DAΦNE-Light Laboratory and Activity

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1 Summary

In 2023 the scientific activity at the DAΦNE-Light laboratory, was mainly performed using conventional sources and the DAΦNE synchrotron radiation beam for some alignment tests and measurements. About 25 experimental teams got access to the DAΦNE-Light laboratory mainly coming from Italian Universities and Research Institutions, third parties and PNRR projects.
The laboratory was opened to visitors in the Open Day in May 2023, to high school students in June and to high school teachers in November during the week dedicated to the "Incontri di Fisica". In 2023 the website of the DAFNE-Light laboratory 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 and XUV beamlines, some tests and alignments were performed between November and December, before the DAΦNE winter shutdown. 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 is dedicated to FTIR (Fourier Transform InfraRed) micro imaging and spectroscopy in different research fields, including material science, biology, radiobiology, live cell imaging, cultural heritage and geophysics. All these studies are possible owing to the imaging capabilities of the IR microscope coupled to the synchrotron source.
The beamline is open to all users coming from Italian and International Institutions and also to EU and non EU experimental teams after the submission of proposals and their approval by the User Selection Panel.
In 2023 the SINBAD-IR beamline has been involved in the following projects:

1. ***ARTEMISIA Project - Regione Lazio***

   The **ARTEMISIA** project or **ART**ificial intelligence **E**xtended-**M**ultispectral **I**maging **S**canner for in-s**I**tu **A**rtwork analysis (22 June 2021 – 22 September 2023) was realised in collaboration with: Sapienza University, University of Roma Tor Vergata, X-Team software solutions s.r.l.s. and Vianet s.r.l..The project was financed by the Regione Lazio in the field of "Centro di Eccellenza Beni e Attività Culturali della Regione Lazio" DTC Lazio. The kickoff meeting of the project was organised at the Frascati National Laboratories in December 16th, 2021.
   During 2023, the progress of all the WPs was achieved: the implementation of the ARTEMISIA prototype (WP1) with the integration of the MA-LED-UV and MA-XRF systems with the ARTEMISIA scanner (Fig.1) for the creation of fluorescence maps of pictorial surfaces induced by LED-UV and X-ray sources, the implementation of the user-friendly software (WP2), the implementation of the material paintings' database (WP3), the organisation

of several *in situ* measurement campaigns at the Museum of *Carlo Bilotti Aranciera di Villa Borghese (Rome)* and at the *Istituto Centrale per il Restauro of Rome* (WP4), and finally the participation to national and international conference and scientific events (WP5).
Among the WP5 activities, also the organisation of the **ARTEMISIA** Masterclass dedicated to stakeholders organised by INFN-LNF and Sapienza University (M. Romani, L. Pronti and G. Capobianco) held online with 50 participants from several Universities and Institutes and the realisation of the **ARTEMISIA** project video in collaboration with the INFN-LNF communication group and Vianet s.r.l. should be mentioned.
Finally, in Fig.2, the invitation related the final project event, held in Rome, the 10th of December 2023, at the *Carlo Bilotti Aranciera di Villa Borghese* is shown. The news on this event were published in many regional and national newspapers (ANSA.it, LA STAMPA, and ARTE Magazine) and in television.
All information regarding the **ARTEMISIA** project can be accessed on the dedicated website: **https://artemisia.lnf.infn.it/**.

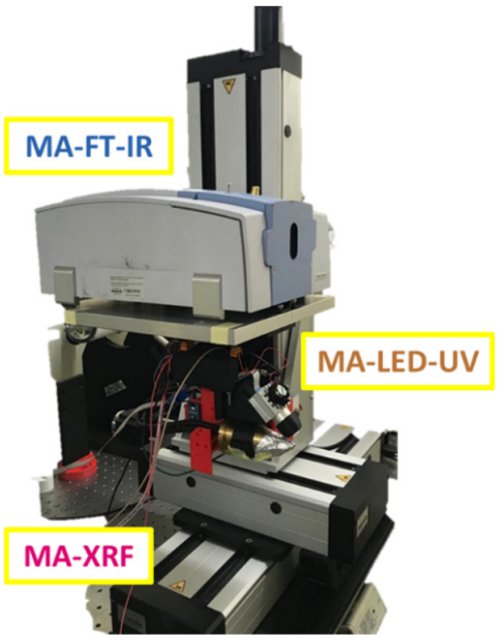

Figure 1: The new Macro (FT-IR-UV-XRF) scanner developed at DAΦNE-Light in the field of the ARTEMISIA project

2. ***PNRR - PE5 CHANGES, Funded by the European Community (EC) and the Italian Ministero dell'Università e della Ricerca (MUR).***

   The project **CHANGES** (**C**ultural **H**eritage **A**ctive **I**nnovation for **N**ext-**GE**neration **S**ustainable Society) is an extended partnership targeted to advance fundamental and applied research on Cultural Heritage that started in December 2022.
   The kickoff meeting was organised at the Sapienza University on January 23-24 2023. INFN, as a member of the "Centro di Eccellenza Beni e Attività Culturali della Regione Lazio" (DTC Lazio) is inlcuded in the activities of the project as reported at the following link: **https://www.mur.gov.it/it/news/mercoledi-03082022/pnrr-mur-selezionati-i-14-partenariati-attivita-di-ricerca**.

Figure 2: The invitation to the ARTEMISIA project final event, held in Rome at the Museum Carlo Bilotti Aranciera di Villa Borghese

The SINBAD-IR beamline is included in the **CHANGES** project in the field of SPOKE 7 with the following thematic line: *Protection of cultural heritage from anthropogenic and natural risks and evaluation of the effectiveness of recovery techniques using non-invasive monitoring technologies.*
During 2023, some activities performed for **CHANGES** included the realisation of measurement campaigns at the Central Institute for Restoration (ICR) of Rome , to identify the degradation processes and support the cleaning processes on pictorial surfaces. The activity is now moving in the direction of making diagnostic information accessible to the large public and museum conservators/curators through the creation of digital content s(e.g. DIGITAL TWINS). Finally, the preliminary results of the **CHANGES** project were presented in national and international conference and in scientific events.

