DAΦNE-Light Laboratory and Activity

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1 Summary

In 2024 the scientific activity at the DAΦNE-Light laboratory, was performed using conventional sources and the DAΦNE synchrotron radiation beam up to July for some tests of detectors and measurements. About 30 experimental teams got access to the DAΦNE-Light laboratory mainly coming from Italian Universities and Research Institutions, third parties and PNRR and other projects.
The laboratory was opened to visitors in the Open Day in May 2024, to high school students in April and June and to high school teachers in November during the week dedicated to the "Incontri di Fisica". In 2024 all the activities on going at the DAΦNE-Light laboratory were presented the 27th of May at the INFN-LNF 67th Scientific Committee Meeting.
The website of DAΦNE-Light at the following link: **https://dafne-light.lnf.infn.it/** was continuously updated with highlights and a complete list of publications.
Concerning the X-ray beamline, the alignment was completed in January and afterwards it was opened to users. Some upgrades were realised on the experimental setup of some beamlines and also new instrumentation was installed.

2 Activity

2.1 SINBAD IR beamline - Resp. Mariangela Cestelli Guidi

The SINBAD IR beamline offers advanced Fourier Transform Infrared (FT-IR) micro-imaging and spectroscopy capabilities, driven by a powerful synchrotron source. This enables researchers to conduct detailed investigations in a wide array of fields, including:

1. **Material Science: Characterising the composition and structure of advanced materials.**
2. **Biology & Radiobiology: Studying cellular processes and the effects of radiation.**
3. **Live Cell Imaging: Monitoring dynamic changes in living cells in real-time.**
4. **Cultural Heritage: Analysing the composition of artifacts and artworks.**
5. **Geophysics: Examining the mineralogical and chemical makeup of geological samples.**

The beamline's high-resolution imaging capabilities, coupled with the brilliance of the synchrotron source, provide exceptional sensitivity and spatial resolution. Access to SINBAD is granted to researchers from Italian and international institutions, including EU and non-EU teams, following a rigorous proposal review by the User Selection Panel.

Projects on external funds.

Throughout 2024, the SINBAD-IR beamline actively supported a range of cutting-edge projects, including:

1. **PNRR_PE5 - CHANGES: Cultural Heritage Active innovation for Next GEn Sustainable Society**

   Funded by the European Union (EU) and the Italian Ministry of University and Research (MUR), the CHANGES project (Cultural Heritage Active Innovation for Next Gen Sustainable Society) started in December 2022. INFN, through its membership in ”Associazione Centro di Eccellenza Beni e Attività Culturali della Regione Lazio ”(DTC Lazio), is actively contributing with four distinct projects. (Reference: *https://www.mur.gov.it/it/news/mercoledi-03082022/pnrr-mur-selezionati-i-14-partenariati-attivita-di-ricerca*)
   The SINBAD-IR beamline is a vital component of CHANGES, specifically within SPOKE 7, focusing on ”Protection of cultural heritage from anthropogenic and natural risks and evaluation of the effectiveness of recovery techniques using non-invasive monitoring technologies.”

   (a) **Deliverable Achievement:** The project successfully delivered D2.3 in December 2024, a ”Technical report on multi-temporal visualisation of climate change effects on heritage contexts.”

   (b) **Measurement Campaign:** A crucial measurement campaign was conducted at the Domus di Vigna Guidi (Terme di Caracalla, Rome) to analyze degradation processes and inform recovery strategies for the pictorial apparatus (Fig.1).

   (c) **Digital Accessibility:** Efforts are underway to transform diagnostic data into accessible digital content, including DIGITAL TWINS, for public engagement and museum professionals.

   (d) **Dissemination:** Project results were presented at national and international conferences and scientific events, ensuring broad knowledge sharing.

Figure 1: In situ investigation at “Domus di Vigna Guidi” (Terme di Caracalla) in Rome.

2. **SUNSTONE: "SESAME's Upgrading Network for Scientific user Training and Outreach into the Next Era".**

   Funded by the European Union's Horizon Europe program (HORIZON-INFRA-2024-SESAME-IBA, G.A. 101177314), SUNSTONE ("SESAME's Upgrading Network for Scientific user Training and Outreach into the Next Era") is a strategic initiative designed to significantly strengthen the SESAME (Synchrotron Light for Experimental Science and Applications in the Middle East) facility.

   Project Timeline: June 30, 2024 - December 31, 2027 (42 months).

   Project Goals: This collaborative project unites eight leading research infrastructures and organizations from Europe and the Middle East, with the Paul Scherrer Institut as a key associate participant. SUNSTONE's core objective is to ensure the long-term sustainability and enhancement of SESAME, a vital research hub serving its eight member nations: Cyprus, Egypt, Iran, Israel, Jordan, Pakistan, Palestine, and Turkey. Furthermore, the project aims to expand SESAME's reach and impact into Africa.

   As part of the project, INFN will provide in the first year the training for SESAME's BEATS XCT beamline users in the cultural heritage field.

   More information about the SUNSTONE project can be found at the following link: *https://sunstone.sesame.org.jo/*

3. **INFN OPEN: "Open INnovation from Fundamental Nuclear Research".**

   Funded by the PON Governance and Institutional Capacity 2014-2020 program, Axis 2 – Specific Objective 2.1 – Action 2.1.1 (CUP: I55F21002820007), the INFN OPEN ("Open INnovation from Fundamental Nuclear Research") project is a strategic initiative designed to accelerate the transfer of scientific and technological knowledge developed by the Istituto Nazionale di Fisica Nucleare (INFN).

   Project Timeline: November 23, 2021 - August 31, 2025.

   Project Goals:

   (a) **Strengthen INFN's Capabilities:** Enhance the technical and organizational skills necessary to translate fundamental research into tangible innovations.

   (b) **Promote Knowledge Transfer:** Effectively facilitate the dissemination and application of INFN's scientific and technological advancements.

   (c) **Drive National Innovation:** Contribute to the technological and industrial innovation of the Italian economy.

   INFN OPEN aims to bridge the gap between cutting-edge fundamental research and real-world applications, fostering a culture of open innovation.
   The project included a market study of compact particle accelerators for cultural heritage, specifically examining the MACHINA (*https://link.springer.com/article/10.1007/s12210-022-01120-6*) case.
   More information about this INFN technology transfer initiative can be found at the following link: *https://web.infn.it/TechTransfer/?page_id=907*

Users and Beamtime

In 2024, the SINBAD-IR beamline provided access and support to numerous experimental teams, facilitating cutting-edge research across diverse scientific disciplines. Here's a brief view into some of the notable studies conducted:

1. **Planetary Science & Mineralogy**

   (a) **ASAMI & ASAMI II: Unveiling the Secrets of Asteroid Ryugu Mapping** Led by S. Rubino from the Institute of Astrophysics and Space Planetology (INAF-IAPS), Italy, these projects utilized FT-IR spectroscopy to analyze fragments (Fig.2) of the Ryugu asteroid. ASAMI II further integrated Raman and SEM-EDX analyses, providing a comprehensive understanding of the asteroid's weathering state. The analysis of these cosmic materials, fragments of the asteroid Ryugu, brought back to Earth by the Hayabusa-2 mission of the Japanese Space Agency JAXA, has garnered significant public attention, featured in online news outlets and on TG3 Leonardo:

      i. *https://www.ansa.it/canale_scienza/notizie/spazio_astronomia/2024/01/10/iniziate-in-italia-le-analisi-dei-grani-dellasteroide-ryugu-video_3e48b9d3-17df-4a0d-9e7d-5e06dac386be.html*

      ii. *https://www.youtube.com/watch?v=PUG1w4v3v48*

      iii. *https://www.media.inaf.it/2024/12/06/campioni-extraterrestri-il-rischio-contaminazione/*

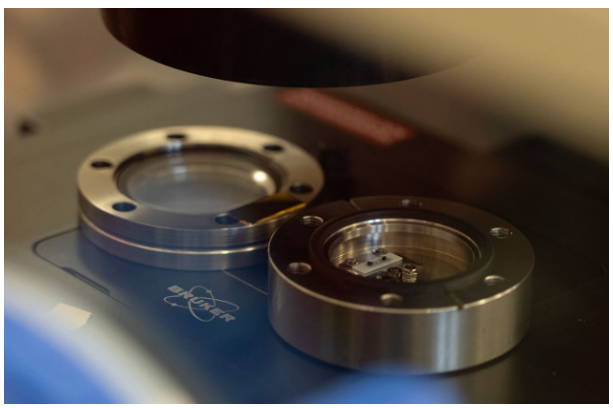

Figure 2: Image of Ryugu asteroid fragments under the IR microscope at the DAΦNE-L laboratory

   (b) **PEITHO: Unraveling Meteorite Mineralogy.** C. Carli (INAF-IAPS, Italy) conducted FT-IR spectroscopic analyses to characterize peculiar meteorites, aiming to understand their origins and parental bodies.

