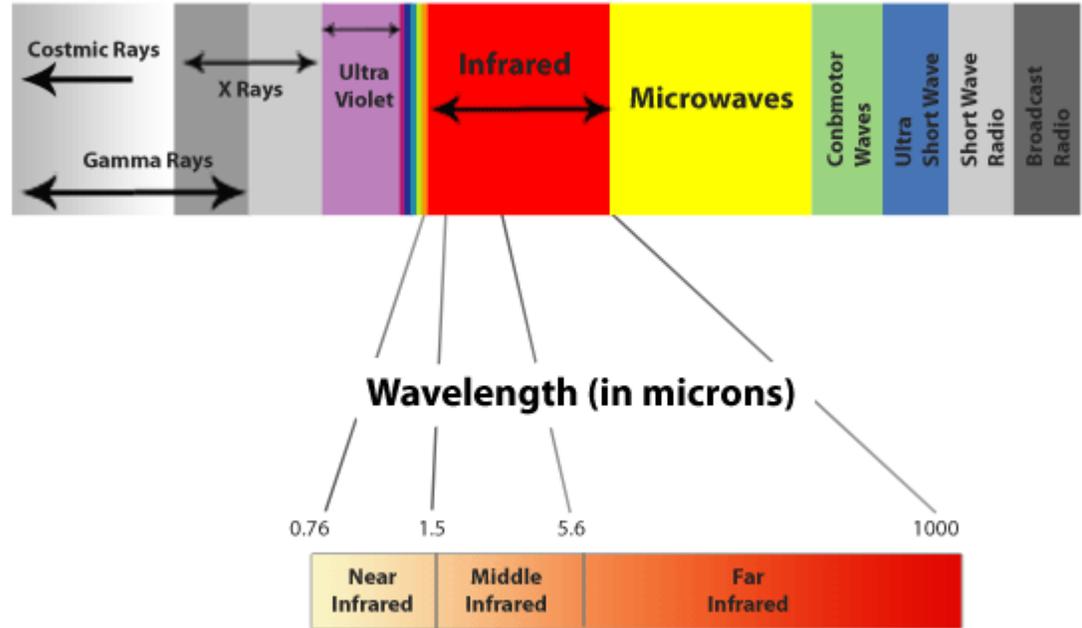
| Parameter | Description | Value |
|----------------|------------------|--------------|
| E | Electron Energy | 0.51 GeV |
| B | Magnetic field | 1.4 T |
| R | Bending radius | 1.2 m |
| I | Electron current | 1.5-2 A |
| E _c | Critical Energy | 208 eV |
| ε _X | Emittance | 0.3 mm. mrad |

LA LINEA DI LUCE DI SINCROTRONE IR «SINBAD»: SYNCHROTRON INFRARED BEAMLINE AT DAFNE LAYOUT OTTICO & COMMISSIONING



| Collecting angle | mrاد |
|------------------|---------|
| Vertical | 35 mrad |
| Horizontal | 40 mrad |

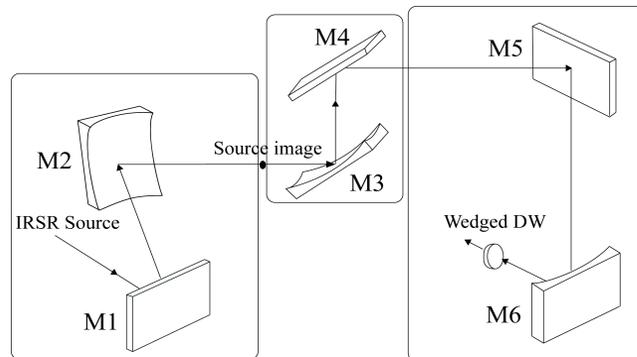
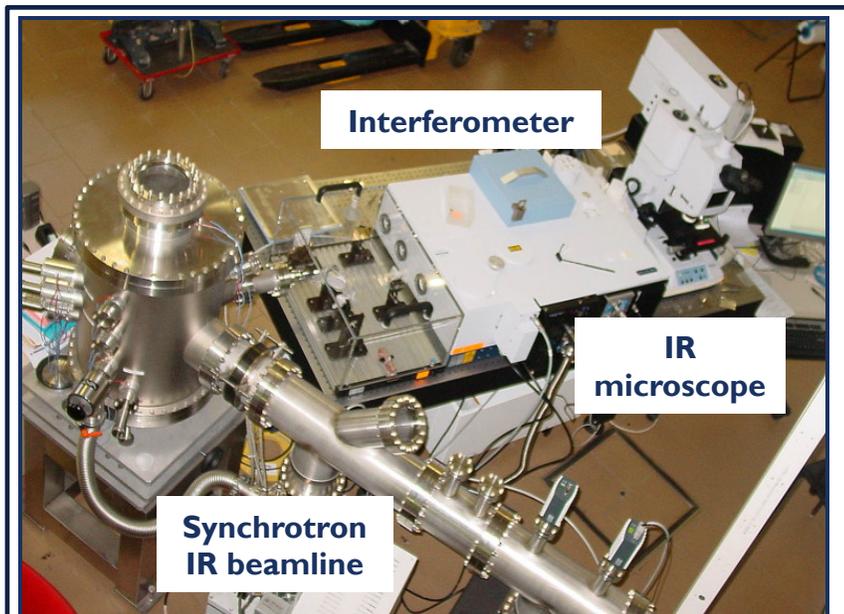




$$\tilde{\nu} \text{ (cm}^{-1}\text{)} = 1/\lambda \text{ (cm)} = 10^7/\lambda \text{ (nm)}$$

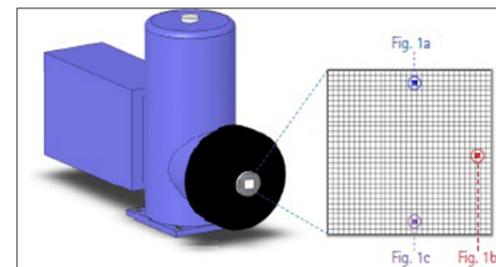
SINBAD IR BEAMLINE

INFRARED DOMAIN FROM 10 TO 10000 CM^{-1}
(1.24 MEV TO 1.24 EV)

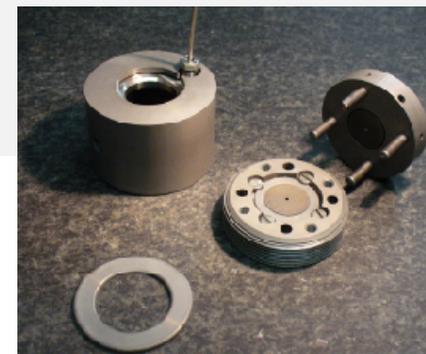


The optical layout

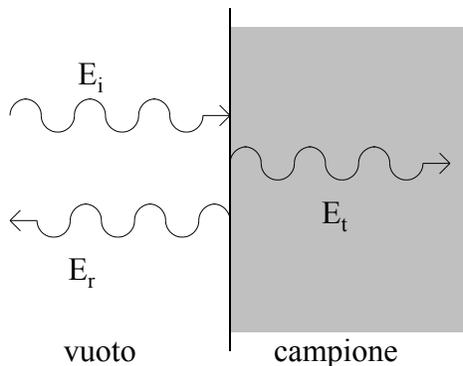
Imaging array detector 64x64 pixel



Cryogenic setup: 2K-RT
High temperature cells: RT-500K
High pressure setup: <20GPa

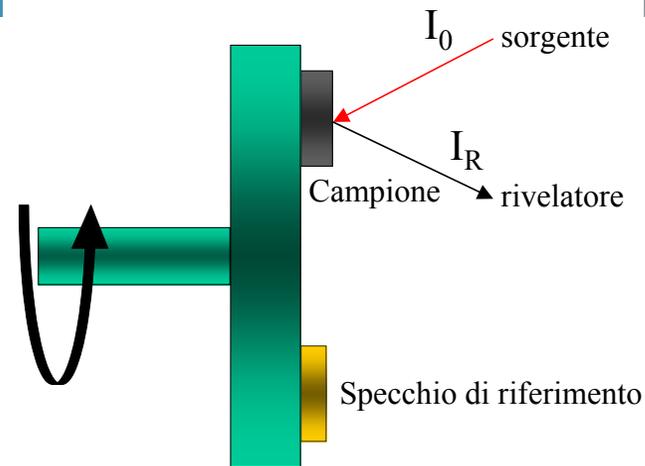


RIFLETTIVITA' E INDICE DI RIFRAZIONE



$$\tilde{\mathbf{n}} = \frac{c}{\omega} \tilde{\mathbf{q}} = \tilde{\mathbf{n}} + i \tilde{\mathbf{k}}$$

$\tilde{\mathbf{k}}$ = *coefficiente di estinzione*
 $\tilde{\mathbf{n}}$ = *indice di rifrazione*



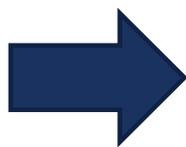
La riflettività misurata R è

$$R = \frac{I_r}{I_0} = \frac{|\tilde{\mathbf{E}}_r|^2}{|\tilde{\mathbf{E}}_i|^2} = \tilde{r}^* \tilde{r} = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2}$$

(una sola equazione nelle incognite n e k)

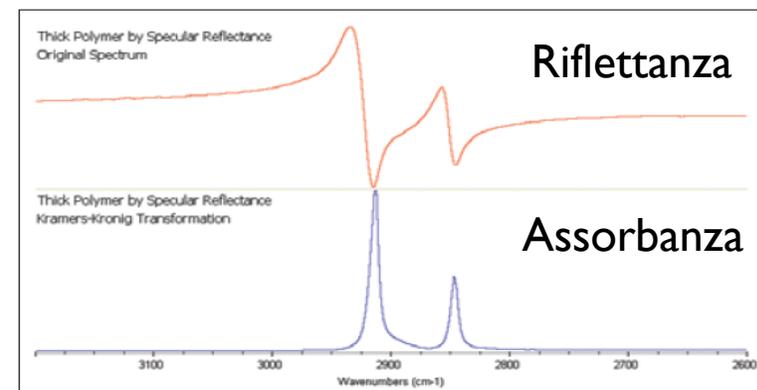
$$\theta(\omega) = -\frac{2\omega}{\pi} P \int_0^{+\infty} \frac{\ln \sqrt{R(\omega')}}{\omega'^2 - \omega^2} d\omega'$$