More than 20 experimental teams submitted their proposals, using short and standard access procedures, to achieve beamtime at the SINBAD-IR beamline. A selection of some scientific studies carried out in 2023 is here summarised:

1. **ASAMI** - Assessing the weathering State of Asteroidal Material via IR-synchrotron mapping, S. Rubino, Institute of Astrophysics and Space Planetology (INAF-IAPS), Italy
2. **CuTMEDA** - Magnetophononics in a Cu(II) dimer system, L. Spitz, Paul Scherrer Institute (PSI), Switzerland.
3. **PEITHO** - PEculiar meteorItes specTral characterisatiOn: unravelling their mineralogy in the IR, implication for their origin and their parental bodies, C. Carli, Institute of Astrophysics and Space Planetology (INAF-IAPS), Italy.
4. **DELIM** - Detection limit of water content in minerals by reflectance spectroscopy, A. Stephant, Institute of Astrophysics and Space Planetology (INAF-IAPS), Italy

5. **MAP** - Multi-analytical approach to monitoring the chemical alterations in Pteris seedings exposed to arsenic for phytoextraction purpose, M.L. Antenozio, CNR, Italy.
6. **Metamaterials for infrared applications** M.C. Larciprete, Sapienza University, Italy
7. **Polished thin sections IR studies** G. Della Ventura, University of Rome 3, Italy.
8. **Characterisation of infrared detectors for cultural heritage** A. Drago, INFN-National Laboratories of Frascati, Italy.
9. **Studies on thick doubly polished slabs of silicate glasses** G. Giuli, University of Camerino, Italy.
10. **Determination of water content in natural impact glasses** G. Giuli, University of Camerino, Italy

The SINBAD-IR beamline was also involved in activities connected to third parties and scientific collaboration:

1. **L. Pavia** - Assessing of cleaning treatments of painting oil "Favretto" by UV-VIS-NIR-SWIR analyses.
2. **ICR - Istituto Centrale per il Restauro** - "Characterisation of Egyptian Cartonnages", from Egyptiam Museum of Turin, during the ICR 2023 restoration". Collaboration in the field of the ARTEMISIA project.
3. **ICR - Istituto Centrale per il Restauro** - "Characterisation of the 15th-century wooden painting titled "Madonna and Child and other sacred episodes" attributed to Arcangelo di Cola, from the Galleria Nazionale delle Marche in Urbino, during the ICR 2023 restoration with a particular focus on the Virgin's mantle. Collaboration in the field of the CHANGES project

During 2023 the laboratory experimental setup was upgraded with the following instrumentation and laboratory facilities:

1. An atmosphere-controlled chamber was developed around the experimental area of LUMOS II. The chamber was equipped with a glove-box to manipulate the samples and dry nitrogen (dry N_2) can be fluxed inside in order to obtain a controlled atmosphere: this set-up is dedicated to the analysis of samples that need a controlled atmosphere;
2. Integration of LED-UV and XRF systems on the ARTEMISIA XYZ Scanner;
3. Motorized high precision rotation stage for in vacuum spectrometer analyses;
4. HERA-IPERSPETTRALE VIS-NIR, hyperspectral camera, CMOS sensor, 1280x1024 pixels, 400 -1000 nm for the EUROMEX fluorescence microscope;
5. OPTOSKY spectrometer (200-1000 nm)

Among the other activities, the SINBAD beamline regularly hosts also different students to carry on their Master or PhD thesis:

1. **B. Valenti**, *Infrared spectroscopy. Theoretical elements and application to pigments.* Faculty of Mathematical, Physical and Natural Sciences, Physics Degree.

Many research activities have been presented in several scientific national and international conferences also as invited talks and in particular the oral presentation *La linea di Spettroscopia Infrarossa con luce di sincrotrone SINBAD IR: Applicazioni e sviluppi nel campo dei Beni Culturali* by **M. Romani**, L. Pronti, M. Cestelli Guidi presented at 109° Congresso Nazionale Società Italiana di Fisica (SIF) in September 2023 has been selected among the best 2023 communications (**https://www.sif.it/attivita/congresso/109/comunicazioni**).

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 2023, some tests to control the beam alignment were performed in autumn and the monochromator was aligned taking into account the new beam position in December. The height and the horizontal position of the double crystal monochromator were changed by a relevant amount. The fluorescent targets used (see Fig. 3) were left-in in order to control the beam position when DAΦNE restarted in January 2024 and then proceed with the alignment of the experimental chamber.

Figure 3: Soft X-ray beam on the fluorescent target placed at first crystal position.

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 2023 the ARTEMISIA portable XRF system was realised and tested on mapping measurements. 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 iron in a small painting of G. Favretto (Venezia 1849-1887) in the DAΦNE-Light DXR1 hutch (see Fig. 4). All security issues are now being studied in order to achieve the XRF system portability (hopefully foreseen in 2024) to be able to use it in-situ mapping measurements.
All the X-ray activities on going at the DAΦNE-Light laboratory including the use of the DXR1 soft X-ray beamline and of the conventional X-ray sources were presented the 25th of October at the INFN-LNF meeting **X-ray facilities at LNF** organised by the Research Division with the title *X-ray activities @ DAFNE-Light.*

Figure 4: The XRF system being placed, using the ARTEMISIA scanner, nearby the Favretto's painting to start the atomic mapping.

The approval of the EuPRAXIA Advanced Photon Sources (EuAPS) project, led by INFN in 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 2023 the in collaboration with other scientists working on EuAPS the project of the 3 m long experimental chamber was realised including the mountings of the sample and of the CCD camera needed for the first X-ray phase contrast imaging experiments in 2025.