   (c) **DELIM: Detecting Trace Water in Minerals.** A. Stephant (INAF-IAPS, Italy) utilized FT-IR spectroscopy to determine the detection limits of water content in various minerals.

2. **Materials Science & Physics**

   (a) **CuTMED** - Magnetophononics in a Cu(II) Dimer System. L. Spitz (Paul Scherrer Institute, Switzerland) performed low-temperature (4K) FT-IR spectroscopy to investigate the magnetophononic properties of a Cu(II) dimer system.

   (b) **IRMat** - Ternary and Quaternary selenodiphosphates and eutectic self-assembled metamaterials for infrared applications. M. C. Larciprete (Sapienza Università di Roma) used micro FT-IR spectroscopic analyses with a micro-cryostat to characterise eutectic materials based on metallic oxides at room temperature and at 68°C.

(c) **LNF Collaboration: EuPRAXIA Accelerator Capillary Characterization.** A. Biagioni and L. Crincoli (INFN-LNF) collaborated on the characterization of capillaries for the EuPRAXIA accelerator.

3. **Cultural Heritage**

(a) **CHNet Collaboration: Analysing "Lo Spasimo di Palermo":** In collaboration with INFN-RM3 and the Accademia delle Belle Arti of Rome, a multi-analytical diagnostic campaign was conducted on an unknown version of the painting "Lo Spasimo di Palermo".

(b) **Workshop Presentation:** Preliminary results from the "Lo Spasimo di Palermo" analysis were presented at a dedicated workshop on October 30th at INFN-National Laboratories of Frascati (Fig.3). The workshop was organised by M. Romani and L. Pronti, in collaboration with LASR3 laboratories (University of Roma 3) and Accademia delle Belle Arti di Roma.

Figure 3: Workshop on the preliminary results achieved on an unknown version of the painting "Lo Spasimo di Palermo".

Beyond the core research projects, the SINBAD-IR beamline actively was also engaged in collaborative and third-party activities.

Instrument Upgrades and Laboratory Enhancements

In 2024, the SINBAD-IR laboratory underwent significant upgrades to enhance its analytical capabilities and expand its research potential. Key improvements included:

1. **Controlled Atmosphere Capabilities** - A custom-designed atmosphere-controlled chamber was integrated around the LUMOS II experimental area. This chamber features a glovebox for sample manipulation and dry nitrogen (N_2) flow capabilities, enabling the analysis of air-sensitive materials under controlled environmental conditions.

2. **Multimodal Analytical Enhancements**

(a) The macro (MA) - multi techniques scanner, ARTEMISIA, was upgraded with integrated LED-UV, XRF, and Reflectance (VIS-NIR) systems, expanding its diagnostic versatility.

(b) HERA-IPERSPETTRALE VIS-NIR, a hyperspectral camera with a CMOS sensor (1280x1024 pixels, 400-1000 nm), was equipped with a EUROMEX fluorescence microscope, enabling advanced hyperspectral imaging.

3. **Data Processing and Analysis Tools** - PLS Toolbox and MIA software were acquired for advanced spectral image processing within the MATLAB environment.

4. **Additional Instrumentation**

   (a) An IR thermal camera was added for thermal imaging applications.

   (b) A 3D laser scanner was acquired for precise three-dimensional object digitisation.

5. **Relocation to Building 24** - The LNF-CHNet laboratory was relocated to Building 24, providing a dedicated room for Cultural Heritage analyses, including a chemical hood for the realisation of cross sections. Moreover, the MA-multi techniques (FT-IR, UV, XRF, and VIS) scanner, developed in the field of the ARTEMISIA project, was also relocated in a dedicated room of the same building.

Educational Outreach and Scientific Dissemination

The SINBAD beamline actively contributes to education by providing research opportunities for students pursuing Master's and PhD degrees. In 2024, the beamline hosted the following students:

1. D. Cappella, Bachelor's Degree in Chemistry (University of Rome Tor Vergata). Thesis: " Applicazione dello scanner multi-sensore ARTEMISIA per l'analisi non invasiva del dipinto "Ritratto di Dama Veneziana" di Giacomo Favretto." INFN Tutor: L. Pronti.

2. V. di Paolo, Bachelor's Degree in Chemistry (University of Rome Tor Vergata). Thesis: "Characterisation of micro-samples from a 19th-century oil painting using FT-IR microspectroscopy and scanning electron microscopy (SEM-EDX): a study of blue pigments." INFN Tutor: M. Romani.

Furthermore, research conducted at the SINBAD beamline was widely disseminated through presentations at many national and international scientific conferences, including invited talks given by M. Romani and L. Pronti

2.2 DXR1 Soft X-ray Beamline - Resp. Antonella Balerna

The DAΦNE soft X-ray beamline, DXR-1, is mainly dedicated to soft X-ray absorption spectroscopy (XAS). The X-ray source of this beamline is one of the 6-poles equivalent planar wiggler devices installed on the DAΦNE electron ring (0.51 GeV) for the vertical beam compaction. The 6 wiggler poles and the high storage ring current (higher then 1 Ampere) give a useful X-ray flux for measurements well beyond ten times the critical energy. The useful soft X-ray energy range is 900 eV - 3000eV where the lower limit is given by the Beryl crystals used in the double-crystal monochromator and the higher limit is given by the wiggler working conditions.
In January 2024 the alignment of the soft X-ray beamline was completed and the beamline was opened to users up to July 2024.

The **DIATOMIX** proposal (Prof. G. Verona Rinati - Univ. Rome Tor Vergata) received beamtime divided, as required, in different months in order to perform improvements while going on with the measurements. This proposal aimed at assessing the capabilities of single crystal diamond arrays, to be employed in soft X-ray tomography systems for plasma diagnostics in thermonuclear fusion reactors. Full tomography systems, based on these diamond diodes have been proposed for future fusion reactors. To this end, it was important to experimentally verify the spectral responsivity and the reproducibility in the response of nominally identical detectors, in view of the production of detection systems involving a much larger number of diodes. The DAΦNE-Light DXR1 beamline (see Fig. 4) provided X-rays in a range which is extremely relevant for plasma diagnostics, and that was not investigated in previous experiments.

Figure 4: Internal view of the DXR1 experimental chamber with a mounted array of detectors.

Other measurements performed were on different samples including lapis lazuli having different origins. These measurements were performed at the Si K edge. To conclude the series of measurements performed in 2024 before closing two standards were measured at the sulphur (see Fig. 5) and silicon K edge (see Fig. 6).
Included in the ARTEMISIA project (see SINBAD-IR scientific activity) there was the study of the feasibility of integrating the FTIR spectrometer scanning system with an X-ray fluorescence (XRF) spectrometer like the one realised by the INFN LABEC laboratory in Sesto Fiorentino (Fi). This spectrometer is a portable XRF system and is used for activities related to the INFN cultural heritage network (CHNet). The integration of a XRF system with the portable FTIR system developed within the ARTEMISIA project is important because X-ray fluorescence is able to provide information on the atomic elements present in the paintings to be studied and is complementary to FTIR.
During 2024 the ARTEMISIA portable XRF system realised using a conventional Rh X-ray source and an Amptek OEM (original equipment manufacturer) SDD detector assembled at LABEC. The XRF system was used to map (22 cm x 15 cm) the presence of different atomic elements in a small painting of G. Favretto (Venezia 1849-1887) in the DAΦNE-Light DXR2 hutch. At the end of 2024 the ARTEMISIA scanner was moved to the building 24 and all security issues were performed having now the possibility to use the XRF system also for in-situ mapping measurements.
Using only the XRF system tests were performed on some systems related to the SIDDHARTA2 and VOXES experiments looking for the presence of contaminants.
The approval of the EuPRAXIA Advanced Photon Sources (EuAPS) project, led by INFN in

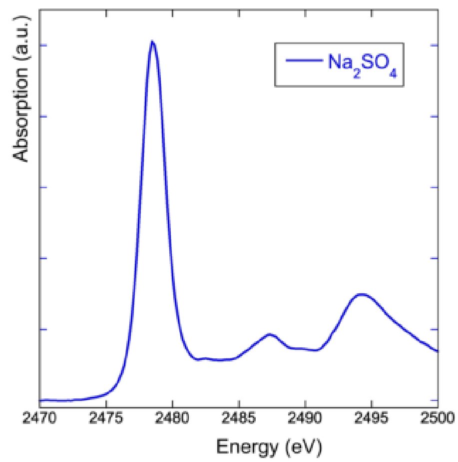

Figure 5: XANES spectrum of a Na_2SO_4 standard at the S K edge.