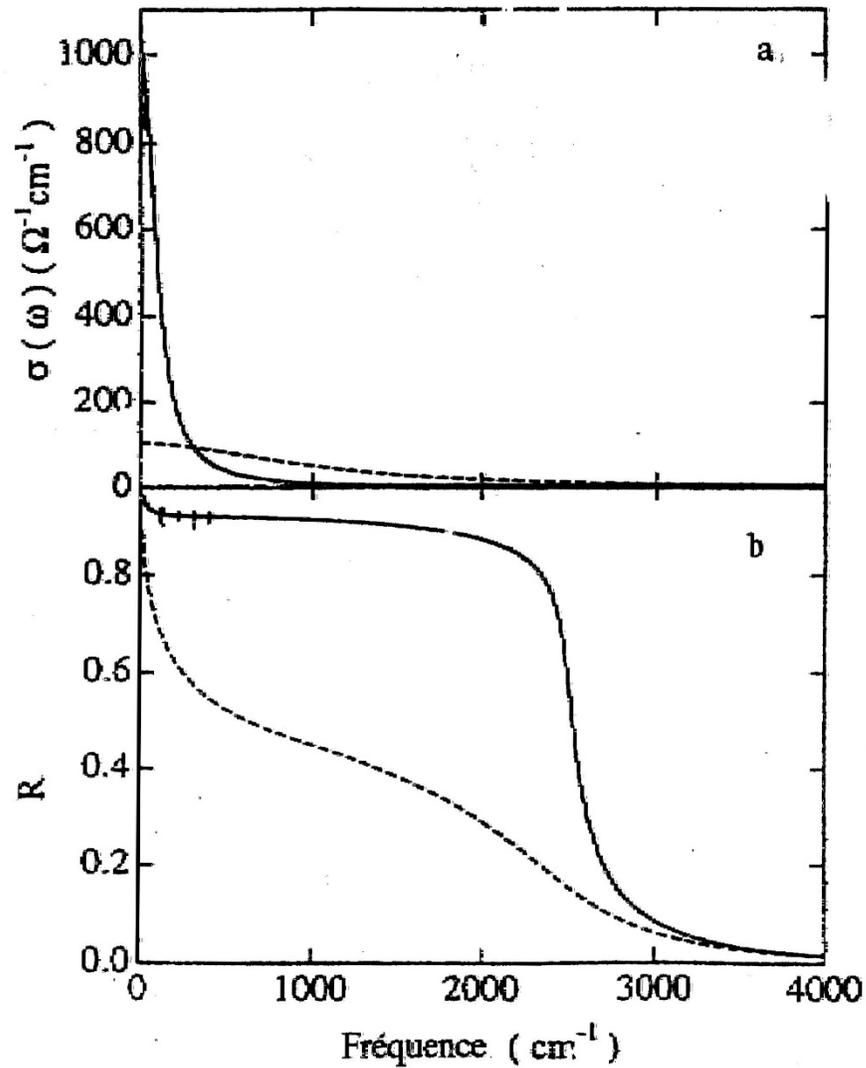
Relazioni di Kramers-Kronig



$$\begin{cases} n = \frac{1 - R}{1 + R - 2\sqrt{R} \cos \theta} \\ k = \frac{2\sqrt{R} \sin \theta}{1 + R - 2\sqrt{R} \cos \theta} \end{cases}$$

$$\begin{cases} \epsilon_1 = n^2 - k^2 \\ \epsilon_2 = 2nk \end{cases}$$





$$\tilde{\varepsilon} = \varepsilon_1 + i \varepsilon_2 = \varepsilon + 4 \pi i \frac{\sigma}{\omega} = \text{funzione dielettrica}$$

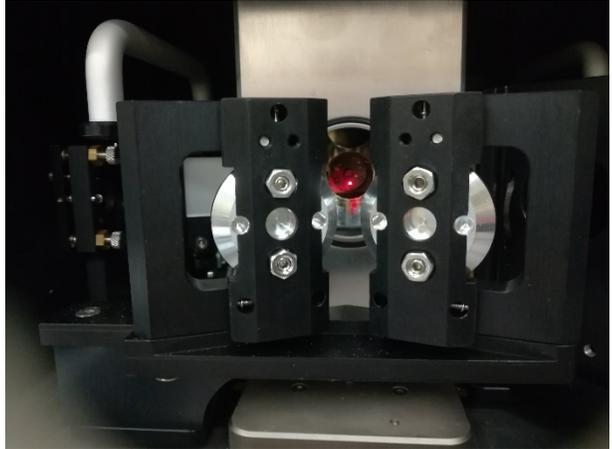
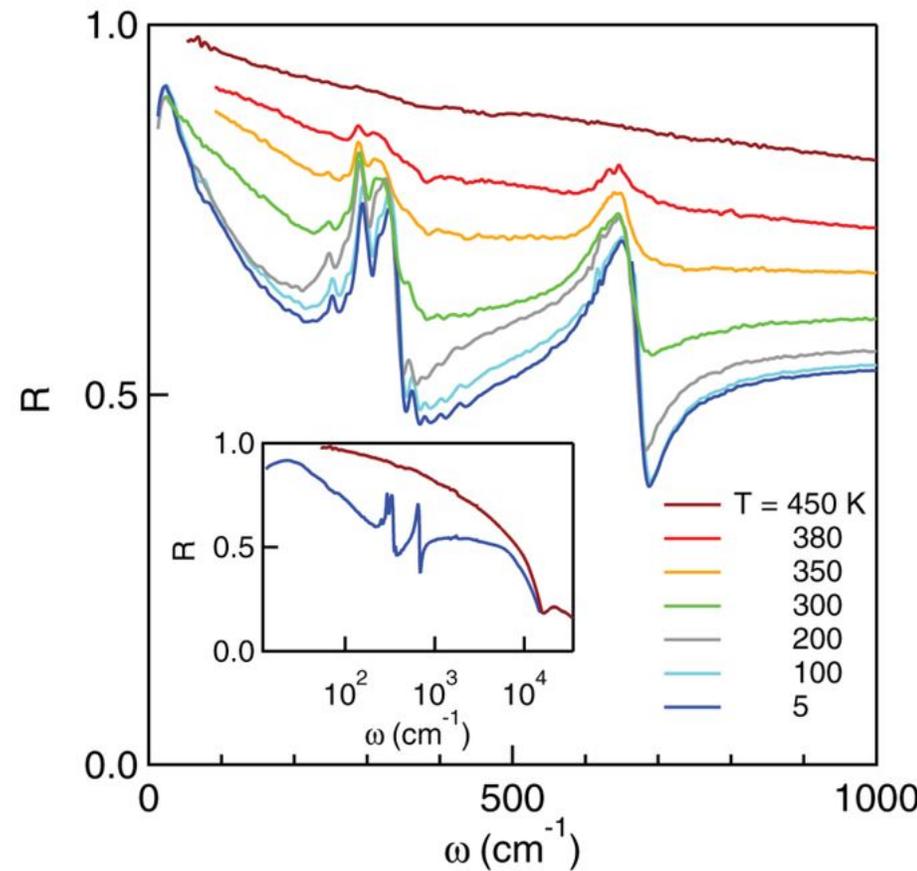
In un **dielettrico**

$$\sigma = 0 \Rightarrow \varepsilon_2 = 0 \Rightarrow k = 0 \Rightarrow \tilde{q}, \tilde{\varepsilon}, \tilde{n} \text{ reali}$$

In un **metallo** (ma anche in un **dielettrico reale** con fononi, eccitazioni interbanda, ecc.) la radiazione ha una *penetration depth*:

$$\lambda_p \propto \frac{1}{\sqrt{\sigma \omega}} \quad \text{se il mezzo è isotropo}$$

Misure di riflettività IR a bassa temperatura (4K)

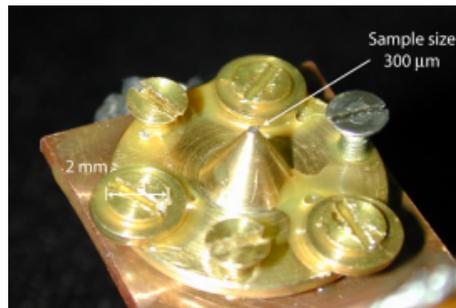


S. Lupi et al, Scientific Reports
volume3, Article number: 2990 (2013)

OPTICAL PROPERTIES OF SOLIDS

SUPERCONDUCTING GAP

PHONON SPECTRA



A. Perucchi et al.

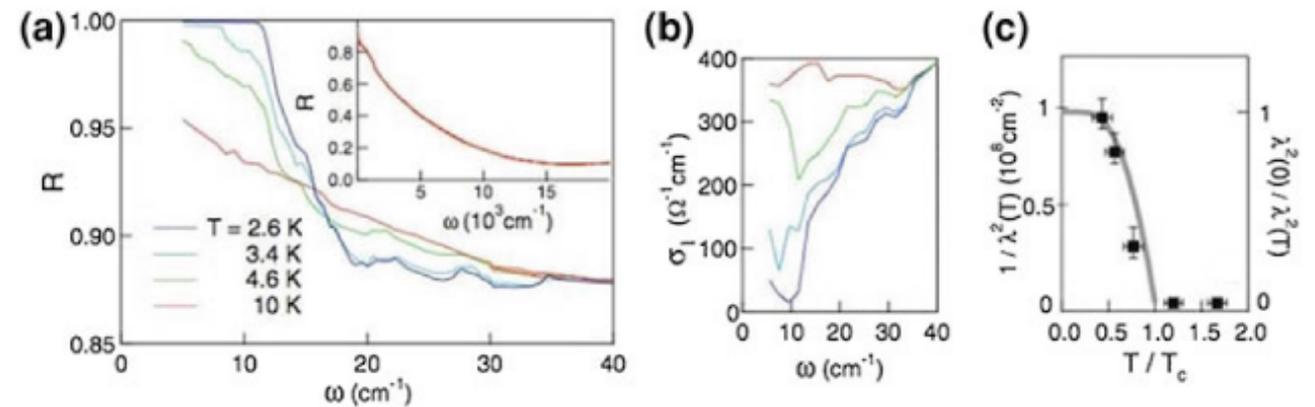
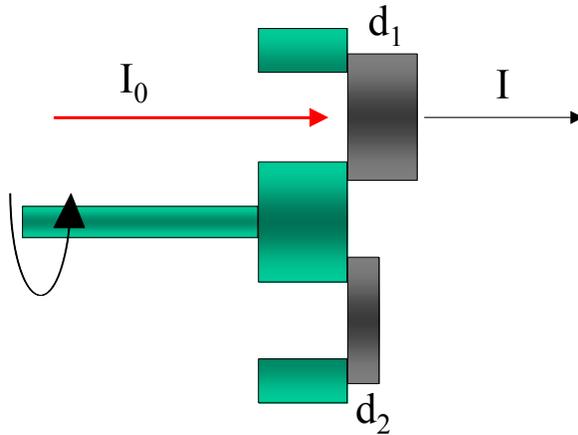