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).
In 2023 the laboratory has been involved in different activities and projects using the VUV-Vis radiation to characterise and qualify materials.
To meet the different technical requirements, the beamline has been equipped with new sources. In previous years the beamline has been updated with discrete LED sources with different wave-

lengths, in the last year a new continuous source covering a spectral range from 200 to 2500 nm and a LED source at 255 nm with 1 mW power emission have been acquired (Fig. 5). All the improvements performed were needed to face some requests for absorption/transmittance/reflectivity measurements and for some preliminary tests of quantum efficiency in the UV range.

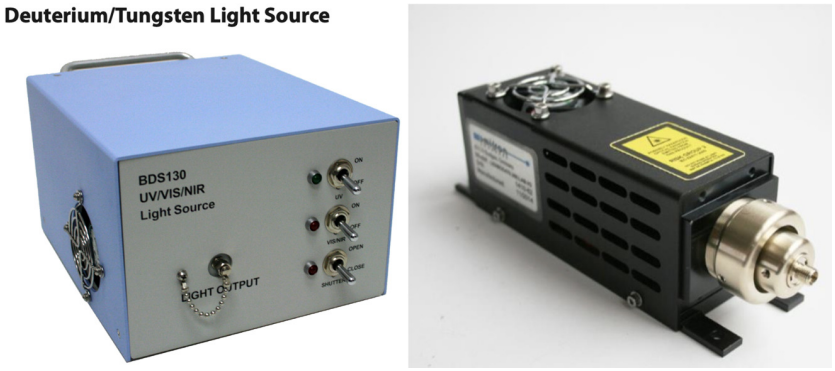

Figure 5: UV/VIS/NIR broad source (left) and 255 nm UV LED source (right).

One of the activities performed during 2023 was the measurement of transmittance of a specific sample of plexiglass in the range 200-800 nm, in collaboration with Davide Pinci from Sapienza University. The measurements show a high transmittance of the sample between 400 and 800 nm with a cut-off around 380 nm (Fig. 6).

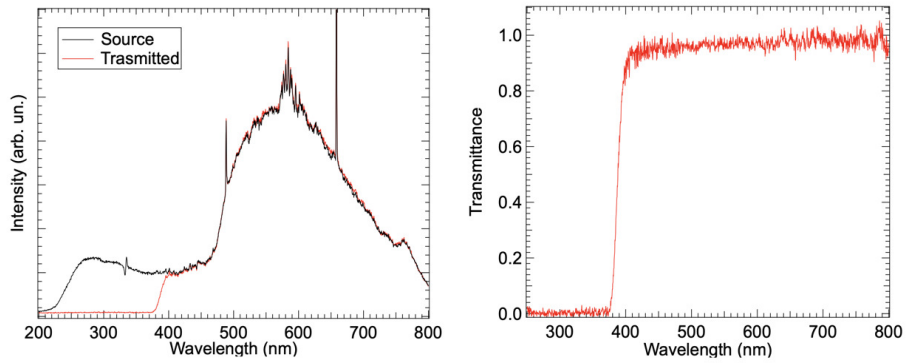

Figure 6: Spectral response (left) and transmittance measurements (right) of a plexiglass sample.

Quantum efficiency (QE) measurements on technical copper surface as a function of the emitted power have been performed during 2023 (Fig. 7). The measurements have been acquired as tests for a possible new facility for research on photocathode in collaboration with Luisa Spallino and the Accelerator Division.
Thanks to the experience gained on the beamline and the knowledge of the VUV spectral range, Marco Angelucci in collaboration with Luisa Spallino, have been involved and are collaborating to the design of the EuPRAXIA@ SPARC_LAB beamlines and on the drafting of part of the TDR.
Other activities that involved the DXR2 beamline and the VUV sources are hereafter reported:

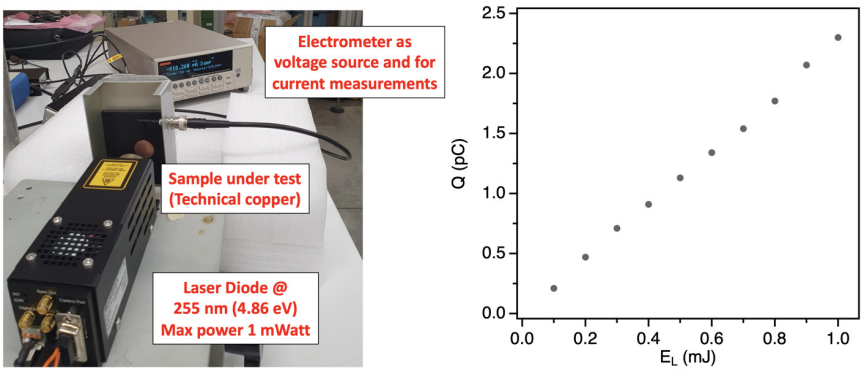

Figure 7: Left: Experimental set-up to measure the QE of a technical copper sample. Right: Measure of the photo-emitted electrons as a function of the source power.

1. **Collaboration within the INFN CSN5 LLMCP project.**
   V. Vagnoni (INFN-BO) (Resp. Naz.)

   The aim of this projects is to develop a novel MCP-PMT Cherenkov-based detector with ps time resolution, moderate cost and high radiation resistance with potential applications in the LHCb and NA62 experiments. The activity at the UV-Vis beamline concerned the study, test and characterisation of different parts of the detector.

2. **WP4 of the ARTEMISIA Project: in collaboration with SINBAD-IR beamline.**

   In collaboration with SINBAD-IR beamline within the ARTEMISIA project (see SINBAD IR beamline activity), after developing the setup (both hardware and software) for the in-situ measurements performed in 2022, during 2023 the activities were focused on the integratiion of the UV setup on the XYZ scanner and on the measurements described in the previous paragraph.

