DAΦNE-Light Laboratory and Activity

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1 Summary

In 2022 the scientific activity at the DAΦNE-Light laboratory, was mainly performed using conventional sources and the DAΦNE synchrotron radiation beam for some tests and measurements. Also in the absence of problems due to the COVID-19 pandemic, the Main Proposers of the approved proposals asked, when required were allowed to perform their measurements using the sample *mail-in* procedure with experiments undertaken by the beamline staff.
About 28 experimental teams got access, in presence or mailing-in their samples, to the DAΦNE-Light laboratory mainly coming from Italian Universities and Research Institutions, third parties and only very few EU and non-EU experimental teams, due to the end of the EU project granting Trans-National Access (TNA) and covering travel and subsistence expenses.
The laboratory was opened to visitors in the Open Day in May 2023 and to high school teachers in November during the week dedicated to the " Incontri di Fisica". In 2022 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 beamlines, some tests and measurements were performed up to the beginning of July 2022, before the DAΦNE 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 2022 the SINBAD-IR beamline has been involved in many projects and conferences.
Concerning the conferences, at the VII edition of NanoInnovation, held in Rome from 19 to 23 September 2022 at the Renaissance Cloister by Sangallo at the Faculty of Civil and Industrial Engineering of Sapienza University of Rome, a special session on *Key Enabling Technologies for the protection of cultural heritage: from earthquakes to big data* was co-organized with the "Centro di Eccellenza Beni e Attività Culturali della Regione Lazio" (CdE DTC Lazio) and was chaired by M. Cestelli Guidi with the aim to bring together specialists and innovators and share different approaches to the development of new technologies in the domain of cultural heritage.
Concerning the projects in 2022 the SINBAD-IR beamline has been involved in the following ones:

1. ***ARTEMISIA, 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) is related to the use of artificial intelligence to support diagnostic technologies for cultural heritage with the realisation of a prototype to asses the state of conservation of pictorial works. In collaboration with: Sapienza, Università di Roma Tor Vergata, X-Team software solutions s.r.l., Vianet. The project was financed by Regione Lazio in the field of the CdE DTC Lazio. The kickoff meeting of the project was organized at the Laboratori Nazionali di Frascati on December 16th, 2021. During 2022 a progress of all the WPs was achieved: the implementation of the ARTEMISIA prototype (WP1) (Fig. 1), the definition and creation of the user-friendly software (WP2), the realisation of the material paintings' database (WP3), the organisation of several *in situ* measurement campaigns at the Museum of Carlo Bilotti Aranceria di Villa Borghese (Rome) (WP4), and finally concerning dissemination the participation to national and international conferences and scientific events (WP5). The ARTEMISIA Advisory Board was constituted during the Focus Groups related to the project that were organised online in October 2022. All information regarding the ARTEMISIA project can be accessed at the dedicated website: **https://artemisia.lnf.infn.it/**.

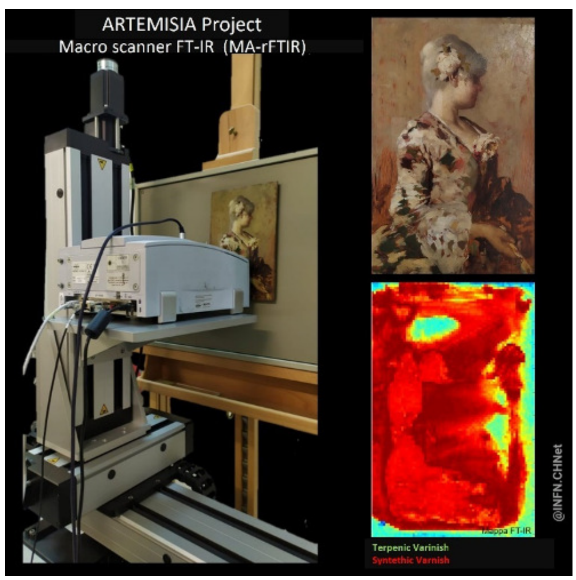

Figure 1: The new ARTEMISIA MAcro FT-IR reflection scanner (MA-rFTIR), developed at SINBAD-IR, was tested on a painting, attributed to Giacomo Favretto, to identify the chemical composition of its surface. The FT-IR maps highlighted the presence of two different varnishes: a terpenic varnish, mainly present on the edges of the picture and a synthetic one (polyethylmethacrylate) on the central area of the painting. These results will be useful to define the restoration strategy of the painting.