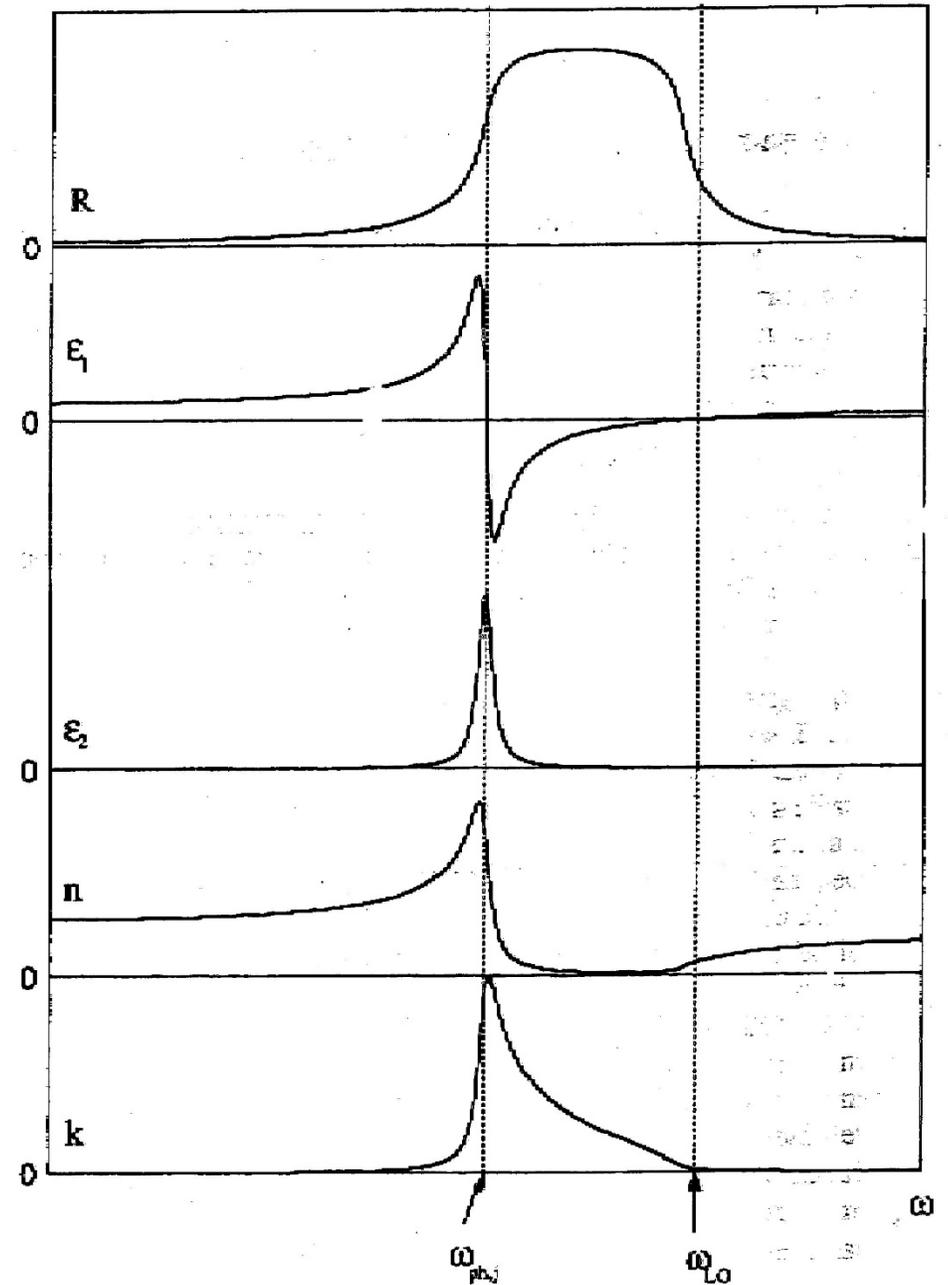
Fig. Optical response of superconducting diamond: **a** absolute reactivity in the THz range, at various temperatures. $R(\omega)$ at 10 K in the full infrared range is shown in the *inset*; **b** real part of the optical conductivity; **c** inverse square of the penetration depth (*black squares*), compared with its behavior for a dirty BCS superconductor (*gray line*).

ASSORBIMENTO E INDICE DI RIFRAZIONE

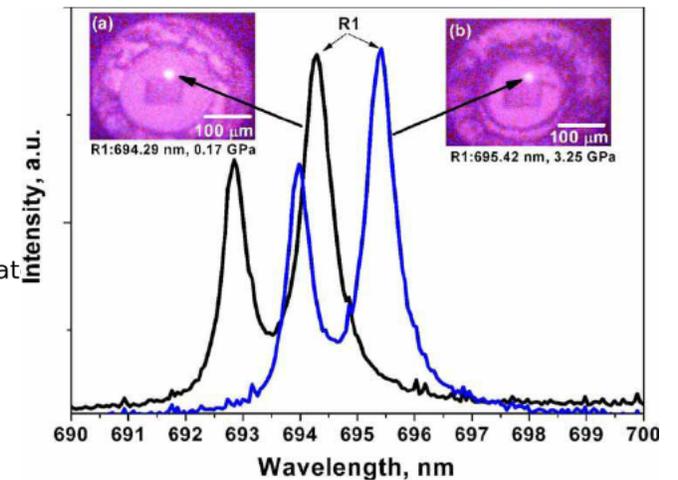
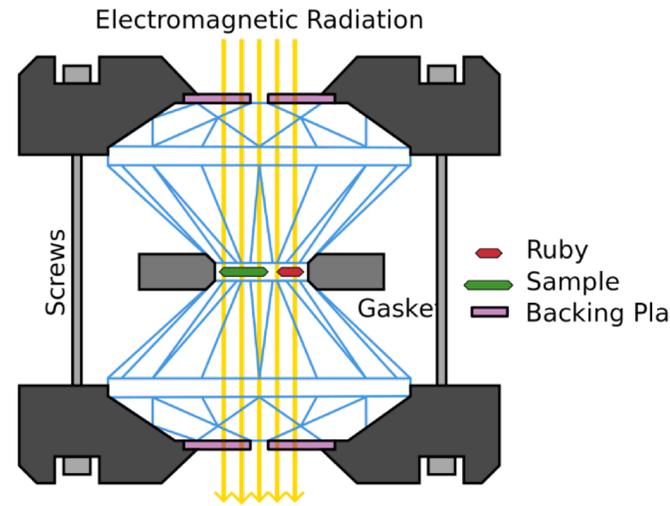
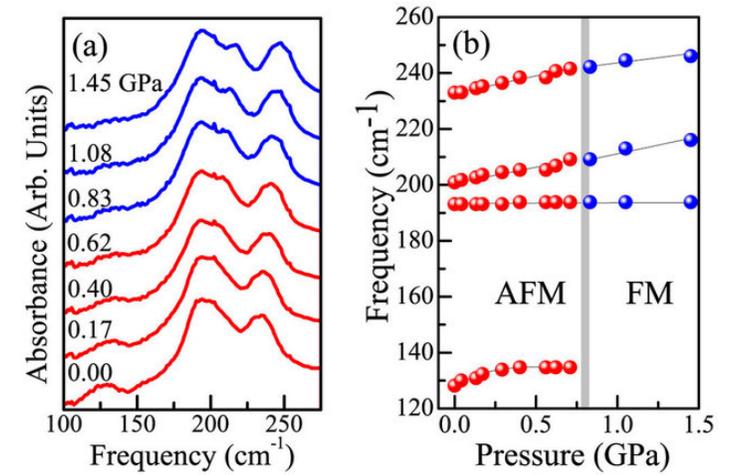
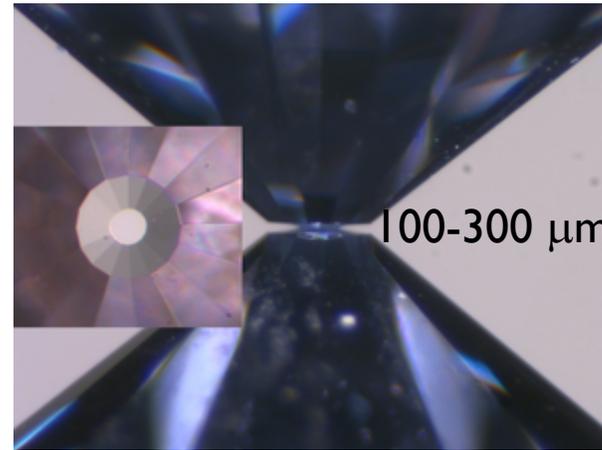
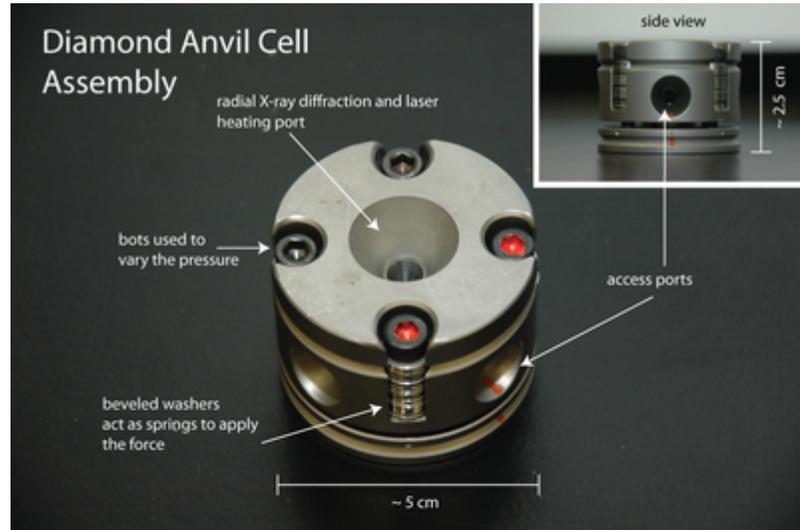