2.4 XUV beamlines and laboratory - Resp. Roberto Cimino

Aim of this laboratory is to host three bending magnet beamlines. Two will offer monochromatic light with a photon energy range from 30 eV to 1000 eV while the third one will provide non-monochromatized SR light.
The Low Energy Beamline, (LEB) will cover the energy range from 30 eV to 200 eV and the High Energy Beamline (HEB) will offer monochromatic photons from 60 eV to 1000 eV. The third beamline, *WINDY* (White lIght liNe for Desorption Yields) offers collimated SR for photodesorption studies on pipe samples up to 3 m long. The three beamlines still need some extensive use of SR delivered by DAΦNE to be finally commissioned.
Only near the end of 2023, for various reasons, DAΦNE started producing some stable SR light used to start making some tests. Even if SR was not available for a long part of the year, we managed to consolidate all the three beamlines and their experimental stations hosting and promoting some mainstream projects.
During 2023, the laboratory has actively worked on ET-ITALIA@LNF project, funded by National Scientific Committee 2 (CSN2), focusing on the studies of the vacuum properties of different com-

ponents 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 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. Moreover, the laboratory has started to collaborate with the BNL Vacuum Group to develop a SEY (Secondary Electron Yield) 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, University of Roma Tre, 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 of our resources to external users are described.

1. ***ARYA***

   In the period between 2020 and 2023 the laboratory hosted the National Scientific Committee 5 (CSN5) founded ARYA project. This project aimed to study material properties of interest for accelerators. Within this project, many activities have been carried out in collaboration with other INFN groups (INFN-Na, INFN-Sapienza) and projects (LHCb-Spin).
   The main activity consisted in investigating the effects induced by the interactions of materials of interest for accelerators with photons and electrons, in terms of Secondary Electron Yield (SEY) and their in vacuum behaviour. These studies have been done both at room and cryogenic temperatures (mimicking the real operational temperatures in various accelerators like LHC, EIC etc.).
   ARYA has significantly contributed, together with the LNF funds, to substantial implementations and hardware upgrades necessary to carry out this kind of studies. A new experimental chamber has been set up, equipped with the necessary instrumentation to perform surface studies by SEY, X-ray Photoelectron spectroscopy (XPS) and desorption investigations (stimulated by electron, photon and by thermal variations) with a Quadrupole Mass Spectrometer (QMS).
   The studies were focused on different surfaces (morphologically modified by laser ablation, carbon coatings...) in cryogenic vacuum, refining the capabilities to perform thermal and electron desorption measurements. This kind of materials are of particular interest due to their low Secondary Electron Yield (SEY<1) but a rigorous evaluation of the consequences on vacuum stability is required, when such surfaces are exploited as cryogenic components undergoing to thermal variation and electron irradiation. To do this Thermal Programmed Desorption and Electron Stimulated Desorption measurements have been done on specific samples, produced by INFN and CERN collaborators, after dosing different gas species (Ar, CO, CH_4, H_2, H_2O).
   In this context, the research, started in 2019, to establish the minimum thickness of an Amorphous Carbon Coating on Copper to obtain the full reduction of the Secondary Electron Yield as low as below 1.1 has been finalised.

All the obtained results have been published in different articles and proceedings and presented at national and international conferences.
The studies and the related competences acquired to carry out ARYA have paved the way for consolidating and opening new scientific collaborations, service contracts, and new projects. ARYA has been essential to foster also the ongoing collaboration with BNL/EIC (described elsewhere).
In particular:

(a) *Collaboration with CAE to address surface properties of thin films oxide coatings on new Niobium materials/hetero-structures for particle accelerators.*

(b) *Collaboration with ONERA to extend our work on SEY of thin amorphous carbon (a-C) coatings on Cu.*

(c) *Collaboration with the Universidade Nova de Lisboa (Portugal) for the presentation of an international project (Graphene Coatings Meet Challenges of Future Accelerators - GRACE).*

(d) *Service Contract with Thales Alenia Space for Secondary Electron Yield investigations.*

(e) *Interactions with BNL for studies contributing to the future EIC that brought to the following steps:*

   i. 2020 - Service Contract for SEY characterisations.
   ii. 2023 - Statement of Work (SoW, Doc No. EIC-VSG-SOW-011) BNL-INFN.
   iii. 2023 - Collaboration to develop a SEY measurement system.

(f) *National and International collaborations with gravitational wave detectors communities (Ego-Virgo, ET).*

(g) *ET-Italia@LNF project, founded by the INFN CSN2 committee.*

The activities of ARYA and the new collaborations led also to the organisation of the ECLOUD'22 and GWDVac'22 workshops in which the scientific communities have discussed topics of common interest.

2. ***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. The study of mirror vacuum system and the reduction of the contaminants at cryogenic temperature on the optic surfaces is a mandatory passive strategy for the maintenance of detector efficiency. This is the aim of the WP2 activities (done in collaboration with the LATINO Vacuum Laboratory in Frascati) focusing on characterisation of the materials' outgassing properties. The WP1 activities are totally carried out in XUV laboratory, with the purpose of investigating the possibility to use low energy electrons as active method to remove ice forming on cryogenic optics by Electron Stimulated Desorption (ESD). Such defrost method will clearly cause electrostatic charging, which has been already shown to affect

gravitational wave detection on running interferometers. In principle, electrons not only can induce ice desorption but can also mitigate charging issues by properly tuning their kinetic energy. In this way, electrons can be used as mitigation method both for ice desorption and for charge neutralisation.
The discharging method by electrons is based on the knowledge of the SEY characteristic of each material. During this year, we have refined the set-up to experimentally validate the charging neutralisation method on small representative samples (8x8 mm^2). As sketched in Fig. 8 we use a non-contact electrostatic voltmeter (ESV 1000) to measure the voltage induced on a surface upon electron irradiation. The voltmeter is positioned outside the UHV chamber where the sample irradiation is done. The sample (electrically insulated) is connected by a BNC to a metallic plate placed ∼2.5 mm from the voltmeter sensor. When the sample is under electron irradiation, an image charge is formed on the metallic plate. Then, the voltmeter sensor will detect the voltage of the image charge induced on the metallic plate connected to the irradiated sample. The voltage revealed by the voltmeter is acquired by a digital multimeter with a resolution of the order of tens of mV. A LabView acquisition program has been optimised to choose data acquisition parameters (resolution and acquisition rate).