2. ***PNRR_PE5 - CHANGES, Funded by European Union (EU) and Ministero dell'Università e della Ricerca (MUR).***

   The project CHANGES (Cultural Heritage Active Innovation for Next-Gen Sustainable Society) is an extended partnership targeted to advance fundamental and applied research on

Cultural Heritage and started in December 2022. The partners of this project will share know-how, research infrastructures, networks with private businesses, local authorities and cultural institutions combining pioneering technological platforms, people- centered capacity building with knowledge-based approaches towards innovation. The project is articulated in 9 spokes, covering a wide range of integrated themes, from cultural tourism to social cohesion and participation through cultural engagement, and green strategies of heritage conservation and preservation. The kickoff meeting was organised at the Sapienza University on January 23-24th, 2023. INFN, as a member of the Associazione Centro di Eccellenza Beni e Attività Culturali della Regione Lazio (DTC Lazio) will take part to some activities (**https://www.mur.gov.it/it/news/mercoledi-03082022/pnrr-mur-selezionati-i-14-partenariati-attivita-di-ricerca**).

More than 16 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 2022 is summarised here:

1. **SpeChMet** - Spectral Characterization of (ungrouped) Meteorites: unraveling their origin and physico-chemical evolution of their parental planetary bodies, E. Bruschini, INAF-IAPS, Italy.

2. **ESLS**- Unraveling low-energy electrodynamics in the quarter-filled spin ladder system α'-NaV_2O_5, F. Giorgianni, Paul Scherrer Institute (PSI), Switzerland.

3. **FAIRTEL** - The FAIRTEL or FAst InfraRed ground-based TELescope experiment has been partially funded for 2022 by the CSNV of INFN to design a detector able to study ultra-fast transients as well as slower time variations of signals in the infrared astronomy. Experience done to detect the pulsed infrared synchrotron light in e+e- circular accelerators has demonstrated the feasibility to acquire mid IR signals with rise time up to about 1 ns using single pixel HgCdTe semiconductors at room temperature. In 2022 some HgCdTe detectors have been tested at the SINBAD-IR beamline using the DAΦNE synchrotron light. S. Bini and A. Drago - INFN Laboratori Nazionali di Frascati, Italy.

4. **Standard access** Optical transmittance measurements were carried out on the CrI_3 (single crystal) and $MnBi_2Te_4$ (film) samples on silicon as a function of temperature - L. Tomarchio - Sapienza University of Rome, Italy

5. **Standard access** Optical transmission and reflection spectroscopy measurements were carried out on the CrI_3 (single crystal) and FeSn (thin films) samples as a function of temperature, L. Mosesso, Sapienza University of Rome, Italy.

6. **Standard access** Confined volatiles (H_2O and CO_2) in amorphous silica: implications for terrestrial and extraterrestrial materials, A. Conte, University of Roma Tre, Italy.

7. **Short access** Study of VO_2 based thermochromic metasurface, M.C. Larciprete, Sapienza University of Rome, Italy.

8. **Short access** Characterization of water content on hydrate silica, A. Stephant, Istituto di Astrofisica e Planetologia Spaziali INAF-IAPS, Italy.

9. **Short access** Characterization of Hypatia meteorite by LUMOS, C. Carli, Istituto di Astrofisica e Planetologia Spaziali INAF-IAPS, Italy.

10. **Short access** Characterization of oil painting "Favretto", S. Di Filippo, Italy

It is important to stress that many results achieved using measurements performed at the SINBAD-IR beamline were published on journals with high impact factors including a publication on ***Nature-NPG Asia Materials*** (Fig. 2) and a publication on *Eur. Phys. J. Plus*, because one of its figures was chosen as cover figure for the June 2022 issue (Fig. 3), both included as highlights:

1. **Electrodynamics of $MnBi_2Te_4$ intrinsic magnetic topological insulators** - *L. Tomarchio, Dept. of Physics, Sapienza University, Rome.*
In this paper the electrodynamics of $MnBi_2Te_4$ (MBT) thin films, an intrinsic magnetic topological material, is reported. The optical conductivity of $MnBi_2Te_4$ from terahertz (THz) to ultraviolet (UV) frequencies as a function of the film thickness was studied, highlighting the presence of surface topological states superimposed on the bulk electrodynamics response. For the thinnest film, where the charge transport is dominated by Dirac surface states, the effect of the phase transition from the high-temperature topological protected state to the low-temperature magnetic (time-reversal broken) state by measuring the optical conductivity across the Néel temperature (T_N) was investigated. At low temperatures, the breaking of the time reversal symmetry affects the optical conductivity, indicating that a magnetic-induced gap opens below T_N. - **https://www.nature.com/articles/s41427-022-00429-w**