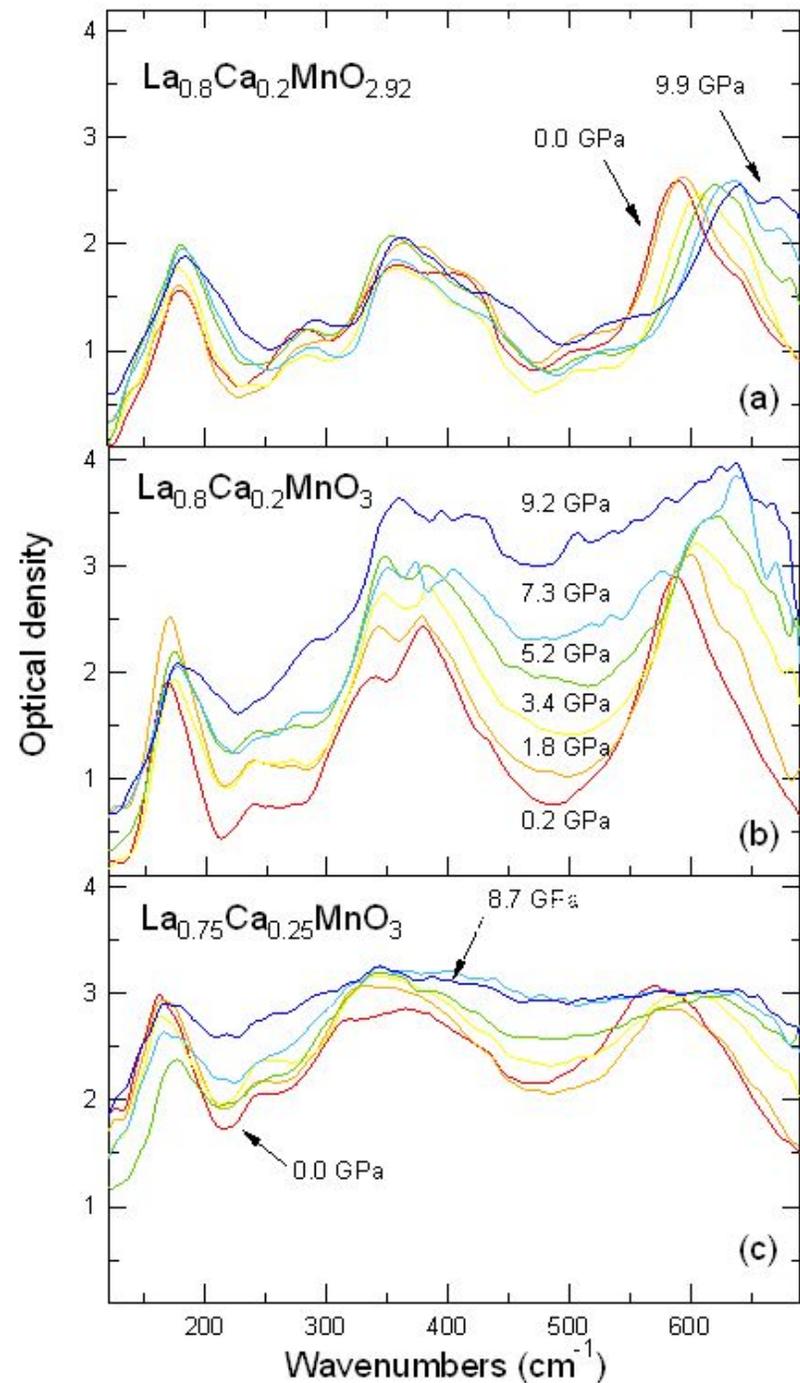
$$I = I_0 e^{-\alpha x}$$

$$\alpha = \frac{2 \omega k}{c}$$

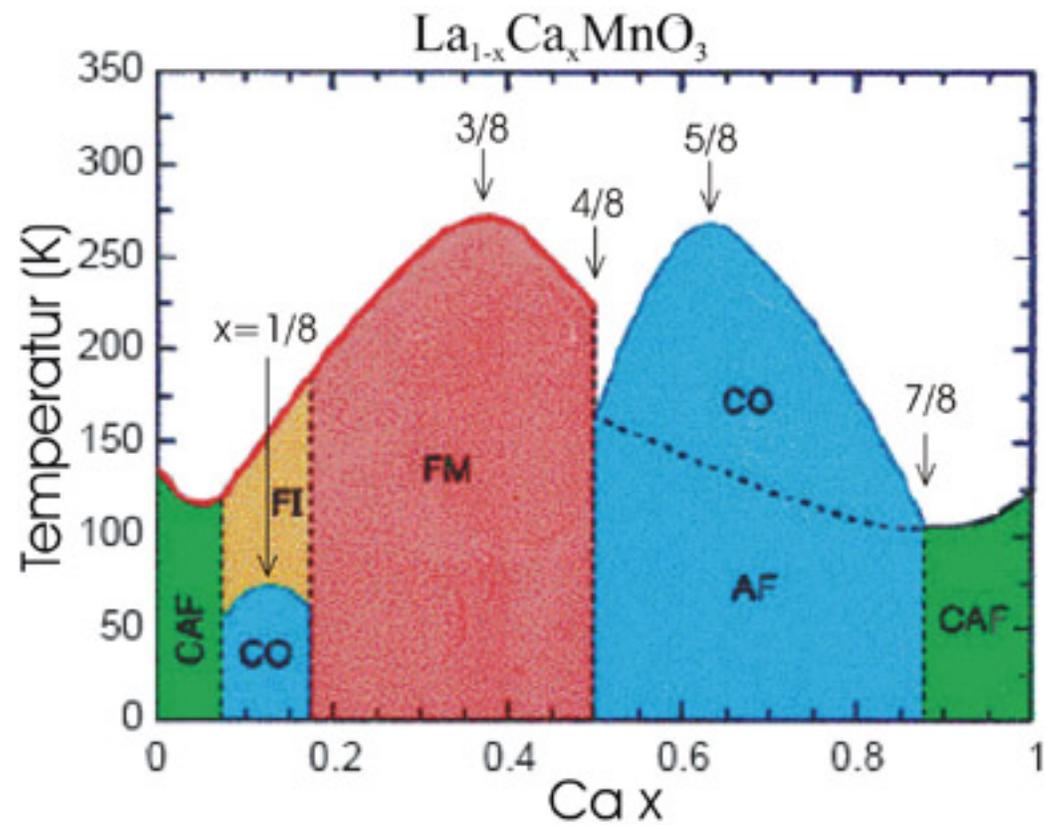


■ Celle ad incudine di diamante per studi di materiali in alta pressione





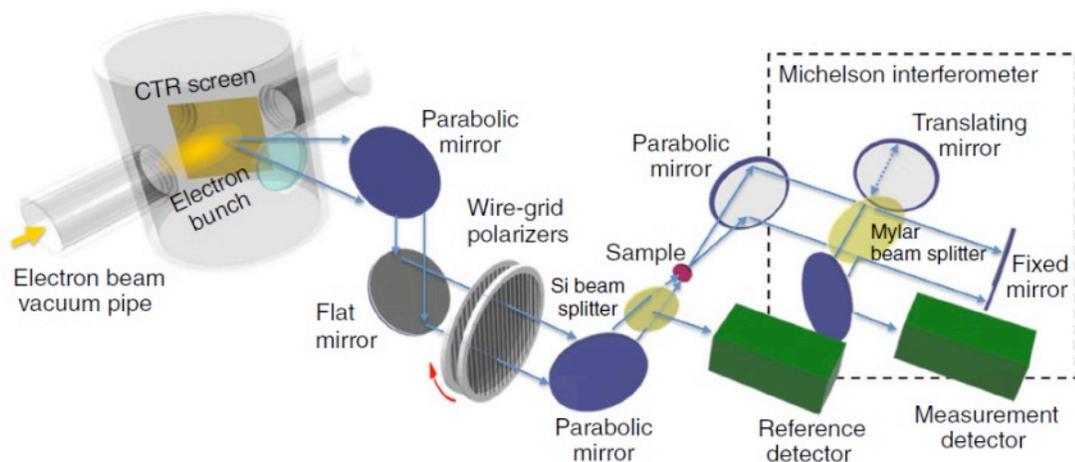
P=0-10 GPa



SVILUPPO DI SORGENTI THz DI 4^a GENERAZIONE

Produzione di radiazione THz da CTR

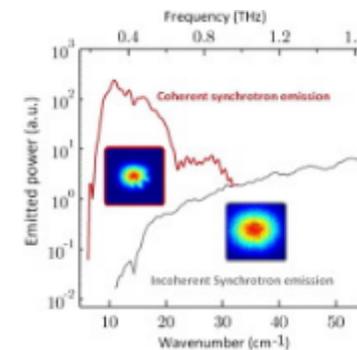
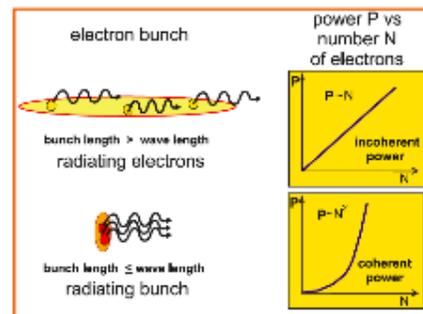
- Colmare la THz gap con campi elettrici da 100KV a 1MV/cm per esperimenti pump (THz) e probe (THz, IR, UV) + diagnostica fascio elettroni



TERASPARC, FEMTOTERA
(CSN5 2010-2012 E 2013-2015)

La radiazione coerente nel THz

- Radiazione di alta intensità e lunghezza d'onda λ è prodotta spontaneamente da un pacchetto di N elettroni quando la sua lunghezza $l_p < \lambda$.
- Gli elettroni emettono in fase e l'intensità è



$$I \propto N^2$$

- Questa condizione si può realizzare nel THz:

$$l_p \approx \lambda \approx 1 \text{ mm} \quad (\tau \sim 1 / \nu \sim 1 \text{ ps})$$

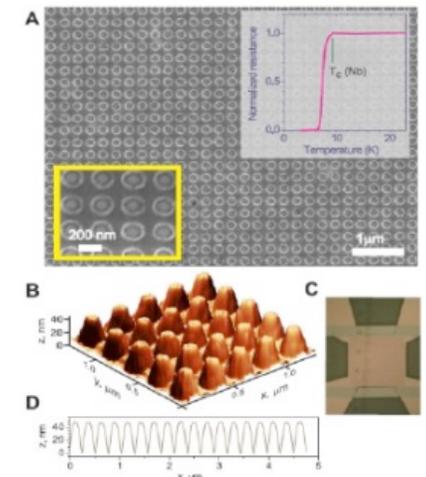
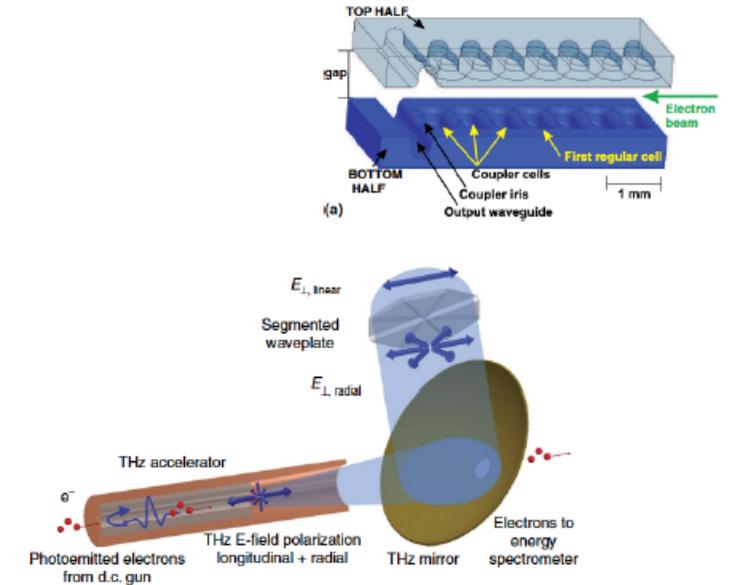
CSN5 CALL TERA (2018-2020)