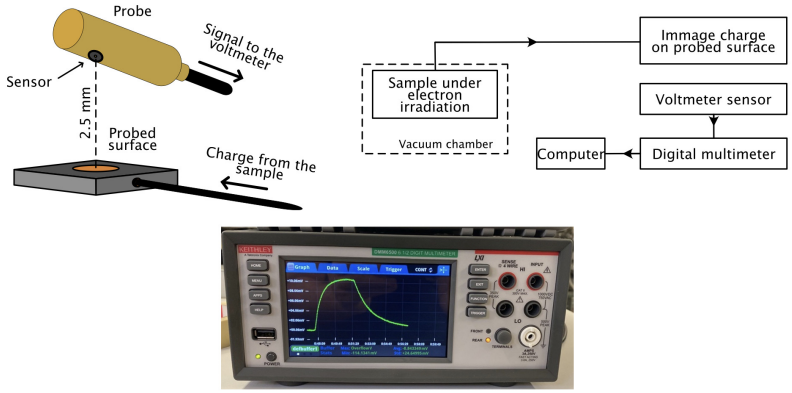

Figure 8: Top right: electrostatic voltmeter set-up. The sample is connected to a metallic plate (probed surface). Under electron irradiation, a sample's image charge is induced on the probed surface. The voltage generated by such a charge is revealed by the voltmeter sensor and acquired by a digital multimeter. Top left: data acquisition scheme for voltage measurements. Bottom: an example of charging/discharging process so as seen in the screen of the multimeter

Fig. 9 shows an example of charging/neutralisation by electron irradiation of a representative sample (20 nm SiO_2/Si). The irradiation electron energy has been chosen by considering the SEY characteristics of the sample showed in Fig. 9(a). Charging measurements are here reported for the specific case of an initially neutral sample. However, the charging behaviour is general whatever the initial surface voltage V_s. Let's consider each case in detail.
Fig. 9(b) represents the positive charging and the irradiation is done with an electron energy E_1=400 eV: at this energy δ>1. The surface will start to positively charge, continuously attracting both the impinging electrons and part of the low energy emitted ones. Emitted electrons, in fact, have an energy distribution between 0 and E_1 and the large part of them has a very low energy (below ∼50 eV). This process leads to reach a stable surface potential V_s which will depend on SEY at that specific impinging electron energy. Fig. 9(c) shows

negative charging and the irradiation is done with electron energy E_2=20 eV: at this energy δ<1. Electrons will be deposited on the surface, inducing an increasingly negative surface charge. Such a negative charge will act as a retarding potential for further incoming electrons. These will continue to be deposited until their effective energy (that is, the energy they have considering the retarding field) is not enough to overcome V_s: a stable condition is reached. Fig. 9 (d) and (e) show neutralisation: whatever the initial V_s, irradiating the surface with electrons at E_0=E(δ=1) charging neutralisation will occur.

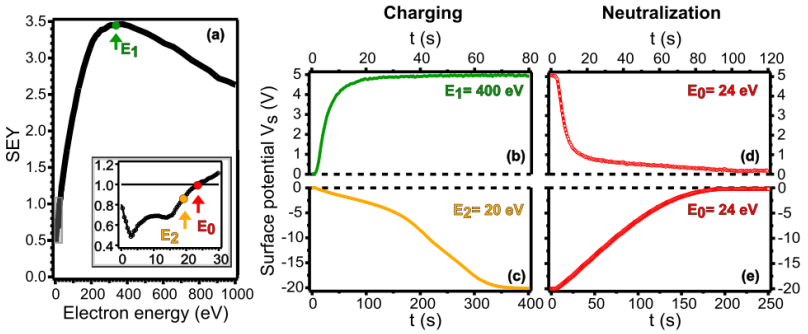

Figure 9: a) SEY curve of 20 nm SiO_2/Si sample. The inset is a magnification of the low energy region. Arrows point to the δ values at the charging/neutralisation irradiation energies. Charging measurements to positive (b) and negative (c) voltage. Neutralisation starting from positive (d) and negative (e) voltage.

These results have been presented in many national and international meetings. The oral presentation *Using low energy electrons to neutralizing electrostatic charges on cryogenic test mass mirrors of future gravitational wave detectors* by **L. Spallino**, M. Angelucci and R. Cimino, presented at 109° Congresso Nazionale Società Italiana di Fisica (SIF) in September 2023, has been selected by the Scientific Committee as one the Best Communications (**https://www.sif.it/attivita/congresso/109/comunicazioni**). The related paper has been submitted and will be published in 2024.

The work is ongoing to validate the charging/neutralisation method on other materials representative for the mirror optics also at cryogenic temperature and after dosing specific gas species (as H_2O). A new experimental set-up will be 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.

Electrostatic charging coming from the beam-pipe is one the few known contributions to optics charging phenomenon. This was already experienced in Virgo, where it has been observed that electrostatic charges, generated by low energy electrons coming from ion pumps, propagate along the beam-pipes finally impinging on the test masses. In this framework, in collaboration with the vacuum group of 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 beam-pipe. 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 this electrostatic ring on baffles to mitigate the charges' flow from the beam-pipes to the mirrors' chamber. With this

aim, both simulations and experimental works is foreseen. During this year, the idea has been discussed with collaborators and it is at an initial stage that needs to be refined.