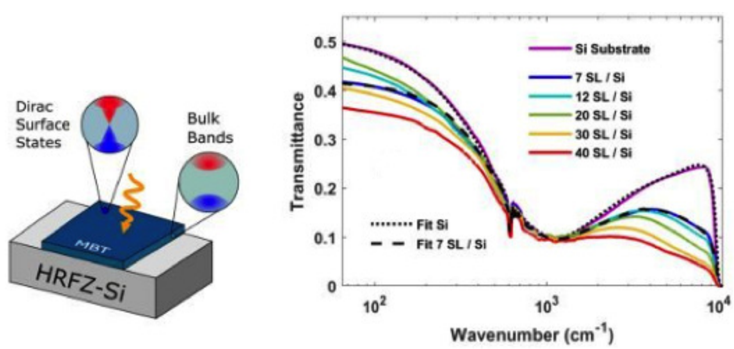

Figure 2: Schematic view of the thin film samples over an high-resistivity floating-zone (HRFZ)-Si(111) substrate (the two surfaces are expected to host Dirac states due to the nontrivial topology of the bulk gapped bands) and the measured optical transmittance of MBT films over a silicon substrate, the 7 SL (septuple-layer) film (black dashed line) and of the bare Si substrate (black points).

2. **Toward an assessment of cleaning treatments onto nineteenth–twentieth-century photographs by using a multi-analytic approach** - *M. Romani INFN-LNF et al.*
The application of cleaning treatments for the restoration of nineteenth–twentieth-century photographs (Fig. 3) represents an innovative and still little explored aspect. In this paper, in order to remove the degradation products, two cleaning methods were used for two different photographic techniques: poly(vinyl alcohol)-based hydrogels were applied to clean an albumen-based print, while calcium chlorine was used to remove the silver mirroring effect on a gelatin silver print. The constituent materials and conservation state of the analyzed photographs were characterized using a multi-analytical approach: imaging analyses (UV–VIS-NIR), attenuated total reflection (ATR) Fourier transform infrared spectroscopy (FT-IR) spectroscopy, macro-X-ray fluorescence scanning (MA-XRF) spectroscopy, pH analyses and particle-induced X-ray emission (PIXE) were applied before and after the cleaning

treatments. The two treatments have permitted of the recovery the degraded parts of the two photos, especially in the first study case. For the silver mirroring effect, further treatments will be required to obtain a complete removal of the effect.

Figure 3: From the paper *Towards an assessment of cleaning treatments onto 19th-20th century photographs by using a multi-analytic approach* published on Eur. Phys. J. Plus 137 the Figure 7 chosen as cover figure for the June 2022 issue

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

1. **ISMEO-Associazione Internazionale di Studi sul Mediterraneo e l'Oriente** - Diagnostic analysis onto the Ali ibn Ahmad al Sharfi's geographic map (1579) preserved at the Biblioteca Nazionale Centrale, Rome.
2. **S. Di Filippo** - Characterisation of painting oil "Favretto" by UV-VIS-NIR-SWIR imaging.
3. **ICR - Istituto Centrale per il Restauro** - Characterization of wooden crucifix (second half of the 13th century), from the monastery of San Gaggio in Florence, during the ICR 2022 restoration: collaboration in the field of ARTEMISIA project (Fig. 4).

During 2022 the laboratory experimental setup was upgraded with the following instrumentation and laboratory facilities::

1. LUMOS II fully motorized FT-IR imaging microscope;
2. Scanner XYZ for the portable FT-IR ALPHA II by Bruker Optics (ARTEMISA project);
3. Platinum-ATR sampling module for FT-IR ALPHA II Bruker Optics;
4. Cooled CCD monochrome camera with internal 8-position filter.

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

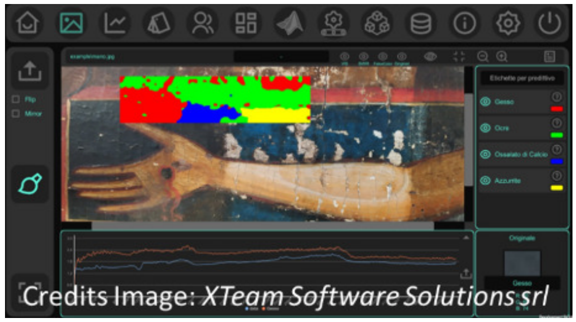

Figure 4: The user friendly software developed by XTEAM in the field of ARTEMISIA project tested on a real artwork during its restoration process.