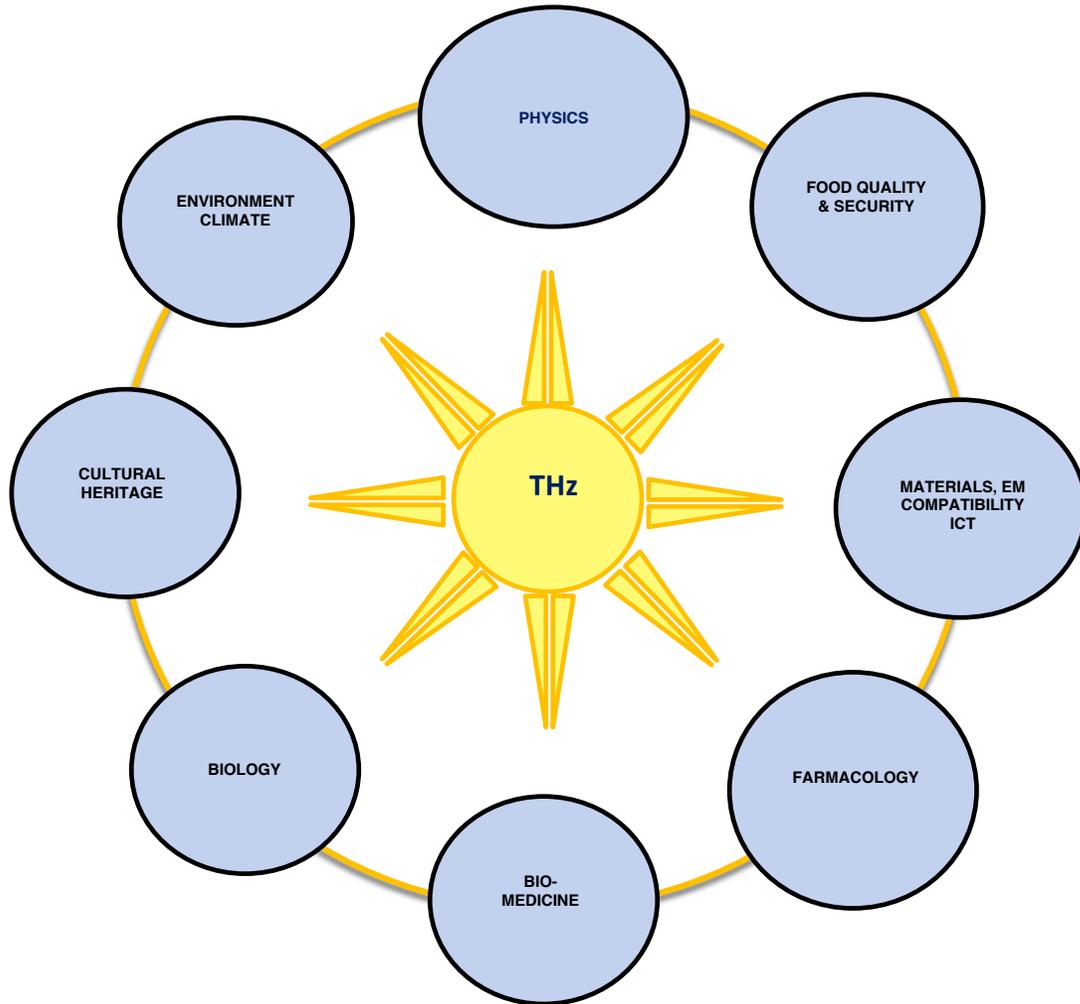
WP1 Roma Sapienza: Sviluppo di una sorgente THz da laser con le seguenti caratteristiche: Rep Rate 1 KHz; Energia/impulso 300 μ J, Campo elettrico associato $E=10-50$ MV/cm; Durata temporale $t=50$ fs; Banda spettrale 50 GHz-10 THz; Polarizzazione variabile.

- **WP2 LNF:** Studio della beam dynamics in strutture acceleranti THz per l'ottimizzazione di processi di accelerazione da single-stage a multistage linac. Simulazioni Start-to-end per dimostrare la possibilità di avere alta brillantezza e determinare il punto di lavoro per un Free Electron Laser;

- **WP3 LNF+Torino:** Sviluppo di detectors a metamateriali superconduttivi, passivi e tunabili; Caratterizzazione spettroscopica in intensità, polarizzazione e campo elettrico; Sviluppo di detectors a superconduttori. Caratterizzazione spettroscopica in intensità, polarizzazione e campo elettrico;

- **WP4 Napoli-Federico II e Università del Sannio:** Sviluppo di materiali innovativi THz; Ottiche sotto diffrattive a metamateriali; Studio spettroscopico di materiali per coating di cavita acceleranti THz; Dispositivi attivi e passivi per il controllo della fase, ampiezza e polarizzazione della radiazione THz;



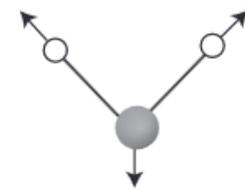


Existing THz/MIR Facilities

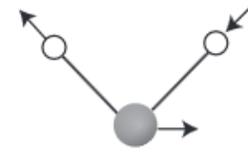
| Name Facility | Source | Bandwidth | Energy/Pulse | Rep Rate | Pulse Duration | Polarization | Electron Energy | Open to Users |
|--|-------------------------|-------------|--------------|-----------|----------------|--------------|-----------------|---------------|
| TERAFERMI@Elettra Italy | CTR/CDR | 0.5-10 THz | 50 uJ | 10-50 Hz | 100 fs | Linear | 1 GeV | Yes |
| THz@ISIR Japan | Ondulator THz Laser | 2-10 THz | 100 uJ | 22.3 MHz | 10 ps | Linear | 180 MeV | Yes |
| FELIX1-2-3 FELICE, FLARE The Netherlands | Ondulator THz Laser | 0.2-120 THz | 1-20 uJ | 15-50 MeV | 250 fs-70 ps | Linear | 10 MeV | Yes |
| FELBE Germany | Ondulator THz Laser | 1.5-80 THz | few uJ | 13 MHz | 1-25 ps | Linear | 5-40 MeV | Yes |
| TELBE Germany | Ondulator THz Laser+CTR | 0.1-3 THz | 1-100 uJ | 100 KHz | 30 fs | Linear | 5-40 MeV | Yes |
| KAERI Korea | Ondulator THz Laser | 0.3-3 THz | NaN | NaN | 20 ps | NaN | NaN | Not yet |
| THz@Novosibirsk Russia | Ondulator THz Laser | 1.5-3 THz | 40 uJ | 11.2 MHz | 10 ps | Linear | 12 MeV | Yes |

IR SELECTION RULES

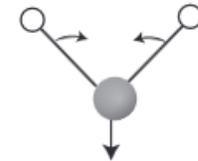
- $3N-6=3$ normal modes



symmetrical stretching



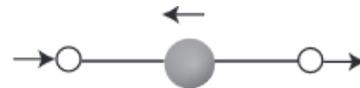
asymmetrical stretching



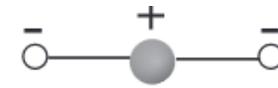
scissoring (bending)

Figure : Stretching and bending vibrational modes for H₂O

- $3N-5=4$ normal modes



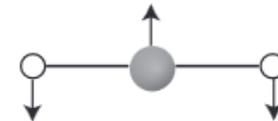
asymmetrical stretching



scissoring (bending in and out of the plane of the paper)