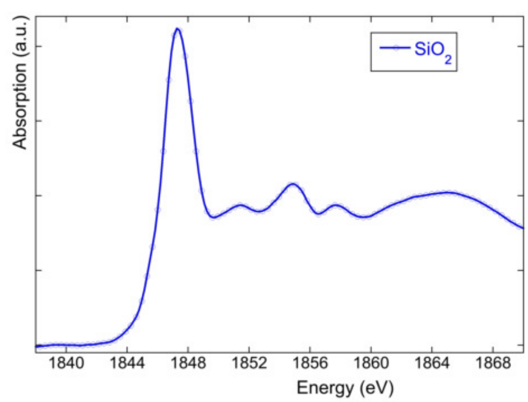

Figure 6: XANES spectrum of a SiO_2 standard at the Si K edge.

collaboration with CNR and University of Roma Tor Vergata, foresees the construction of a laser-driven "betatron" X-ray user facility at the LNF SPARC_LAB laboratory. Looking for X-ray applications above 1 keV, the idea of measuring time resolved XAS data at the Al K edge for experiments related to the field of warm dense matter (WDM) was proposed, taking also into account the possibility to check, at least the solid state data, with the ones collected at the DAΦNE-Light DXR1 beamline. In 2024 the in collaboration with other scientists working on EuAPS the construction of the 3 m long experimental chamber started and the mountings of the sample and the CCD camera needed for the first X-ray phase contrast imaging experiments in 2025 were purchased.

2.3 DXR2 UV branch Line - Resp. Marco Angelucci

The DXR2 beamline at DAΦNE- Light operates with UV radiation on an extended spectral range from 120 nm to 650 nm. The UV radiation can be used in a wide range of experiments such as reflectance/transmittance, ageing and response of optical systems and detectors.

The UV light has been used at the DXR2 branch-line in many and different research fields from biological to high energy physics experiments, to study solar-blind UV diamond-based detectors or FOAM for space missions. Furthermore, coupling the UV radiation and IR spectroscopy it is possible to study in real time the evolution of analysed samples, measuring the variation of IR spectra during UV exposure.

The facility operates with UV radiation obtained as synchrotron radiation (SR) or standard sources (Deuterium lamp for the Deep UV 120-250 nm, HgXe lamp in the 200-650 nm range, broad UV/VIS source in the 200-800 nm range, and different LED sources between 255 and 465 nm).

To meet the various technical requirements, the beamline has been fitted with new sensors. In previous years, the beamline was upgraded with discrete LED and continuous light sources of varying wavelengths. During 2024, new systems for light characterisation have been developed. For this purpose, the laboratory has been equipped with new UV-Vis sensors with a measurement range in the μW, as well as dedicated setups as shown in Fig. 7, to face some requests for absorption/transmittance/reflectivity measurements.

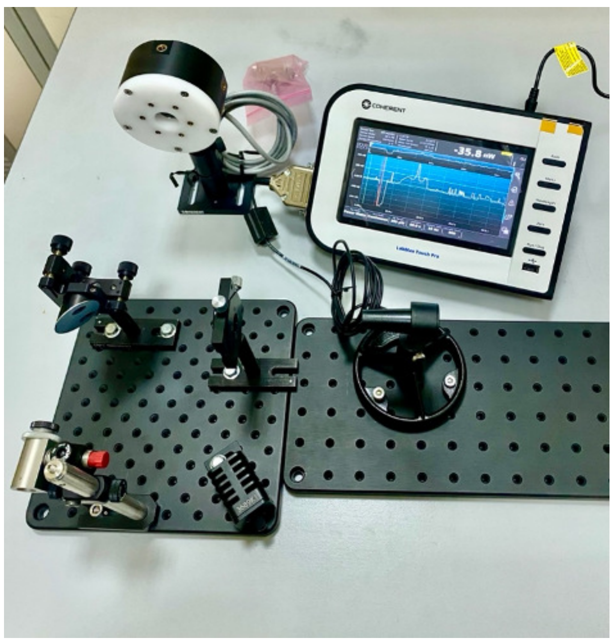

Figure 7: Setup for characterization of light power with specific sensors in the UV-Vis spectral range.

The laboratory was also involved in the structural and elemental characterization of NEG-coated samples using SEM-EDX (see Fig. 8). This activity is conducted in collaboration with the XUV laboratory as part of the partnership with BNL.

ARTEMISIA scanner- in collaboration with SINBAD-IR beamline.

In collaboration with SINBAD-IR beamline, during this last year, some activities were focused on improving the integration of the UV setup in the general structure of the ARTEMISIA scanner and in some cultural heritage measurements already described in the SINBAD-IR activities.

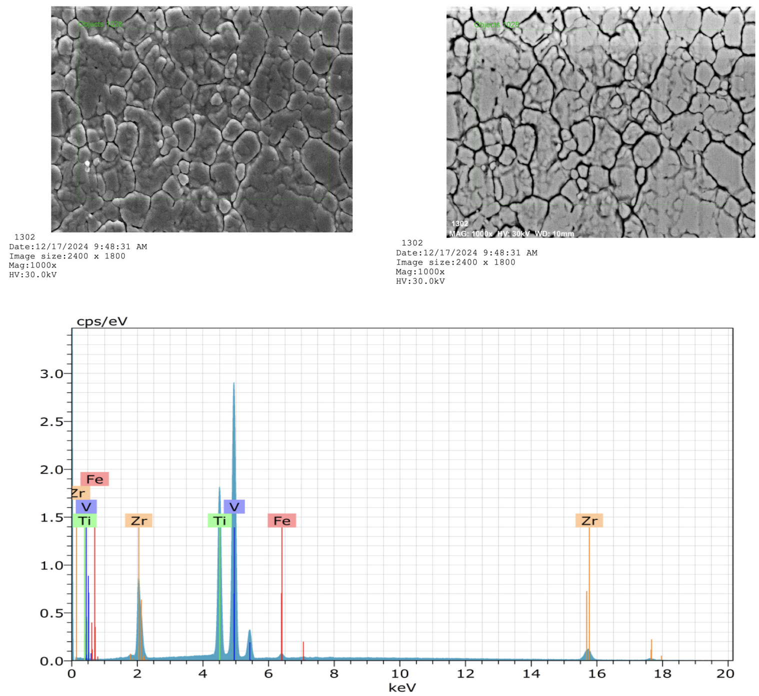

Figure 8: SEM Images (top) and EDX spectrum (bottom) of a NEG-coated sample.