3. ***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, contributing on issues related to the tower vacuum issues and to the pipe arm vacuum.

4. ***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 possesses 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 studying and designing the future EIC is following by 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 to qualify 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 are reported in Fig. 10 and Fig. 11.

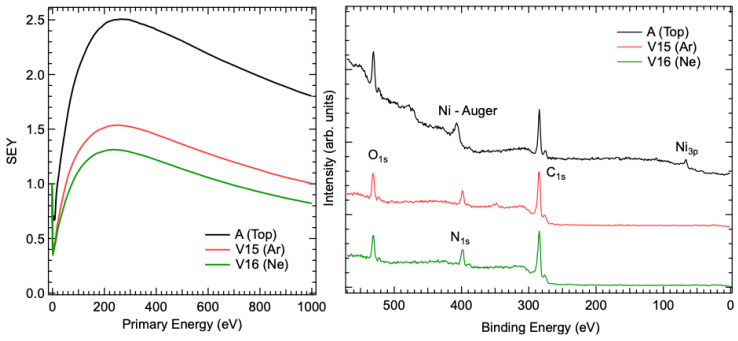

Figure 10: SEY (left) and XPS (right) measurements on three selected carbon films produced by BNL.

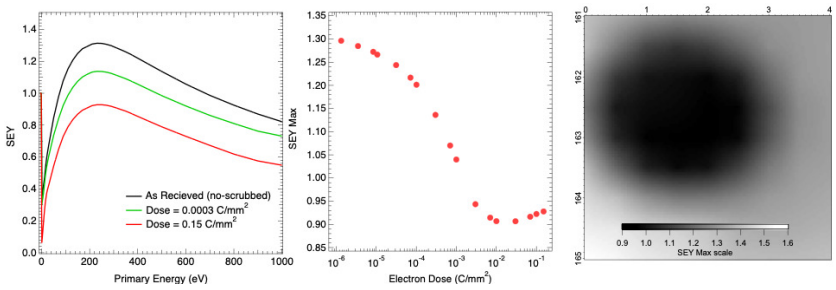

Figure 11: From the left: SEY curves on a selected sample as a function of electron irradiation (scrubbing) at 300 eV; trend of the maximum value of SEY as a function of the electron dose deposited on the sample; SEY maps of the sample surface after the scrubbing. The black area corresponds to the scrubbed zone.

(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 to qualify the materials after their production is essential to avoid expensive and time-consuming validation by external laboratories. For this reason, during 2023, the laboratory has started a collaboration 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. This collaboration is at an initial stage of discussion, with the aim to identify a possible design of a measurement chamber.

5. ***WINDY***

During the last part of 2023, the alignment of the beamline continued, solving some technical problems regarding the last mirror. The collimated white beam was brought inside the measurement chamber and the system was subjected to initial conditioning. The result is shown in Fig. 12 where the part of the beam impinging a control target is clearly visible. The collimated beam will be used for photo-desorption experiments from long tubes. However, the beam is not yet completely homogeneous (a more intense part can be seen on the left) and requires further work which will be carried out during 2024 following the DAΦNE operation.

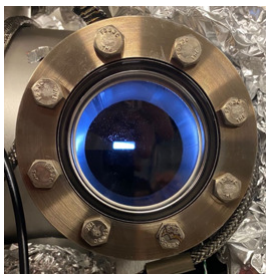

Figure 12: White beam impinging on the control target inside the measurement chamber of the WINDY branch line.

6. ***Collaboration with the University Roma Tre***

   This collaboration is based on the interest of carbon based 2D materials. During this year the laboratory continued the collaboration with some colleagues from University of Roma Tre to grow graphene on crystalline Ge substrates by Chemical Vapour Deposition. The experiments have been performed with the CVD furnace varying the physicochemical conditions. Results have been published and will appear online in 2024.

3 Acknowledgments

Acknowledgements are due to the INFN-LNF Synchrotron Light Service for providing a great technical service.

4 List of Talks, Posters and Proceedings

1. **M. Romani**, L. Pronti, A. Balerna, M. Angelucci, G. Viviani, V. Sciarra, M. Cestelli Guidi, *Mapping Multi Sensore per lo studio delle opere pittoriche in situ*, **4th Convegno Nazionale Annuale del Centro di Eccellenza DTC Lazio**: Tecnologie e patrimonio culturale: nuove competenze e professioni, 30/11/2023, Sapienza University, Rome **(2023)**

2. M. Romani, **L. Pronti**, M. Cestelli Guidi, *Infrared spectroscopy with synchrotron radiation applied to cultural heritage: applications and developments of the SINBAD-IR,* **XIV Convegno internazionale AIES**: diagnosi, conservazione e valorizzazione del patrimonio culturale, 14-15/12/ 2023, Napoli **(2023)**

3. **M. Romani**, L. Pronti, M. Cestelli Guidi, A. Balerna, V. Sciarra, G. Viviani, *Macroscopic FT-IR mapping for the in situ characterisation of pictorial materials: technological advances and applications*, **MetroArcheo 2023**, 19-21 October **(2023)**

4. **M. Romani**, L. Pronti, M. Cestelli Guidi, *La linea di Spettroscopia Infrarossa con luce di sincrotrone SINBAD IR: Applicazioni e sviluppi nel campo dei Beni Culturali*, **109° Congresso Nazionale Società Italiana di Fisica**,11-15/09/2023, Fisciano (Salerno) **(2023)**

5. **L. Pronti**, M. Romani M., Cestelli Guidi, *Macro FTIR mapping for the in-situ study of pictorial materials: technological advances and applications*, **109° Congresso Nazionale Società Italiana di Fisica** 11-15/09/2023, Fisciano (Salerno) (Invited) **(2023)**