1. **Alessandra Conte**, *Confined volatiles (H_2O and CO_2) in amorphous silica: implications for terrestrial and extraterrestrial materials.* PhD Thesis, Roma Tre University, Rome.
2. **Eleonora Gorga**, *Sviluppo di un sistema portatile MA-FTIR Imaging per lo studio di materiali nel settore dei Beni Culturali.* Master Thesis on Scienze e Tecnologie per la Conservazione dei Beni Culturali, Sapienza University, Rome

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 2022, some tests to control the beam alignment were performed in summer. There is surely the need to move once again the experimental chamber but final movements will be probably performed in 2023.
Included in the ARTEMISIA project (see SINBAD-IR scientific activity) there is 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 to be 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 2022 different visits al the LABEC laboratory were done in order to realise the ARTEMISIA portable XRF system.Using a conventional X-ray source and an Amptek OEM (original equipment manufacturer) SDD detector assembled at LABEC the system was realised and now needs to be tested at DAΦNE-Light (see Fig. 5).
In the mean time, always within the ARTEMISIA project, some XRF measurements were performed using a portable XGLab spectrometer on different points of a De Chirico painting, “Mobili nella stanza” at the Museum of Carlo Bilotti - Aranceria di Villa Borghese (Rome), using a 40 keV Rh tube voltage and an acquisition time of 60 s per point in order to achieve other useful information on the chemical composition of the colours used.

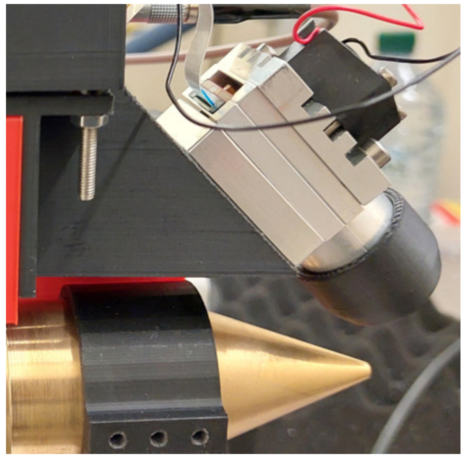

Figure 5: SDD detector e X-ray source of the ARTEMISIA portable XRF system.

Another important achievment of 2022 was the publication of the XAS (X-ray Absorption Spectroscopy) measurements performed at the Si K edge using the DAΦNE electron ring synchrotron radiation at the DXR1 beamline on the *Journal of Magnetism and Magnetic Materials*. In the reported study the XAS techniques was used to characterise the electronic properties of $CaCoSi_2O_6$ pyroxene and several of its potential derivatives $CaCoSi_nO_{2n+2}$. A quantitative XRD analysis of the synthesised samples revealed that despite earlier reports there are no other materials than n = 2. Similar qualitative conclusions were drawn from investigation of magnetic (DC magnetometry) and electronic properties including XPS and Si K edge XAS spectra. Additionally, *ab initio* DFT(density-functional theory) calculations were carried out to get insight into electronic structure of the base system and compare them to XAFS results. The influence of the excess of SiO_2 was investigated using Si K XANES. Further study concentrated on n = 2 material revealed possible lowering of local symmetry evidenced by splitting of vibrational modes.
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.

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

(HgXe lamp in the 200-650 nm range and Deuterium lamp for the Deep UV 120-250 nm).
IIn 2022, a part of the activities of UV beamline was dedicated to qualifications and studies of different systems (minerals, metals, coatings) with Scanning Electron Microscopy (SEM) associated with Energy Dispersive X-Ray Spectroscopy (EDS). The characterisations were performed on behalf of scientific collaborations with other institutes (INAF) and university (Roma3) and of third parties contract (DTC Aerospazio, Avio Interiors). The laboratory is involved in different activities and projects that use the VUV-Vis radiation to characterise and qualify materials:

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. **Summer Fellowship, "La fisica Astroparticellare nei Laboratori".**
   Carmen Gimmillaro, collaboration with Roma Tre University and LEGEND project

   The aim of project was the determination of the reflectivity (at various incidence angle) of samples of Ge, Si and Cu in the vacuum ultraviolet (VUV) range. These data are essential in the project of a shield of liquid Argon, whose scintillation peak is centred at 128 nm, that will be utilised as background veto in an experiment (LEGEND), planned at LNGS, devoted to the measurement of the hypothesised neutrino-less double beta decay. During the summer fellowship, the activity concerned the upgrade of the measuring setups for reflectivity in UHV with remotely controlled motors, Fig. 6 and acquisition systems.
   The first step was to implement the system with a rotary stage and to develop a specific software, based on LabView, to control it. The developed setup was used for scanning at different incident/reflection angles, Fig. 7, the reflectivity of samples of interest for LEGEND project.