2.4 XUV beamlines and laboratory - Resp. Roberto Cimino

This laboratory hosts three bending Magnet beam lines and their “state of the art” UHV spectroscopy systems. Two beamlines will offer monochromatic light with a photon energy range from 30 eV to 1000 eV the third one will provide un-monochromatized SR light. The Low Energy Beam line, (LEB) will cover from 30 to 200 eV and the High Energy Beam line (HEB) will offer monochromatic photons from 60 to 1000 eV. The third beamline, WINDY, (White lIght liNe for Desorption Yields) offer collimated SR for photodesorption studies on pipe samples up to 3-meter length. The three beamlines still need some extensive use of SR delivered by DAΦNE to be finally commissioned. During 2024 DAΦNE did not produce any usable light.
Also if SR was not used, all the three beamlines and their experimental stations hosting and promoting some mainstream projects were consolidated.
During this year, the laboratory the laboratory continued to work on the ET-ITALIA@LNF project, funded by National Scientific Committee 2 (CSN2), focusing on the studies of the vacuum properties of different components of the cryogenic vacuum system of the future **Einstein Telescope** (ET). This activity was carried out in collaboration with the LATINO Vacuum Laboratory at LNF. The ET-ITALIA@LNF project also focuses focuses on the study of a new a strategy to reduce the mirror’ contamination due to the residual gases in the ET mirrors’ tower and on the implementation of a possible passive mitigation method for electrostatic charging affecting Gravitational Wave (GW) optics. This latter activity, in its basic aspect, started in 2023 in collaboration with EGO-Virgo and the Institut de Física d’Altes Energies (IFAE) in Spain.
Following the collaboration already established in the past years with Brookhaven National Laboratory (BNL) (USA), and in particular with the working group studying and designing the new

Electron Ion Colllider (EIC), in 2023 the laboratory has operatively strengthened such an interaction by a Statement of Work (SoW, Doc No. EIC-VSG-SOW-011). The SoW is for surface studies needed for qualifying the hadron storage ring vacuum chamber of EIC, including the measurements and analyses of thin films produced by BNL. During 2024, the laboratory continued to study different carbon coated samples (30 samples) and started the study of NEG coated sample. Moreover, the laboratory continued to collaborate with the BNL Vacuum Group to develop a SEY measurement system which will be employed by BNL for the quality control of the coated screens which will be installed in the EIC hadron storage ring vacuum chamber.
Furthermore, the laboratory has continued the collaboration activities with national and international groups (CNR, Uniroma1, ET- International collaboration, Virgo, etc) on different topics requiring the expertise and experimental equipment available in the laboratory.
Hereafter all those activities which have been performed in the spirit of opening some resources to external users are described.

1. ***ET-ITALIA@LNF***

   The ET-ITALIA@LNF project is organized in three WPs:

   (a) **WP1: Frost Mitigation and Electrostatic Charging**

   (b) **WP2: Material Properties**

   (c) **WP3: Passive mitigation method for electrostatic charging.**

   Gases composing the residual vacuum in the low frequency detector chambers of ET will tend to build a contaminant ice layer (“frost”) on the cryogenic mirrors’ surfaces (T$\sim$10 K). Depending on the thickness of such ice layer, various detrimental effects may affect the detector performances.
   Studying the mirror vacuum system and reducing contaminants on the optical surfaces at cryogenic temperatures is a necessary passive strategy for maintaining detector efficiency. This is the focus of WP2 activities (in collaboration with the LATINO Vacuum Laboratory in Frascati), which aim to characterise the outgassing properties of materials.
   The WP1 activities are carried out entirely in the XUV laboratory and aim to explore the use of low-energy electrons as an active method to remove ice from cryogenic optics through Electron Stimulated Desorption (ESD). This defrosting method will inevitably result in electrostatic charging, which has already been shown to affect gravitational wave detection in operating interferometers. In principle, electrons can not only induce ice desorption but can also help mitigate charging issues by tuning their kinetic energy appropriately. In this way, electrons can serve as a mitigation method for both ice desorption and charge neutralisation. The electron-based discharging method relies on understanding the SEY characteristics of each material. WP3 activities began in 2024.
   During this year, first results have been obtained experimentally demonstrating the possibility to use electrons to neutralise charges of both polarity at room and cryogenic temperature (RT and LT), as well. Fig. 9 shows the case of a Si sample, considered as representative for the ET mirrors’ material. In panel (a) the comparison between the Si SEY characteristics at RT and LT is reported. The observed slight differences between the SEY curves are likely due to adsorption on the sample surface, unavoidable at cryogenic temperature (10 K), of molecular contamination typically present in UHV (p$\sim$1 x 10^{-10} mbar). Starting from the neutral surface, both at RT and LT, it is possible to induce at will positive (panel b) or negative (panel c) charge on the sample surface by properly choose an irradiation energy for which SEY >1 or <1, respectively. In the same way, given a positive (panel d) or a negative (panel e) charged surface, it is possible to neutralise it irradiating the surface with electrons having energy around E (SEY=1), both at RT and LT.

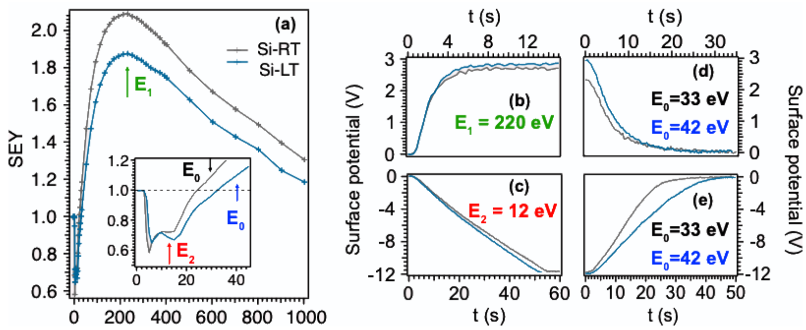

Figure 9: Ta) SEY curves of Si sample acquired at RT and LT (10 K). The inset is a magnification of the low energy region. Arrows point to the SEY values at the charging/neutralisation irradiation energies. Charging measurements to positive (b) and negative (c) voltage. Neutralisation starting from positive (d) and negative (e) voltage.

These results have been published and presented in national and international meetings. A further article has been accepted in December 2024 and will appear online in 2025.

The work is ongoing to validate the charging/neutralization method on other materials representative for the mirror optics at cryogenic temperature and after dosing specific gas species (as H_2O).

Moreover, a new experimental set-up has been equipped with a Kelvin probe to apply the method and to study the charge spatial distribution on big dielectric samples (1 inch) of realistic composition and quality. Fig. 10 shows a picture of the part of the chamber. The 1-inch sample holder (center), the electron gun (left) and the Kelvin probe (right) can be observed.

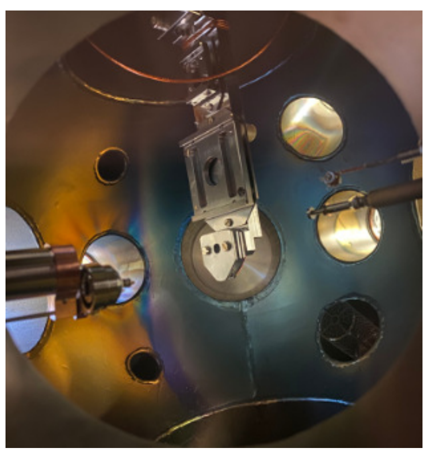

Figure 10: Inner view of the new measurement chamber where to carry out SEY, charging and neutralisation studies on 1-inch samples. In the centre the sample holder is clearly visible; from the lateral flanges, the electron gun (left) and the Kelvin probe heads (right) can be recognised, pointing to the sample holder.

The test of the whole system is ongoing, together with the implementation of the LabView data acquisition code.

Electrostatic charging coming from the beampipe is one the few known contributions to optics charging phenomenon. This is already experienced in Virgo, where it has been observed that electrostatic charges, generated by low energy electrons coming from ion pumps, propagate along the beampipes finally impinging on the test masses.

In this framework, in collaboration with the vacuum groups of LNF and EGO-Virgo and IFAE (Spain), the aim of WP3 of ET-ITALIA@LNF is to carry out a R&D activity to develop a passive mitigation strategy for the electrostatic charging coming from the beampipe. The idea is to install an electrostatic ring in selected baffles of the vacuum pipe. Opportunely polarised at a given voltage, such rings can catch electrons coming from the ion pumps and propagating along the vacuum tube. The general activity proposes to test the possibility of integrating such an electrostatic ring on baffles to mitigate the charges' flow from the beampipes to the mirrors' chamber.