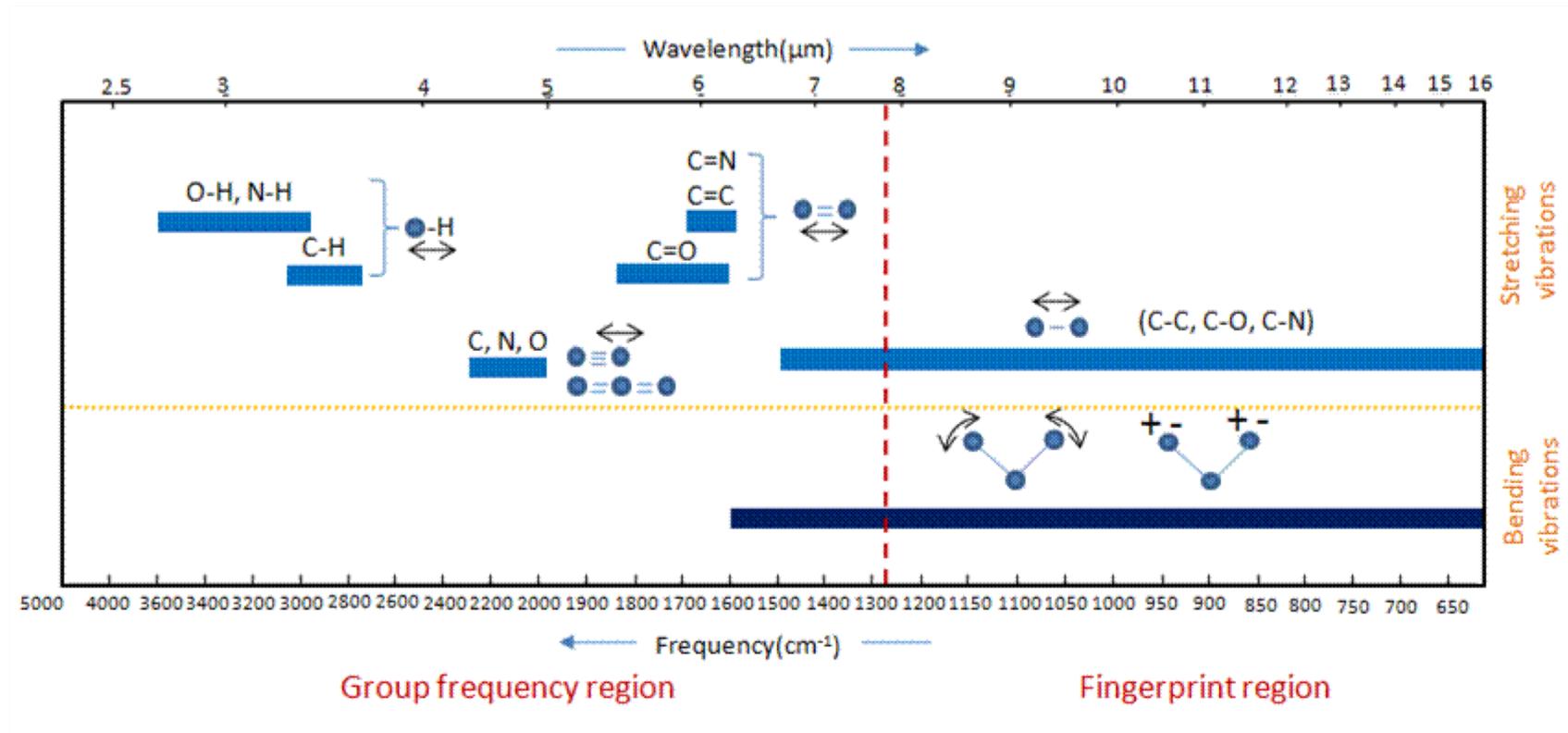
symmetrical stretching



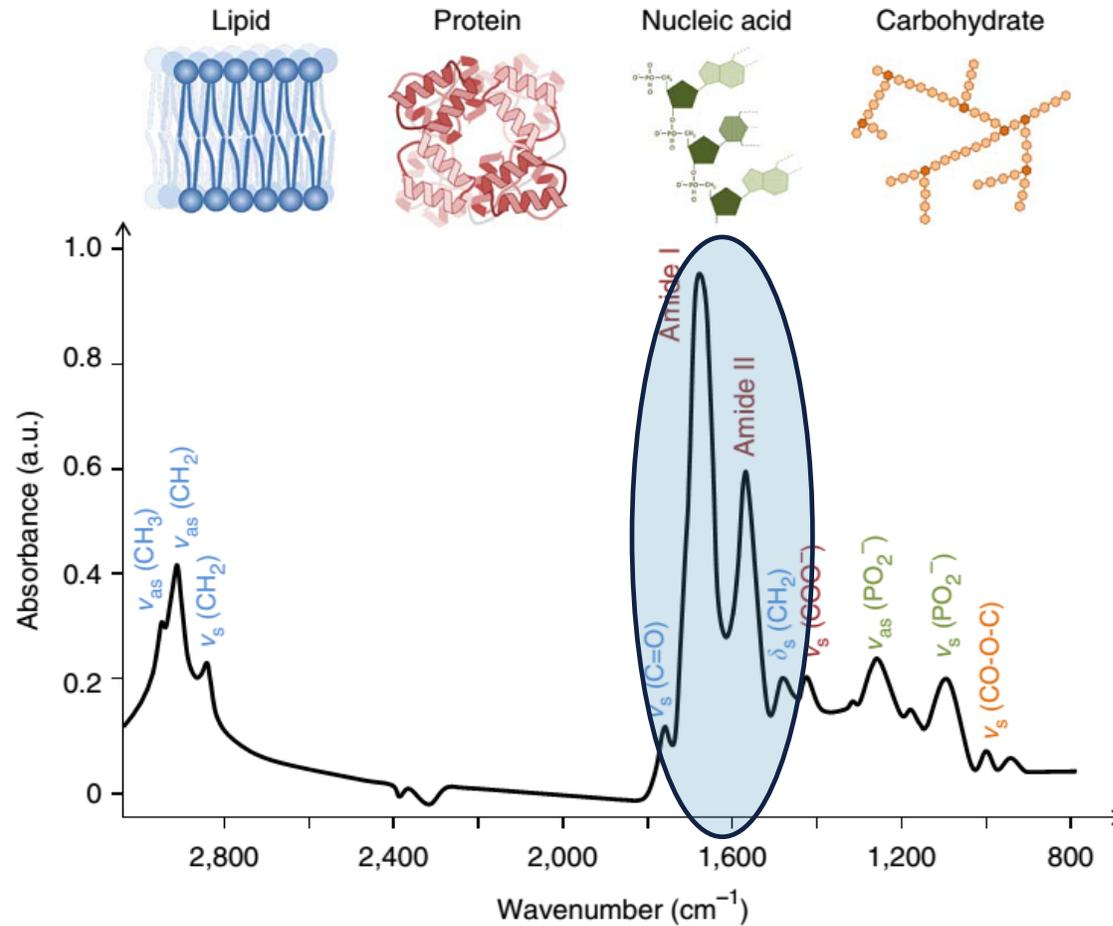
scissoring (bending in the plane of the paper)

Figure : Stretching and bending vibrational modes for CO₂

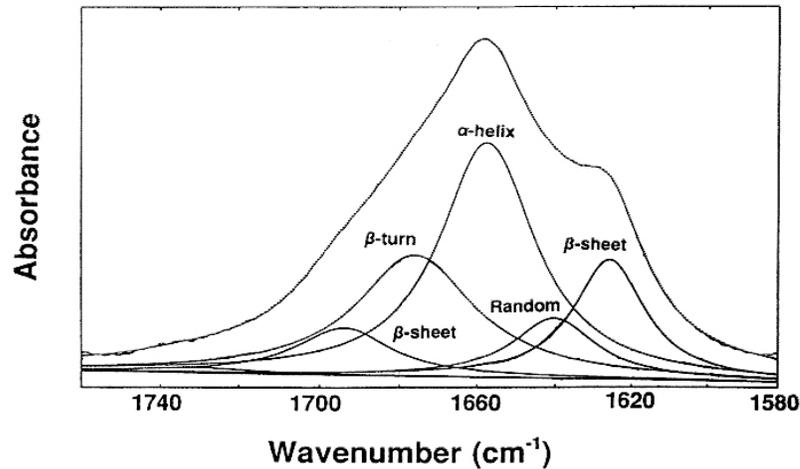
IR active modes are related to a change in the electrical dipole moment



Every FTIR spectrum contains information about fundamental constituents of a biological specimen:



Study of protein secondary structure



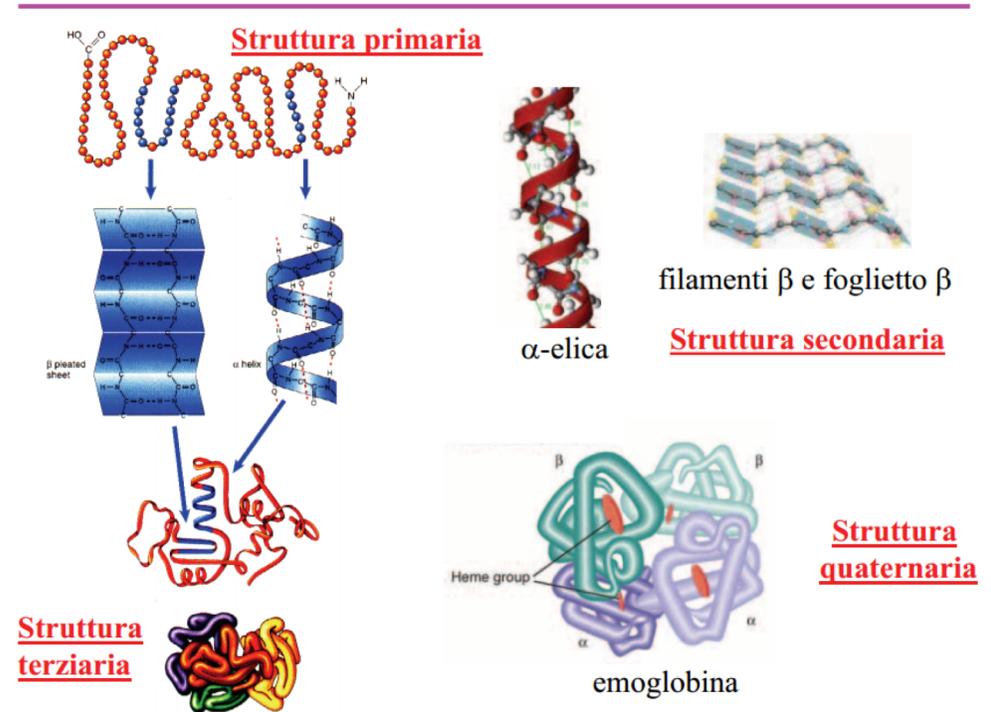
The frequency limits for the different secondary structures were as follows:

α-helix: 1662-1645 cm⁻¹;