6. **M. Cestelli Guidi**, *L'impatto della fisica fondamentale sulla società attraverso gli strumenti del Trasferimento Tecnologico: Modelli e storie di successo dell'INFN*, **109° Congresso Nazionale Società Italiana di Fisica**, 11-15/09/2023, Fisciano (Salerno) (Invited) **(2023)**

7. **E. Bruschini**, C. Carli, M. Romani, T. Cuppone, M. Cestelli Guidi, G. Viviani, G. Pratesi, *Multiscale spectroscopic characterisation of ungrouped achondrites*, **Europlanet Science Congress**, 18-23/09/2023, Palacio de Congresos de Granada, Spagna **(2023)**

8. **M. Romani**, S. Lemmers, L. Pronti, G. Kamel, K. Lorentz, M. Cestelli Guidi, *Optimisation of the methodology for the FT-IR spectroscopic characterisation of archaeological human long bone samples*, **TECHNART 2023**, International conference on analytical techniques in art and cultural heritage, 7-12 Maggio 2023, Lisbona **(2023)**

9. **G. Capobianco**, L. Pronti, M. Romani, S. Di Filippo, G. Bonifazi, M. Cestelli Guidi, S. Serranti, *Multi-sensor imaging coupled with chemometric techniques for the characterisation of pictorial materials*, **TECHNART 2023**, International conference on analytical techniques in art and cultural heritage, 7-12 Maggio 2023, Lisbona **(2023)**

10. **L. Pronti**, M. Romani, M. Ioele, I. Sinceri, E. Cianca, E. Gorga, G. Tranquilli, F. Fumelli, M. Cestelli Guidi, *Micro and Macro FT-IR spectroscopic imaging and mapping as a tool for the detection of degradation products and for monitoring the cleaning processes of painted surface*, **TECHNART 2023**, International conference on analytical techniques in art and cultural heritage, 7-12 Maggio 2023, Lisbona.

11. **M. Cestelli Guidi**, F. Aramini, A. Balerna, S. Brandalesi, G. Bonifazi, G. Capobianco, E. Giani, E. Gorga, M. Ioele, B. Lavorini, A. Manotan, L. Pronti, M. Romani, S. Serranti, V. Sciarra, M. Simeone, S. Tamascelli, G. Verona Rinati, G. Viviani, *ARTEMISIA: artificial intelligence to support diagnostic technologies for Cultural Heritage. An integrated multimodal approach for assessing the state of conservation of pictorial works.*, **TECHNART 2023**, International conference on analytical techniques in art and cultural heritage, Lisbon, Portugal 7-12 May **(2023)**

12. **L. Pronti** et al. *New technologies for monitoring degradation processes on painted surfaces. Integrated spectroscopies to support restorers and conservators.* Proceeding of the 3rd Annual Conference **Digital transformation and green deal in Cultural Heritage** Roma - Sapienza 23/09/2022 -DTC Lazio **(2023)**

13. **L. Manzanillas Velez**, ... A. Balerna et al, *Performance studies of pixelated HPGe detectors for synchrotron applications*, **2023 IEEE NSS MIC RTSD**, Vancouver, Canada 4-11 November **(2023)**

14. M. Angelucci, **A. Balerna**, M. Cestelli Guidi, M. Pietropaoli, L. Pronti, M. Romani, V. Sciarra, G. Viviani, *Activities using X-rays at DAΦNE-Light.* High Precision X-ray Measurements 2023 **HPXRM23** Frascati - LNF 19-23 June **(2023)**

15. **A. Balerna** et al., *EuAPS: User Perspectives.* **EuPRAXIA Advanced Photon Sources (EuAPS) Kick-off meeting**, Rome - INFN 28 February **(2023)**

16. **A. Balerna** et al., *X-ray activities @ DAΦNE-Light.* **X-rays facilities at LNF**, Frascati - LNF 25 October **(2023)**

17. **L. Spallino**,M. Angelucci and R. Cimino, *Using low energy electrons to neutralizing electrostatic charges on cryogenic test mass mirrors of future gravitational wave detectors*, **109° Congresso Nazionale Società Italiana di Fisica**, 11-15/09/2023, Fisciano (Salerno) (Invited) **(2023)**

18. **M. Angelucci**, L. Spallino, R. Cimino, C. Hetzel, S. Verdu Andres, D. Weiss, *Surface studies on a-Carbon coating of interest for future accelerators*, **109° Congresso Nazionale Società Italiana di Fisica**, 11-15/09/2023, Fisciano (Salerno) (Invited) **(2023)**

19. **L. Spallino**,M. Angelucci and R. Cimino, talk, *Electrostatic charge mitigation by electrons: status of the activities and perspectives*, ET-ISB division IV (Vacuum&Cryogenics) Meeting, La Biodola (Isola d'Elba), 27-28 May 2023.

20. **L. Spallino**,M. Angelucci and R. Cimino, poster, *Low energy electrons to neutralize electrostatic charges on cryogenic test mass mirrors*, GWADW23 - Gravitational-Wave Advanced Detectors Workshop, La Biodola (Isola d'Elba), 21-27 May 2023.

21. **L. Spallino**,M. Angelucci and R. Cimino, poster, *How low energy electrons can neutralize electrostatic charges on cryogenic test mass mirrors in gravitational wave detectors*, XIII Einstein Telescope Symposium, Cagliari, 8-12 May 2023.

5 Lectures and outreach

1. **M. Cestelli Guidi**, *Donne nella scienza: parola a 12 italiane che sanno il fatto loro*, Il-Sole24Ore, Alley Oop: L'altra metà del sole -L. Giangualano, 11 February 2023
https://alleyoop.ilsole24ore.com/2023/02/11/donne-nella-scienza/

2. **M. Romani**, **L. Pronti**, G. Capobianco, Masterclass ARTEMISIA Project : *ARTificial intelligence Extended Multispectral Imaging Scanner for In-situ Artwork analySis*, 20/09/2023.