During this year, an experimental system has been designed and set up to perform the first tests to measure the current emitted by an ion pump. As shown on the left of Fig. 11, the system consists of a vacuum tube with several flanges. The vacuum tube is equipped by a turbomolecular pump (TMP) to evacuate the system before to switch on an ion pump (300 l/min). The TMP can be isolated from the vacuum tube by a valve. The ion pump is connected at the bottom of the vacuum tube. An ion gauge is also mounted to check the vacuum of the system (base pressure with ion pump: p$\sim10^{-8}$ mbar). In front and at 90° with respect to the ion pump port, two metallic screens have been placed. One of these is shown in the right picture of Fig. 11. Each screen is insulated from the vacuum tube and electrically connected to a pico-ammeter to measure the electron current generated by the ion pump once it is switched on. Moreover, each screen can be put at a given potential (between -500 V and 500 V) to study, for each geometry, the effect of voltage in capturing charges coming from the ion pump.

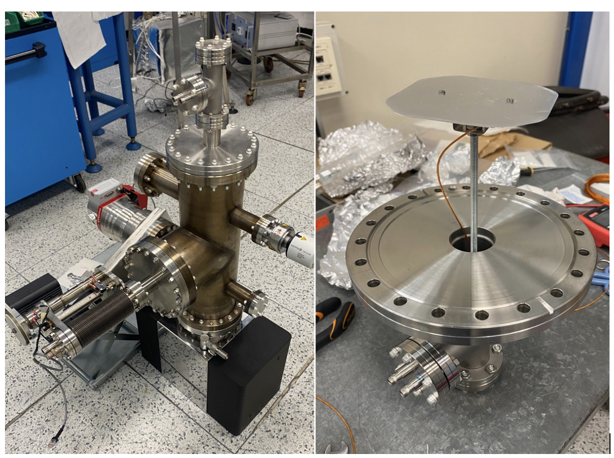

Figure 11: (a) Overview of the experimental setup to measure the charges emitted by an ion pump. (b) Detailed view of one of the metallic screens mounted in the upper flange, facing the ion pump port, and at 90° with respect to the ion pump to collect charges emitted once the ion pump is switched on. Both screens are connected to two different pico-ammeter for current measurements and can be held at a given voltage between -500 V and 500 V.

First measurements campaign has started and is still ongoing. The concept of the study has been already presented at national and international meetings. An upgrade of the system, for studies of electron propagation in long pipe, will be developed and mounted during 2025 in building 24.

2. ***Collaboration with the "Einstein Telescope -ET- International collaboration"***

   The activities carried out within ET-ITALIA@LNF project are of general interest in the international framework of R&D scheme for ET. Indeed, with the activities on frost and charging mitigation of cryogenic mirrors, the laboratory is involved in the ET-ISB Division II (Optics) collaboration. Moreover, the laboratory is also active in the ET-ISB Division IV (Vacuum and Cryogenics) collaboration.

3. ***Collaboration with EIC (Eelectron Ion Colllider) at Brookhaven National Laboratory (BNL - USA)***

   The mitigation of electron cloud buildup in high-luminosity circular accelerators like the hadron storage ring of the EIC relies heavily on the development and experimental surface characterization of technical materials with low SEY. Our laboratory has the experience and the "state of the art" equipment to perform such investigations. Detailed material and surface studies are indeed needed for qualifying the hadron storage ring vacuum chamber, where new beam screens with a low SEY coating need to be inserted into the present Relativistic Heavy Ion Collider (RHIC) beam tubes to suppress electron cloud buildup and guarantee operation with the high luminosity beams of the EIC.
   Electron cloud, dynamic vacuum, material coatings and their surface and bulk properties at low operating temperatures as well as under electron, and ion bombardment are critical to guarantee the accelerator does not suffer any limitation induced by the detrimental collective effects driven by instabilities. The interaction with the working group in BNL that is studying and designing the future EIC is carried out through two different paths.

   (a) *Statement of Work (SoW, Doc No. EIC-VSG-SOW-011) between BNL and INFN.*

      The SoW is for surface studies needed for qualifying the thin films of carbon produced by BNL and sent in our laboratory. SEY and XPS measurements at Room Temperature of different samples have been performed during this year, also as a function of electron irradiation (scrubbing or conditioning).
      Some representative results achieved in 2024 are reported in Fig. 12 and Fig. 13.

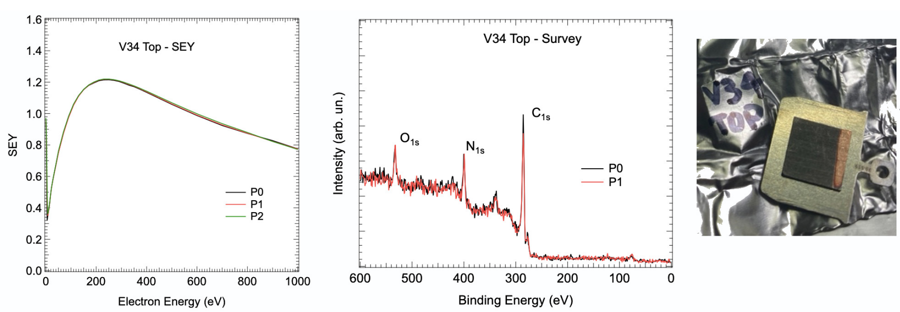

Figure 12: SEY (left) and XPS (center) measurements on a selected coated carbon film sample (right) produced by BNL.

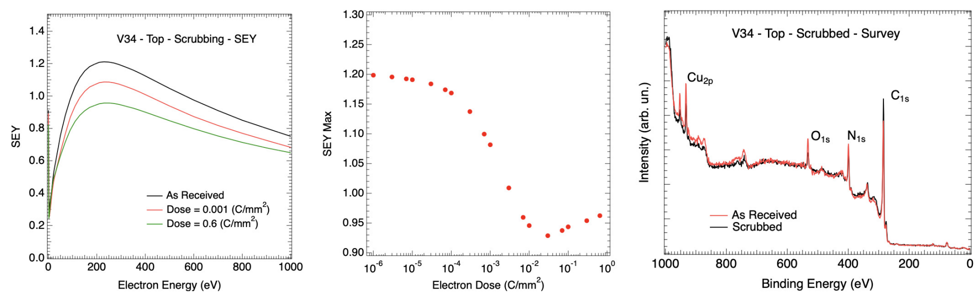

Figure 13: From the left: SEY curves on a selected sample as a function of electron irradiation (scrubbing) at 300 eV; trend of the maximum value of SEY as a function of the electron dose deposited on the sample; XPS spectra acquired at the initial and final state of scrubbing process.

(b) *Collaboration to develop a SEY measurement system*

The qualification of materials after their production is a necessary step to verify that the produced coatings meet the required specifications prior to installation into the hadron storage ring. Having an in-house measurement system for this purpose is vital to avoid costly and time-consuming validation by external laboratories. For this reason, this year, the laboratory began a collaboration with the BNL Vacuum Group to develop a SEY measurement system. This system will be delivered to and used by BNL for quality control of the coated screens to be installed in the EIC hadron storage ring vacuum chamber. This system is part of the INFN contribution to the EIC and is highly regarded and appreciated.
The work started in 2024, and the design of the measurement chamber has been realised (Fig. 14).
The system will be composed of:

i. *UHV μ-metal main chamber with pumping system and a 4-axis manipulator;*
ii. *Sample insertion chamber with pumping system and samples carousel;*
iii. *Stable support for the chambers;*
iv. *Sources and electronics for SEY measurements and electron irradiation experiments;*
v. *Acquisition software developed in the XUV laboratory.*

At the end of the 2024, most of the components have been ordered. During 2025 each part of the system will be made available, assembled and tested at the LNF in building 24.