Figure 6: Setup for reflectivity measurements in UHV.

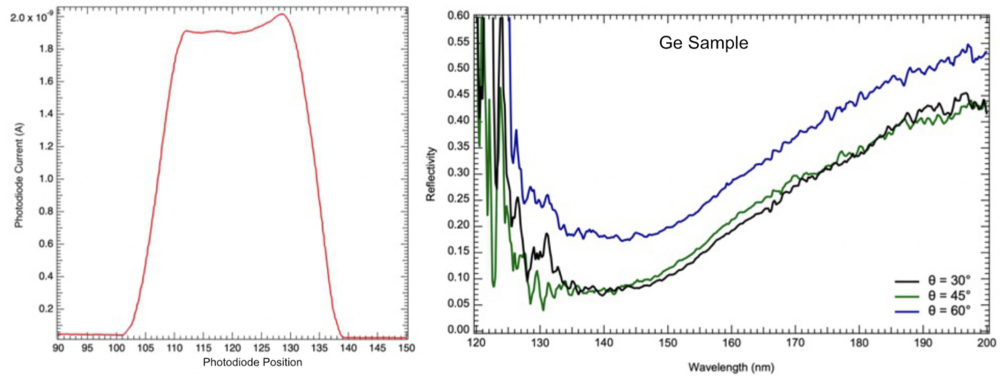

Figure 7: Angular distribution of the current generated on the photodiode as function of photodiode position (left panel). Reflectivity of Ge sample in 120-200 nm range (right panel).

3. **ARTEMISIA - WP4 in collaboration with SINBAD-IR beamline.**

In collaboration with SINBAD-IR beamline within the ARTEMISIA project, using the different instruments and sources available at the UV beamline, a new system for the in-situ measurements of the UV induced fluorescence is under development.
The system is composed by LED sources at different discrete wavelengths, a spectrometer working in the 200-800 nm region, a centring system and a multicore fibre compatible with UV radiation coupled with a specific filter to select the wavelength of interest.
The setup was tested in laboratory on a small painting, attributed to Giacomo Favretto (Fig. 8). The same setup has been used to perform in situ measurement campaigns at the Museum of Carlo Bilotti Aranceria di Villa Borghese (Rome) (Fig. 9).

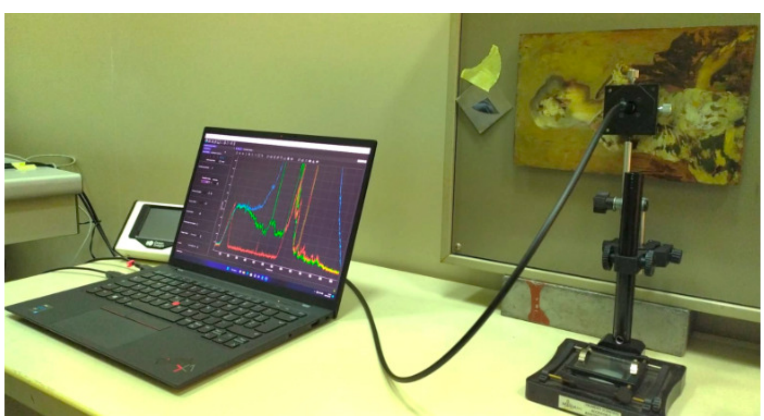

Figure 8: Experimental setup for UV induced fluorescence in situ measurements.

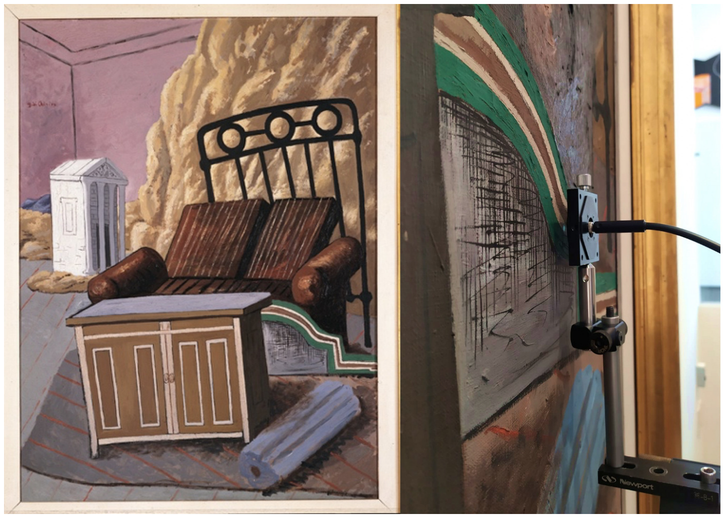

Figure 9: Example of in situ UV induced fluorescence measurements on De Chirico painting at Museum of Carlo Bilotti Aranceria di Villa Borghese.