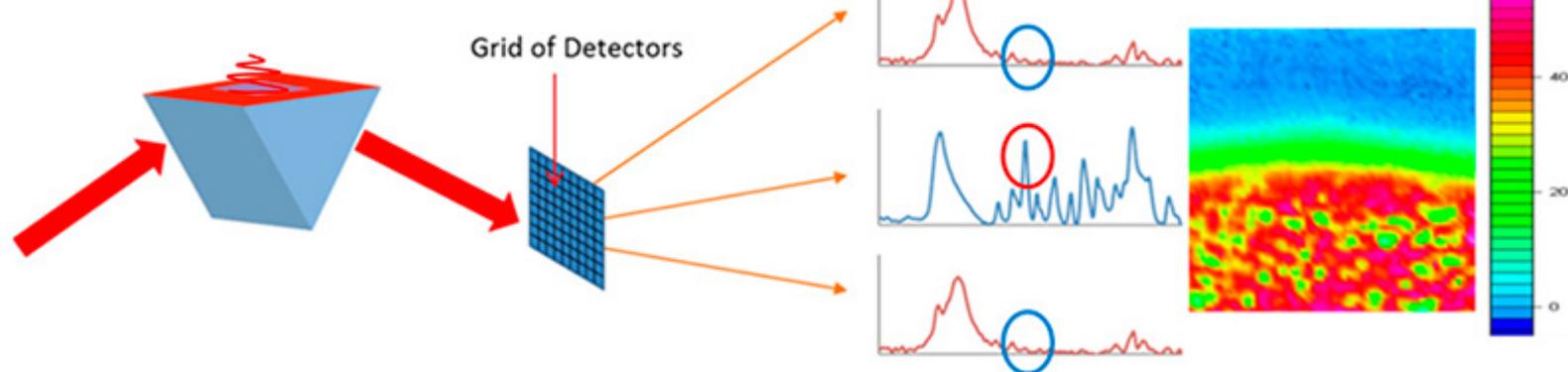
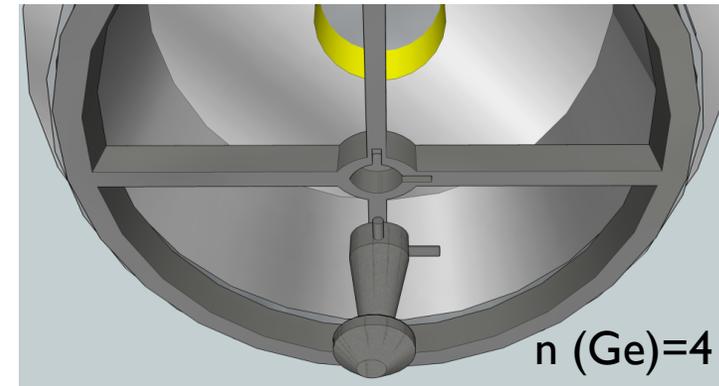
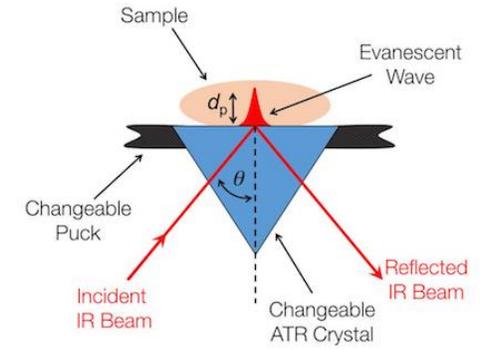
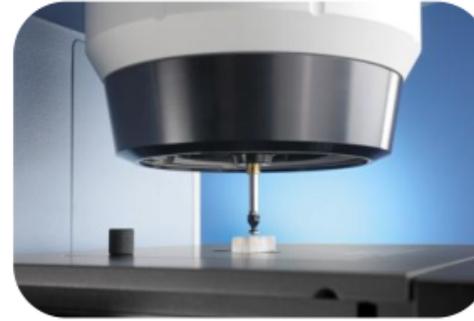
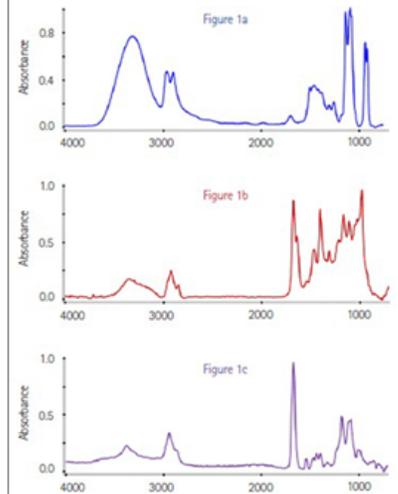
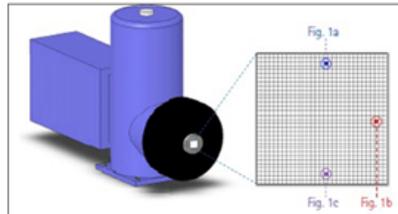
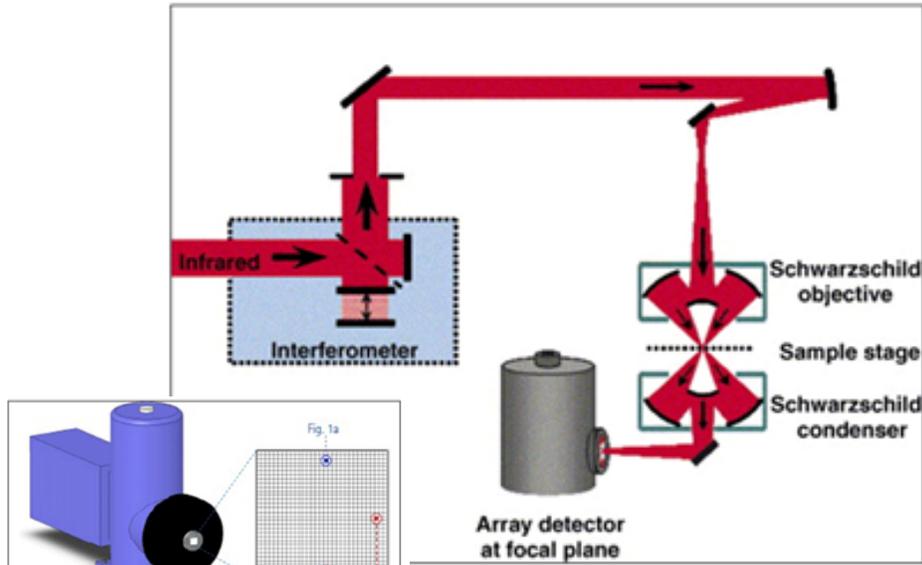
β-sheet: 1637-1613 cm⁻¹ and 1689-1682 cm⁻¹;

β-turns: 1682-1662 cm⁻¹;

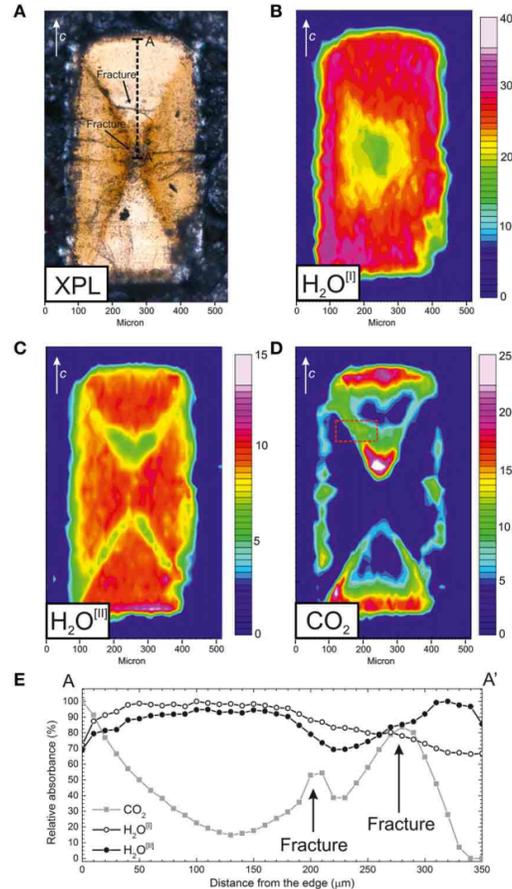
disordered structure(random) 1645-1637 cm⁻¹.



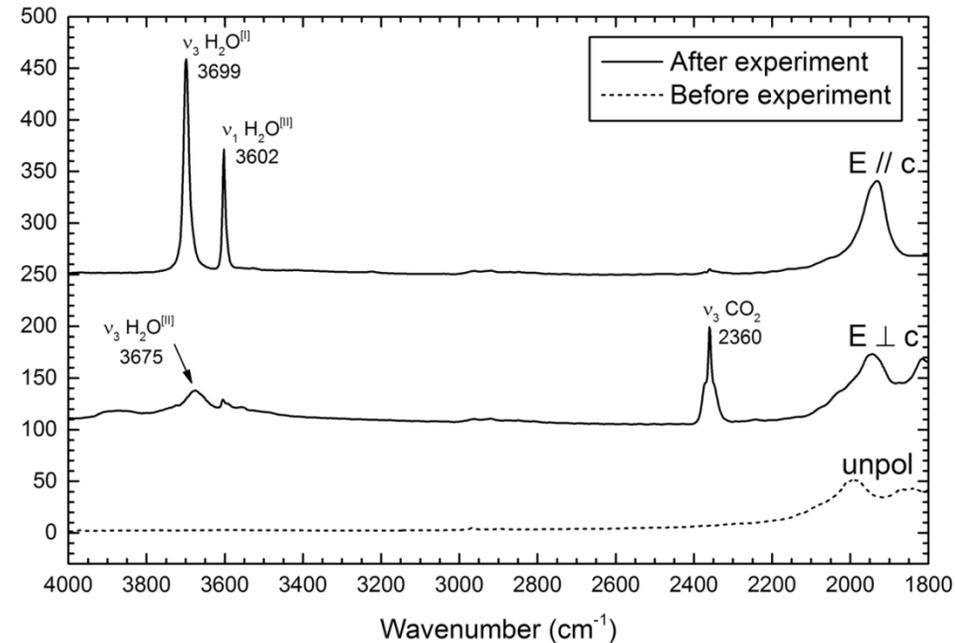
■ Microspettroscopia IR e imaging



FTIR IMAGING IN DIFFUSION STUDIES: CO₂ AND H₂O IN A SYNTHETIC SECTOR-ZONED BERYL



Strongly inhomogeneous distribution of CO₂ and H₂O in a synthetic beryl having a peculiar hourglass zoning of Cr due to the crystal growth. The sample was treated at 800°C, 500 MPa, in a CO₂-rich atmosphere.

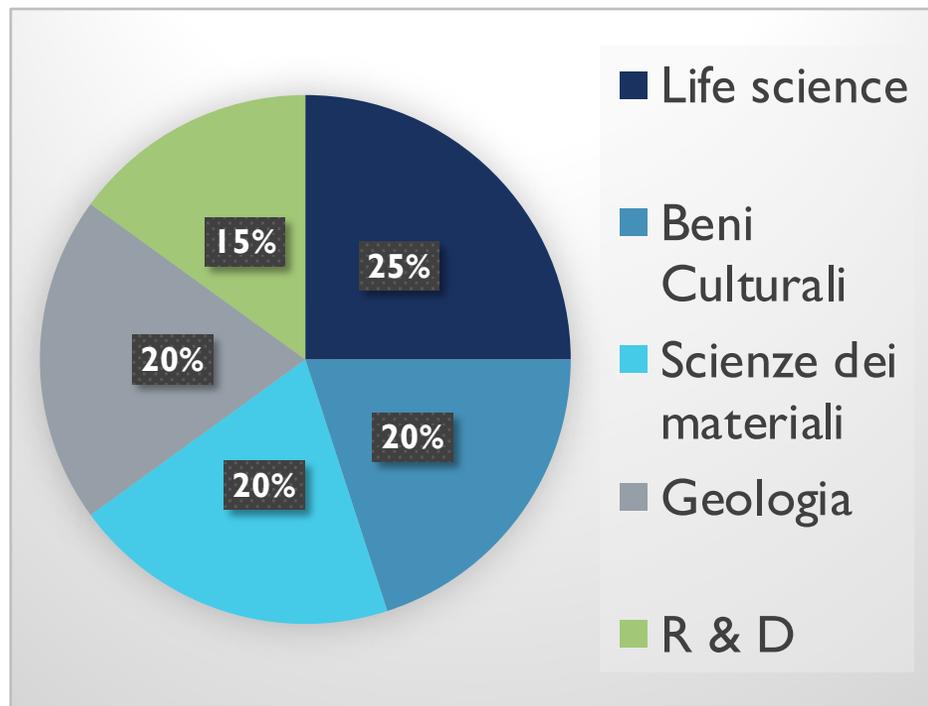


(A) Crossed polars optical image (XPL) of the treated beryl sample. Polarized-light FPA-FTIR images of (B) H₂O[II] distribution, E//c, integration range 3740–3655cm⁻¹, (C) H₂O[III] distribution, E/c, integration range 3630–3577cm⁻¹, and (D) CO₂ distribution, E,c, integration range 2396–2325cm⁻¹.