4. ***Collaboration with "Università degli Studi di Roma La Sapienza (Uniroma1)"***

The formation of complex molecules on cryogenic surfaces subjected to external stimuli (photons, electrons, etc.) is ubiquitous and has been observed in the most diverse fields of physics. In accelerators, for example, it is the basis of the formation of graphitic films starting from carbon-containing molecules present in the atmosphere and on cryogenic surfaces, and this phenomenon is the basis of the decrease in the SEY (Secondary Electron Yield) of the surface and allows the mitigation of the electron cloud.
The objective of the collaboration was to study the formation of complex organic molecules

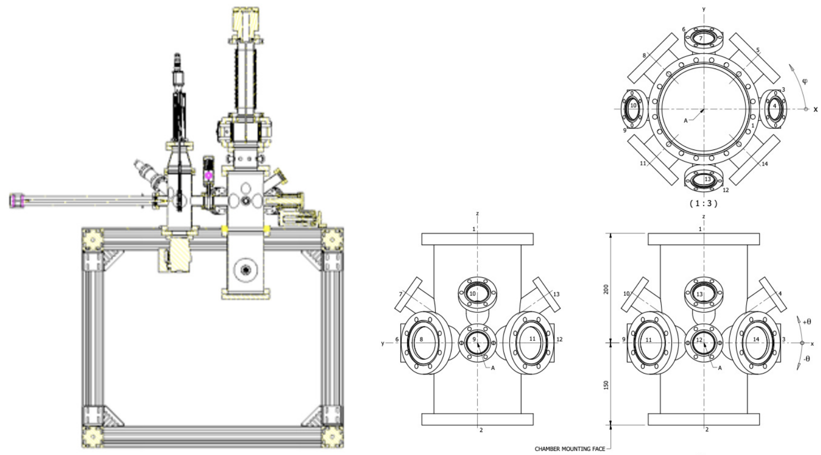

Figure 14: From left side, preliminary design of the system for SEY measurements and μ-metal chamber final design.

such as formamide (NH_2CHO) at cryogenic temperatures from its fundamental components' ammonia and carbon monoxide (NH_3 & CO) on an atomically clean silicon surface. This molecule is of extreme interest in astro-chemistry and astrobiology as it is estimated to be a precursor to more complex molecules such as nucleobases (for example, adenine, uracil, thymine, cytosine, and guanine), which are found in the structures of RNA and/or DNA.
In the last months of 2024, the work focused on preparing the substrate, studying the adsorption of CO and NH_2CHO molecules on surfaces (copper and silicon), and conducting investigations using thermal desorption and other spectroscopic techniques (XPS, SEY) available in the laboratory.
Within a scientific collaboration (n. 2422), these activities have been carried out together with a PhD student (Nicolas Antonio Martinez Sepulveda) from Chile hosted in the XUV laboratory. Some representative results are reported in Fig. 15 and Fig. 16.

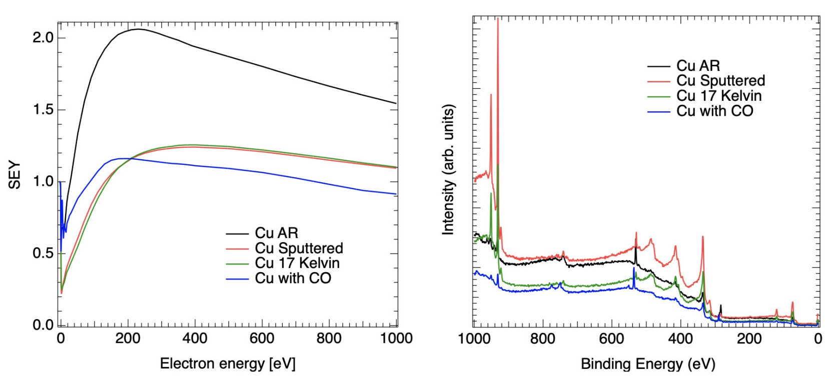

Figure 15: SEY (Left) and XPS (Right) measurements of Cu sample in different conditions (as Received, atomically sputtered, at cryogenic temperature, and with 10 L of CO adsorbed on the surface).

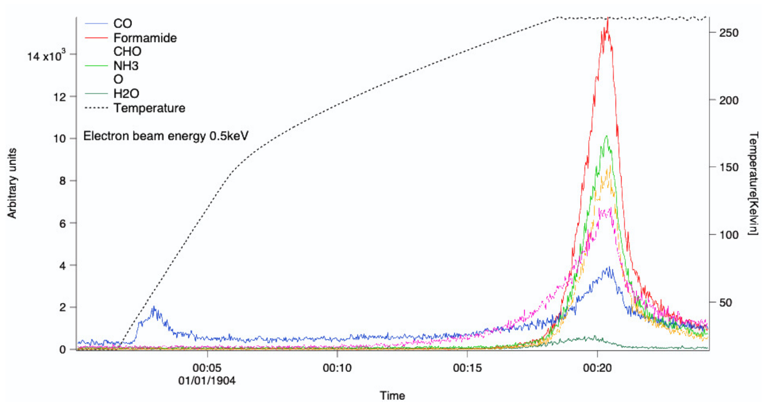

Figure 16: Thermal Programmed Desorption (TPD) measurements performed on a Cu sample with 1 L of formamide adsorbed on the surface and after an irradiation with low energy electrons.

5. ***Students***

The laboratory is also routinely hosting students. In 2024, a post-graduated summer student has been involved, for two months, in the activity done in collaboration with BNL. In close collaboration with Brookhaven National Laboratory (BNL), the project aims to test and validate material surfaces proposed to be used in the EIC hadron ring vacuum chamber using all the surface science spectroscopies available in the laboratory (SEY, XPS). Some representative results are reported in Fig. 17.

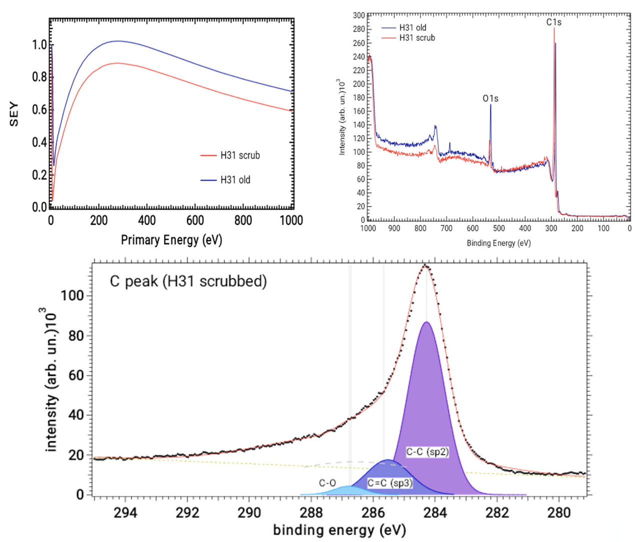

Figure 17: SEY (top left), XPS (top right) and XPS C1s analysis (bottom) of a carbon coated sample (H31) coming from the atmosphere (old) and after scrubbing process (scrub).

3 Acknowledgments

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4 List of Talks, Posters and Proceedings

1. **M. Romani**, L. Pronti, G. Viviani, V. Sciarra, M. Cestelli Guidi, *SINBAD-IR beamline at DAFNE-Light: applications and developments of FT-IR spectroscopy in the field of Cultural Heritage*, **ICFDT7 - 7th International Conference on Frontier in Diagnostic Technologies**, 21/10/2024, INFN-National Laboratory of Frascati (Invited) **(2024)**

2. **L. Pronti**, M. Romani, A. Balerna, M. Angelucci, G. Viviani, V. Sciarra and M. Cestelli Guidi, *IComprehensive scanning system utilizing multiple sensors covering X-ray to infrared range, dedicated to the analysis of paintings*, **ICFDT7 - 7th International Conference on Frontier in Diagnostic Technologies**, 21/10/2024, INFN-National Laboratory of Frascati (Invited) **(2024)**

3. **M. Romani**, L. Pronti, M. Cestelli Guidi, *SINBAD-IR beamline at DAFNE-Light: applications and developments of FT-IR spectroscopy in the field of Earth Science*, **Geology for a sustainable management of our Planet**, 3-5 September (Invited) **(2024)**

4. **L. Pronti**, M. Romani, M. Cestelli Guidi, *Analyses of mineral pigments on painted surfaces by using External Reflection FT-IR spectroscopy and mapping in situ*, **Geology for a sustainable management of our Planet**, 3-5 September (Talk) **(2024)**

5. **N. Quaglieri, E. Marconi**, L. Pronti, M. Romani, A. Balerna, M. Cestelli Guidi, C. Invernizzi, V. Sciarra, G. Viviani, *Visualizzazione multitemporale degli effetti dei cambiamenti climatici, naturali e antropogenici*, **Convegno CHANGES SPOKE 7**, 20-22 November 2024, Parco Archeologico di Selinunte (Talk) **(2024)**