3. **M. Romani**, Invited talk *Scientific Investigations applied to Cultural Heritage*, as part of the **Christian and Medieval Archaeology** course of the Bachelor's Degree in Cultural Heritage Sciences and of the **Digital Curation of Archaeological Heritage** course of the Master's Degree of Archeology and History of Art, 18 April 2023.

4. **A. Balerna**, **M. Cestelli Guidi**, **L. Pronti**, **M. Romani**, *OPEN Labs 2023*, 27 May 2023, Frascati.

5. **M. Romani**, **L. Pronti**, *Scientific investigations applied to cultural heritage*, Liceo Scientifico M. Azzarita, 17 April 2022, Rome.

6. **A. Balerna**, *Indagini sulla struttura della materia: atomi, acceleratori e raggi X*, Gruppi di Lavoro - Summer School 2023, Frascati, LNF 14 June 2023

7. **A. Balerna**, *Synchrotron Radiation and DAΦNE-Light*, Corso di "Fisica degli acceleratori", organised by LNF-INFN and Università La Sapienza (Rome) in the framework of the "Corso di Eccellenza – Laurea Magistrale in Fisica - Università La Sapienza di Roma", LNF Frascati, 17-18 July 2023.

6 Publications

1. E. Fardelli, A. D'Arco, S. Lupi, D. Billi, R. Moeller, M. Cestelli Guidi, ″Spectroscopic evidence of the radio resistance of Chroococcidiopsis biosignatures: a combined Raman, FT-IR and THz-TDS spectroscopy study″. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy **288** (2023) 122148. **https://doi.org/10.1016/j.saa.2022.122148**

2. V. Lazic, M. Romani, L. Pronti, M. Angelucci, M. Cestelli-Guidi, M. Mangano, R. Fantoni, ″Identification of materials in oil paintings through studies of correlations and ratios between the element line intensities during LIBS stratigraphy″. Spectrochimica Acta Part B: Atomic Spectroscopy **201** (2023) 106601. **https://doi.org/10.1016/j.sab.2022.106601**

3. A. Drago, E. Pace, S. Bini, M.Cestelli Guidi, F. Cioeta, A. Marcelli and V. Bocci, ″ Fast transient infrared detection for time-domain astronomy″. J. of Instrumentation **18** (2023) C02012. **https://doi.org/10.1088/1748-0221/18/02/C02012**

4. L. Tomarchio, L. Mosesso, S. Macis, L.T. Nguyen, A. Grilli, M. Romani, M. Cestelli Guidi, R. J. Cava, S. Lupi, ″Phonon Anharmonicity and Spin–Phonon Coupling in CrI_3″. Materials **16** (2023) 4909. **https://doi.org/10.3390/ma16144909**

5. S. Caldrer, N. Deotto, G. Pertile, G. Bellisola, M.Cestelli Guidi, ″Infrared analysis in the aqueous humor of patients with uveitis: Preliminary results″., Journal of Photochemistry and Photobiology B: Biology **243** (2023) 112715.
https://doi.org/10.1016/j.jphotobiol.2023.112715

6. G. Capobianco, M.L. Antenozio, G. Bonifazi, P. Brunetti, M. Cardarelli, M. Cestelli Guidi, L. Pronti, S. Serranti, ″Multi-Analytical Approach to Evaluate Elements and Chemical Alterations in Pteris vittata Plants Exposed to Arsenic″. Water **15** (2023) 1333. **https://doi.org/10.3390/w15071333**

7. A Drago, E Pace, S Bini, MC Guidi, C Curceanu, A Marcelli, V Bocci, M. Cestelli Guidi, L. Pronti, S. Serranti, ″Ultra-fast infrared detector for astronomy″. Nuclear Instrum. Meth. A **1048** (2023) 167936. **https://doi.org/10.1016/j.nima.2022.167936**

8. A. Balerna, M. Ferrario and F. Stellato, ″The INFN-LNF present and future accelerator based light facilities″, Eur. Phys. J. Plus **138** (2023) 37. **https://doi.org/10.1140/epjp/s13360-022-03611-9**

9. L. Manzanillas, S. Aplin, A. Balerna et al., ″Development of Multi-element Monolithic Germanium Detectors for X-ray Detection at Synchrotron Facilities″. Nuclear Instrum. Meth. A **1047** (2023) 167904. **https://doi.org/10.1016/j.nima.2022.167904**

10. L. Manzanillas Velez, ... A. Balerna et al., ″ Performance studies of pixelated HPGe detectors for synchrotron applications″. **2023 IEEE NSS MIC RTSD** Nuclear Science Symposium, Medical Imaging Conference and International Symposium on Room-Temperature Semiconductor Detectors, Vancouver, Canada, 2023, pp. 1-2. **https://ieeexplore.ieee.org/document/10338395**

11. A. Grado, E. Tofani, M. Angelucci, R. Cimino, J. Gargiulo, F. Getman, A. Liedl, L. Limatola, V. Mennella, A. Pasqualetti, F. Ricci, D. Sentenac, and L. Spallino,″ Ultra-high vacuum beam pipe of the Einstein Telescope project: Challenges and perspectives″. J. Vac. Sci. Technol. B **41** (2023) 024201. **https://doi.org/10.1116/6.0002323**

12. F. Villa et al., ″EuPRAXIA@ SPARC_LAB status update″ Proc. SPIE **12581** (2023) X-Ray Free-Electron Lasers: Advances in Source Development and Instrumentation VI, 125810H (29 June 2023). **https://doi.org/10.1117/12.2668643**