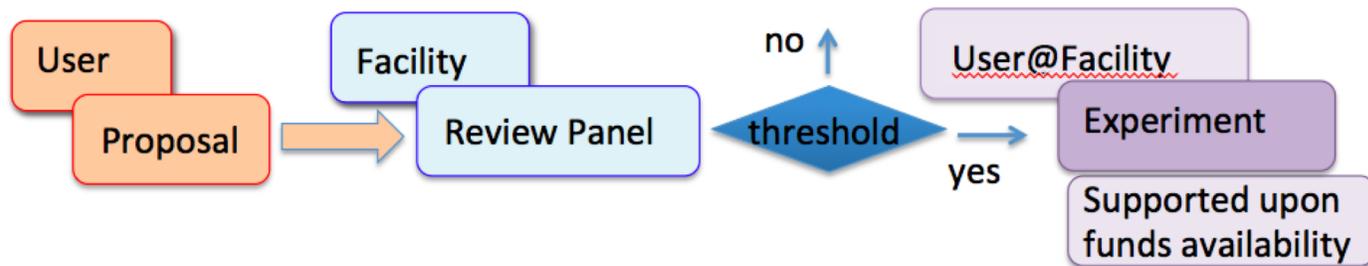


Elettra Sincrotrone Trieste

Utenti esterni

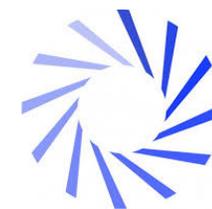


~30 proposal/anno

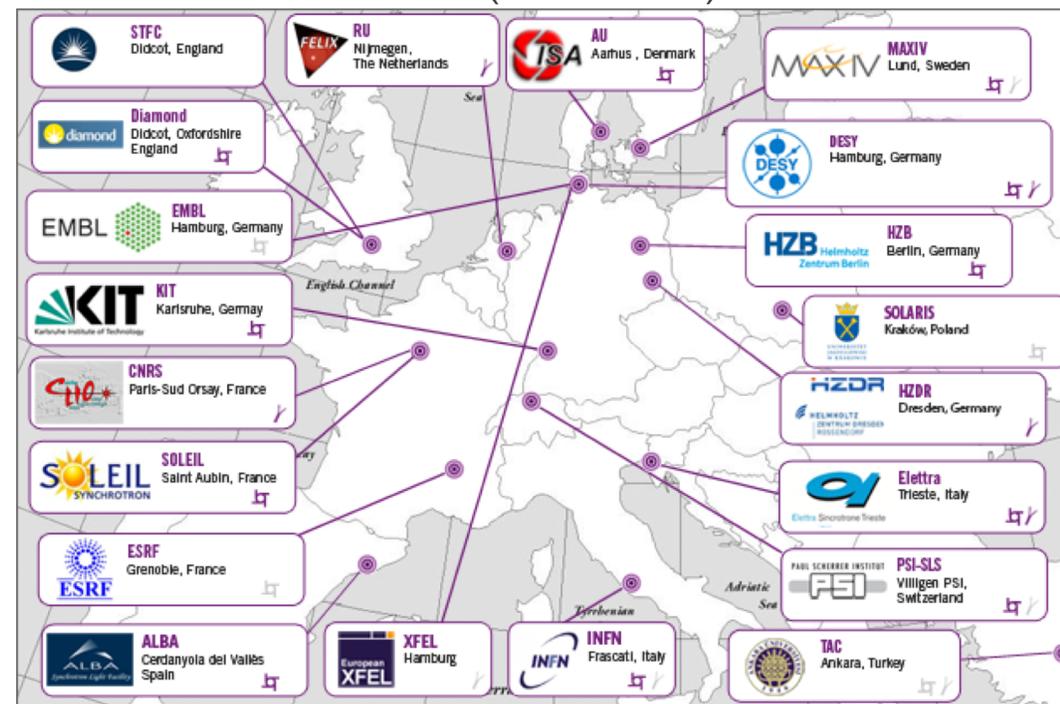


Programmi EU per alle infrastrutture

- TARI – Hadron Physics FP6 (
- E.Li.Sa FP7 (2009-2011)
- CALIPSO (2012-2015)
- CALIPSO PLUS (2017-2019)
- LEAPS H2020 (2020-2030)



SESAME





The school covers a comprehensive training in Synchrotron Infrared Spectroscopy and Imaging for Life-Science applications, to train researchers who will benefit from the techniques that will become available at the SESAME InfraRed beamline.

Within the OPEN SESAME project (www.opensesame-h2020.eu) INFN (Istituto Nazionale di Fisica Nucleare) and the INFN-LNF DAFNE-Light Synchrotron radiation facility are offering 20 full grants for a dedicated training programme open to young researchers from the SESAME Members (Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, the Palestinian Authority and Turkey) to strengthen the role of SESAME in the region.

The programme includes a number of learning sessions, both theoretical and practical, run by top scientists working in European Synchrotron beamlines and international research infrastructures.

Participants will explore and develop a range of key practices, capabilities and skills associated with the use of an infrared synchrotron beamline, including sampling techniques, sample preparation and data handling.

Lecturers

Lisa Vaccari, Elettra Sincrotrone Trieste (Italy)
Christophe Sandt, Synchrotron Soleil (France)
Que Nguyen, Diamond Light Source (UK)
Liljana Puskar, Helmholtz-Zentrum Berlin (Germany)
Gihan Kamel, SESAME (Jordan)
Mariangela Cestelli Guidi, LNF-INFN (Italy) - Chair

Topics

Life Science Infrared Synchrotron spectroscopy
IR Microscopy and Imaging
Cells and tissue spectroscopy
Sample preparation and handling
Multivariate data analysis



Organizing Committee

Mariangela Cestelli Guidi, LNF-INFN
Antonella Balerna, LNF-INFN
Daniela Ferrucci, LNF-INFN
Rawan Ramadan, SESAME
Greta Facile, SESAME

Scientific Committee

Mariangela Cestelli Guidi, LNF-INFN
Paul Dumas, Synchrotron Soleil
Gihan Kamel, SESAME
Miguel Aranda, Cells
Ed Mitchell, ESRF

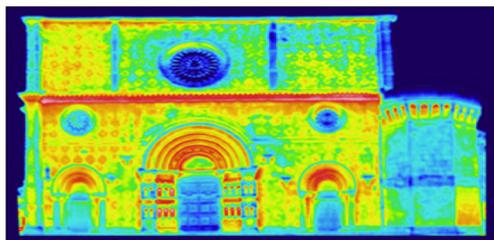
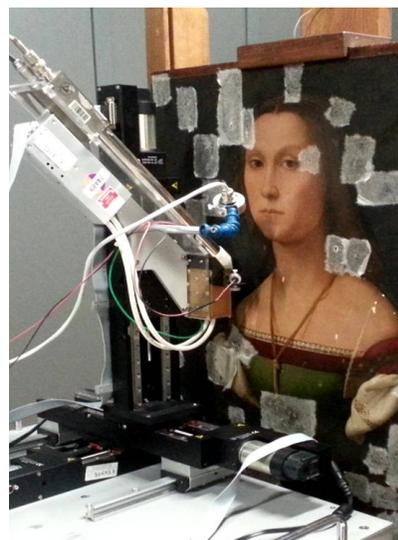


Istituto Nazionale di Fisica Nucleare
Cultural Heritage Network

CHNet-Cultural Heritage Network
Rete di competenze dell'INFN-Istituto Nazionale di Fisica Nucleare
per lo studio e la diagnostica dei Beni Culturali.

Tecnologie e competenze all'avanguardia, sviluppate dalla ricerca fondamentale dell'INFN, per rispondere alle esigenze di studiosi e operatori pubblici e privati: conservatori, restauratori, curatori, storici dell'arte e archeologi

RICERCA



FORMAZIONE



<https://chnet.infn.it> | chnet.infn@infn.it



ANALYSES

Portable Systems:

Raman Spectroscopy 785 nm (**LNF**)

FTIR spectroscopy (**LNF**)

X-Ray Fluorescence Spectroscopy (**RM2**)

Multi Spectral Imaging 370-1700 nm (**RM2**)

Laser Induced Fluorescence Spectroscopy (LIF) (**RM2**)

FORS and Colorimetric Analysis (**RM2**)

Lab Systems:

SEM Microscopy (**LNF**)

Raman microscopy 512nm, 785 nm (**LNF**)

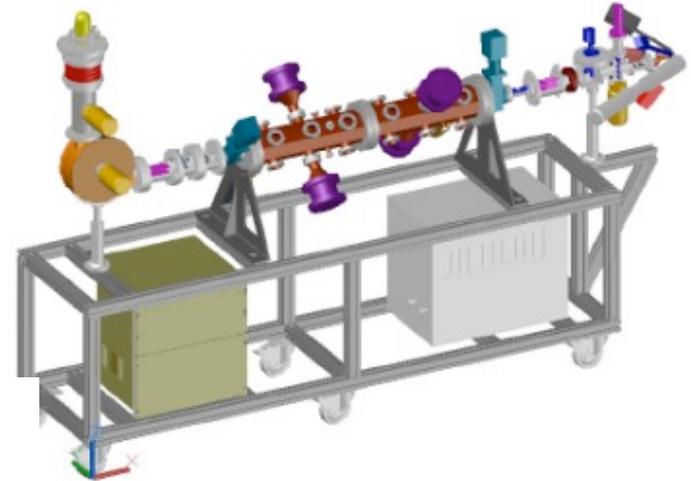
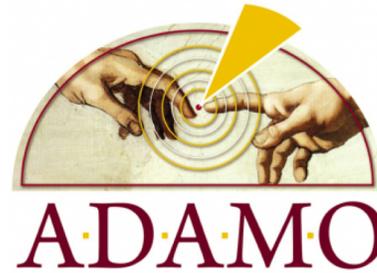
FT-IR Spectroscopy (micro and imaging) with SR (**LNF**)

ATR FT-IR Spectroscopy (micro and macro) with SR (**LNF**)

X-Ray Diffraction (**RM2**)

Time Gated LIF Spectroscopy (TG-LIF) (**RM2**)

TOF-SIMS (**RM3**)



I ADR per sviluppo sistemi di controllo acceleratore
trasportabile «MACHINA» (Labec)