6. **C. Invernizzi**, L. Pronti, M. Romani, A. Balerna, M. Cestelli Guidi, V. Sciarra, G. Viviani, *Approccio multi-tecnica per la valutazione dello stato conservativo e il monitoraggio dei processi di pulitura di superfici dipinte*, **Convegno Progetto CHANGES**:Nuove prospettive di valorizzazione dei luoghi della cultura: i casi studio del CdE-DTC Lazio, 10 - 11 October 2024, Castello Angioino di Gaeta, Gaeta (LT) (Talk) **(2024)**

7. **M. Cestelli Guidi**, *Tavola Rotonda sul trasferimento tecnologico nell'settore dei beni culturali*, **Giornata sul Trasferimento Tecnologico**, 30 September 2024, Dipartimento di Architettura dell'Università di Roma Tre, Rome **(2024)**

8. **L. Pronti**, *Il progetto ARTEMISIA: Imaging iperspettrale esteso e intelligenza artificiale per l'analisi in situ delle opere d'arte.* Proceeding of the 3rd Annual Conference **Nanoinnovation 2024** 9-13 September, Rome (Talk) **(2024)**

9. **L. Pronti**, M. Romani, A. Balerna, D. Cappella, M. Angelucci, G. Viviani, V. Sciarra and M. Cestelli Guidi, *Multi-sensor scanning system from X-ray to Infrared range for the analyses of paintings.* **2024 Meeting on X-ray fluorescence imaging (MA-XRF) and reflectance imaging spectroscopy (RIS)**. Washington (USA) 4-7 June (Talk) **(2024)**

10. **L. Pronti**, M. Romani, A. Balerna, M. Angelucci, G. Viviani, V. Sciarra and M. Cestelli Guidi, *Protection of Cultural Heritage from anthropogenic and natural risks and evaluation of the effectiveness of recovery techniques using non-invasive monitoring technologies.* **Annual**

meeting DTC-Lazio Centro di Eccellenza. Villa Mondragone, Monte Porzio Catone (RM) 21 March (Talk) **(2024)**

11. **L. Pronti**, M. Romani, M. Cestelli Guidi, *The LNF IR-THz beamline @ DAΦNE, Experimental set-ups and perspectives.* **Teradays**. Naples 19-20 February (Talk) **(2024)**

12. **L. Pronti**, M. Romani, G. Viviani, V. Sciarra and M. Cestelli Guidi, *Macroscopic FT-IR, UV and XRF mapping for the in-situ characterization of pictorial materials: Technological advances and applications*, **Dat@MI**, Convegno Tematico AIAr 2024, Milan 7-9 February (Talk) **(2024)**

13. **L. Pronti**, M. Romani, G. Viviani, V. Sciarra and M. Cestelli Guidi, *Toward the monitoring of cleaning treatments on painted surfaces: the potential of macroscopic FT-IR mapping*, **Dat@MI**, Convegno Tematico AIAr 2024, Milan 7-9 February (Talk) **(2024)**

14. **A. Balerna** on behalf of the DAΦNE-Light facility, *DAΦNE-Light INFN-LNF synchrotron radiation facility.* **67th LNF Scientific Committee Meeting**, LNF - INFN 27 May **(2024)**

15. **M. Quispe**, ... A. Balerna et al, *Thermal and Vibrational Studies of a New Germanium Detector for X-ray Spectroscopy Applications at Synchrotron Facilities*, **IPAC'24 - 15th International Particle Accelerator Conference**, Nashville, Tennessee, USA 19-24 May **(2024)**

16. **N. Goyal**, S. Aplin, A. Balerna et al, *Progress in the Development of Multi-Element Monolithic Germanium Detectors in LEAPS-INNOV Project: Insights from Detector Performance Simulation*, **SRI 2024 - 15th International Conference on Synchrotron Radiation Instrumentation**, Hamburg (Germany) 26 - 30 August **(2024)**

17. **L. Spallino**, *Active mitigation studies for frost and charging issues*, **ET-ISB Fall Workshop 2024** - ET-LF TM Tower Integration Concepts, La Biodola (Isola d'Elba), 18 - 22 September (Talk) **(2024)**

18. **M. Angelucci**, *Passive mitigation studies for charging issues*, **ET-ISB Fall Workshop 2024** - ET-LF TM Tower Integration Concepts, La Biodola (Isola d'Elba), 18 - 22 September (Talk) **(2024)**

19. **L. Spallino**, M. Angelucci, and R. Cimino. *Frost formation and electrostatic charging: one possible solution for both issues in future gravitational wave detectors*, **SIF2024** - Congresso Nazionale della Società Italiana di Fisica, Bologna, 9 - 13 September (Talk) **(2024)**

20. **M. Angelucci**, P. Chimenti, A. Liedl, M. Pietropaoli, L. Spallino, G. Viviani, J. Gargiulo, D. Sentenac, L. Francescon, A. Pasqualetti, and R. Cimino. *Frost formation and electrostatic charging: one possible solution for both issues in future gravitational wave detectors*, **SIF2024** - Congresso Nazionale della Società Italiana di Fisica, Bologna, 9 - 13 September (Talk) **(2024)**

21. **L. Spallino**, M. Angelucci, and R. Cimino. *Low energy electron irradiation as mitigation strategy for two potential showstoppers in future gravitational wave detectors*, **EVC-17** - 17th European Vacuum Conference and **ECOSS-37** - 37th European Conference on Surface Science, Harrogate (UK), 17 - 21 June (Talk) **(2024)**

22. **M. Angelucci**, L. Spallino, and R. Cimino. *Low energy electrons to cure frost and electrostatic charging in future GW mirrors*, **ET Italia** - 1° Workshop on Coatings, Università La Sapienza (Rome), 30 - 31 May (Talk) **(2024)**

23. **L. Spallino**, M. Angelucci, and R. Cimino. *Low energy electrons to actively cure frost and electrostatic charging issues in future gravitational wave detectors*, **XIV ET Symposium**, Maastricht (Nederland), 6 - 10 May (Poster) **(2024)**

5 Lectures and outreach

1. **M. Romani, L. Pronti, M. Cestelli Guidi**, C. Barbieri, G. Iorio, N. Zappalà, *Research and development at the DAΦNE-L and LASR3 laboratories connected to the INFN- Cultural Heritage network (CHNet): Preliminary results achieved on an unknown version of the painting "Lo Spasimo di Palermo"*. Organized by M. Romani and L. Pronti, 30 October 2024, INFN-LNF, Frascati

2. **M. Romani, L. Pronti** , *Scientific Investigations applied to Cultural Heritage Materials*, INSPYRE 2024 – INternational School on modern PhYsics and REsearch - INFN Frascati National Laboratory, 9 April 2024

3. **A. Balerna**, **M. Cestelli Guidi**, **L. Pronti**, M. Pietropaoli, *OPEN Labs 2024 - DAΦNE-Light facility*, 18 May 2024, Frascati.

4. **A. Balerna, L. Pronti, M. Romani**, G. Viviani, V. Sciarra, M. Pietropaoli, M. Cestelli Guidi. *Studio e caratterizzazione dei materiali attraverso l'uso di sorgenti convenzionali e luce di sincrotrone. un approfondimento sui materiali che costituiscono i beni culturali.*, Incontri di Fisica 2024, XXIV Edizione Corso di formazione e aggiornamento in Fisica Moderna - INFN Frascati National Laboratory, 13-15 novembre 2024

5. **A. Balerna**, *Atoms, X-rays and Synchrotron Radiation*, INSPYRE 2024 – INternational School on modern PhYsics and REsearch - INFN Frascati National Laboratory, 11 April 2024

6. **A. Balerna**, *DAΦNE-Luce un laboratorio per vedere l'invisibile: acceleratori, luce e applicazioni*, Pint of Science - Pub Flanagan's Frascati, 15 May 2024

7. **A. Balerna**, *Indagini sulla struttura della materia: atomi, acceleratori e raggi X*, Gruppi di Lavoro - Summer School 2023, Frascati, LNF 12 June 2024

8. **A. Balerna**, *Introduction to Synchrotron Radiation*, ″Gilberto Vlaic″ XVII School on Synchrotron Radiation: Fundamentals, Methods and Applications, Muggia (Trieste), 16 - 26 September 2024.

6 Publications

1. A. Mazzinghi, L. Castelli, C. Ruberto, S. Barone, F. García-Avello Bofías, A. Bombini, C. Czelusniak, N. Gelli, F. Giambi, M. Manetti, M. Massi, L. Sodi, A. Balerna, L. Pronti, M. Romani, M. Angelucci, G. Viviani, V. Sciarra, M. Cestelli Guidi, et al... L. Giuntini,″ X-ray and neutron imaging for cultural heritage: the INFN-CHNet experience″, Eur. Phys. J. Plus **139**, 635 (2024). **https://doi.org/10.1140/epjp/s13360-024-05429-z**

2. V. Ponza, C. Ricci, D. Scalarone, M. Cestelli Guidi, L. Pronti, M. Romani, A. F. Previtali, A. Bassi, L. Avataneo, S. Abram, M. Cardinali, A. Piccirillo, ″ The Ketone-Based Varnish Removal from an Oil Painting by Wassily Kandinsky: Comparison and Assessment of Cleaning Methods Through Preliminary Test on Mock-Ups and Multi-Analytical Investigation.″ Applied Sciences, **14**, 10385 (2024). **https://doi.org/10.3390/app142210385**

3. L. Pronti, M. Romani, M. Ioele, G. Tranquilli, F. Fumelli, S. Sechi, A. Donati, E. Cianca, I. Sinceri, M. Cestelli Guidi. ″ Using MA-rFTIR Mapping as a Tool to Assess the Efficacy of Cleaning Treatments and to Aid in the Restoration Activities of Paintings.″ Coatings, **14**, 511 (2024). **https://doi.org/10.3390/coatings14040511**

4. M. Romani. ″Cultural heritage investigations at the INFN SINBAD-IR beamline.″ IL NUOVO CIMENTO, 100(275), **47**, (2024). **DOI 10.1393/ncc/i2024-24275-8**

5. G. Capobianco, L. Pronti, E. Gorga, M. Romani, M. Cestelli-Guidi, S. Serranti, G. Bonifazi. ″Methodological approach for the automatic discrimination of pictorial materials using fused hyperspectral imaging data from the visible to mid-infrared range coupled with machine learning methods.″ Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, **304**, 123412 (2024). **https://doi.org/10.1016/j.saa.2023.123412**

6. M. Romani, L. Pronti, M. Sbroscia, O. Tarquini, G. Verona-Rinati, M. A. Ricci, M., ... & M. Cestelli Guidi. ″Characterization of Bernini's Mural Drawing Preserved in Palazzo Chigi in Ariccia (Rome) Using a Multi-Analytical and Chemometric Approach.″ In: Ceccarelli, S., Missori, M., Fantoni, R. (eds) Advanced Technologies for Cultural Heritage Monitoring and Conservation. Digital Innovations in Architecture, Engineering and Construction. Springer, Cham. (2024) **https://doi.org/10.1007/978-3-031-52497-4_7**

7. L. Pronti, M. Romani, O. Tarquini, G. Verona-Rinati, M. Colapietro, A. Pifferi, .. & M. Cestelli Guidi. ″Multi-sensor Imaging Approach to Highlight Hidden Pentimenti and Underdrawings: The Case of ″the Spring″ Painting at Chigi Palace of Ariccia.″ IIn: Ceccarelli, S., Missori, M., Fantoni, R. (eds) Advanced Technologies for Cultural Heritage Monitoring and Conservation. Digital Innovations in Architecture, Engineering and Construction. Springer, Cham. (2024) **https://doi.org/10.1007/978-3-031-52497-4_3**

8. L. Pronti, M. Romani, M. Cestelli Guidi. ″Analisi spettroscopiche non invasive: Spettroscopia Raman e FT-IR in situ″ In G. Germinario, G. Tranquilli, D. Vinci (eds) ″Antonello da Messina nella Pinacoteca Civica di Reggio Calabria. Studi scientifici, tecnica di esecuzione, notizie storico-artistiche e restauro″, **Parte II** - *Risultati delle indagini scientifiche sul dipinto Visita dei Tre Angeli ad Abramo*, ed. Rubbettino, 2024. **ISBN 9788849880335**

9. L. Pronti, M. Romani, M. Cestelli Guidi. ″Analisi spettroscopiche non invasive: Spettroscopia Raman e FT-IR in situ″ In G. Germinario, G. Tranquilli, D. Vinci (eds) ″Antonello da Messina nella Pinacoteca Civica di Reggio Calabria. Studi scientifici, tecnica di esecuzione, notizie storico-artistiche e restauro″, **Parte III** - *Risultati delle indagini scientifiche sul dipinto San Girolamo penitente*, ed. Rubbettino, 2024. **ISBN 9788849880335**

10. L. Pronti, M. Romani, M. Cestelli Guidi. ″Monitoraggio del processo di pulitura tramite Spettroscopia Infrarossa in Trasformata di Fourier (FT-IR) in situ″ In G. Germinario, G. Tranquilli, D. Vinci (eds) ″Antonello da Messina nella Pinacoteca Civica di Reggio Calabria. Studi scientifici, tecnica di esecuzione, notizie storico-artistiche e restauro″, **Parte IV** - *Restauro e tecnica di esecuzione*, ed. Rubbettino, 2024. **ISBN 9788849880335**

11. E. Petronijevic, M. C. Larciprete, M. Centini, L. Pronti, V. Aglieri, L. Razzari, A. Toma, R. Macaluso, R. Li Voti, C. Sibilia. ″Active infrared tuning of metal–insulator-metal resonances by VO_2 thin film.″ Scientific Reports **14**, 123412 (2024). **https://doi.org/10.1038/s41598-024-75430-0**

12. M. Perino, L. Pronti, C. Moffa, M. Rosellini and A. C. Felici. ″New Frontiers in the Digital Restoration of Hidden Texts in Manuscripts: A Review of the Technical Approaches″ Heritage **7**, 683-696 (2024). **https://doi.org/10.3390/heritage7020034**

13. L. Mosesso, P. Gori , A. Grilli, M. Cestelli Guidi, J. Philip, O. Pulci and S. Lupi. ″Evidence of high electron mobility in magnetic Kagome topological metal FeSn thin films.″ Nanoscale Adv. **6**, 6378 (2024). **https://doi.org/ 10.1039/d4na00737a**

14. G. Della Ventura, N. El Moutaouakkil, B. Boukili, S. Bernardini, A. Sodo, L. Pronti, M. Cestelli Guidi, F. Holtz, F. Lucci. ″Tracking the Ti4+ substitution in phlogopite by spectroscopic imaging: A tool for unravelling the growth of micas at HP-HT conditions.″ Geoscience Frontiers **15**, 101777 (2024). **https://doi.org/10.1016/j.gsf.2024.101777**

15. F. Radica, M. Cassetta, G. Iezzi, A. Pisello, F. Vetere, A. Del Vecchio, M. Cestelli Guidi, B. T Poe. ″Short-range order and chemical compositions of glasses along the basaltic-rhyolite subalkaline join by Raman and FTIR spectroscopies.″ Chemical Geology **648**, 121938 (2024). **https://doi.org/10.1016/j.chemgeo.2024.121938**.

16. A. Drago, S. Bini, M. Cestelli Guidi, A. Marcelli, V. Bocci and E. Pace. ″A proposal for a fast infrared bursts detector.″ JINST **19**, P05027 (2024). **10.1088/1748-0221/19/05/P05027**

17. L. Persichetti, D. Paoloni , A. Apponi, L. Camilli, A. Caporale, V. Babenko, S. Hofmann, M. Angelucci, R. Cimino, M. De Seta, A. Ruocco, L. Di Gaspare. ″Probing post-growth hydrogen intercalation and H2 nanobubbles formation in graphene on Ge(110)″. Materials Sci. in Semic. Processing **173**, 108111 (2024). **https://doi.org/10.1016/j.mssp.2024.108111**

18. L. Spallino, M. Angelucci and R. Cimino. ″Using low energy electrons to neutralize electrostatic charges on cryogenic test mass mirrors of future gravitational wave detectors″. Il Nuovo Cimento **147 C**, 307 (2024). **DOI: 10.1393/ncc/i2024-24307-5**

19. F. Galdenzi, M. P. Anania, A.Balerna et al. ″The EuAPS Betatron Radiation Source: Status Update and Photon Science Perspectives″ Condens. Matter **9** 30 (2024). **https://www.mdpi.com/2410-3896/9/3/30**