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.
During 2022, for various reasons, DAΦNE did not produce any continuously usable SR light. Even if SR was not available, we managed to consolidate all the three beamlines and their experimental stations hosting and promoting some mainstream projects.
The laboratory actively worked on various INFN funded experiments and within some national and international collaboration like:

1. The INFN CSN5 founded **ARYA** project that aims to study material properties of interest for accelerators. Within this project, activities have been carried out in collaboration with other INFN groups (INFN-Na, INFN-Sapienza) and projects (LHCb-Spin).

2. **ET-ITALIA@LNF** has been started, funded by INFN CSN2, focusing on studies of vacuum properties of different components (in collaboration with LATINO) of cryogenic vacuum system and on the study of a new a strategy to reduce the mirror' contamination due to the residual gases in Einstein Telescope (ET) mirrors' tower.

Furthermore, the laboratory continues the collaboration activities with national and international groups (from CNR, Sapienza, Uniroma3, ONERA, ET- International collaboration, EIC, etc) on different topics requiring the expertise and experimental equipment available in the laboratory.
All the activities which have been performed in the spirit of offering some of our resources to external users are listed below.

1. ***ARYA***

   The laboratory host the Gr. V founded activity ARYA. The project is organized in four different WPs, two of them are LNF responsibility:

   (a) **ARYA WP1 - Comparative study and characterisation of the stimulated desorption induced by electrons and photons.**

   (b) **ARYA WP2 - LHCspin: Validation of the surface properties of the storage cell with atomic H.**

   To carry out the related activities, project fundings have significantly contributed to substantial implementations and hardware upgrades. The latter ones have been launched in 2021 and finalised during 2022.
   A new experimental chamber is set-up, equipped with the necessary instrumentations to perform surface studies by Secondary Electron Yield (SEY), X-ray Photoelectron spectroscopy (XPS), desorption investigations (stimulated by electron and photon and by thermal variations) with a Quadrupole Mass Spectrometer (QMS), and atomic Hydrogen interaction.
   During this year we have proceeded with the commissioning of the flood electron gun, non-monochromatic (with Al and Mg anodes) and monochromatic (Al and Ag anodes) sources, electron analyser and the atomic Hydrogen source (Fig. 10 and Fig. 11)

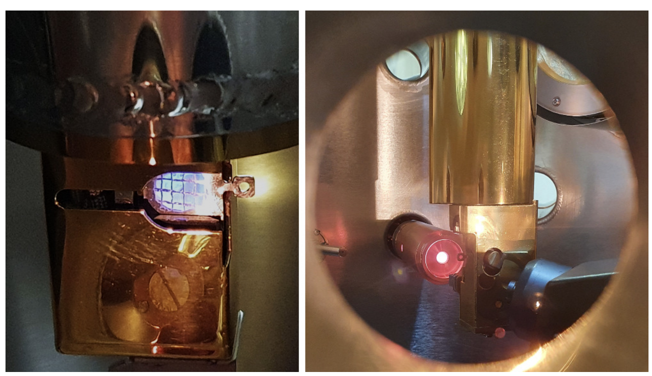

Figure 10: Picture of a phosphor screen (left) and the hydrogen source (right) during the commissioning.

2. ***ET-ITALIA@LNF***

   During this year, in the framework of the international ET project, the laboratory has lunched new activities by the ET-ITALIA@LNF project, funded by the INFN CSN2.
   The future ET detectors will present a series of complex challenges. Among others, the cryogenic vacuum system hosting the cold mirrors. Gases composing the residual vacuum will tend to cryosorb and build a contaminant ice layer ("frost") on the mirror surface held at T$\sim$10 K. Depending on such ice layer thickness, various unwanted detrimental effects may occur affecting mirror performances. Our material and surface science laboratory and our longstanding vacuum and cryogenic experience are relevant to tackle cryogenic vacuum issues in the ET mirrors' towers.

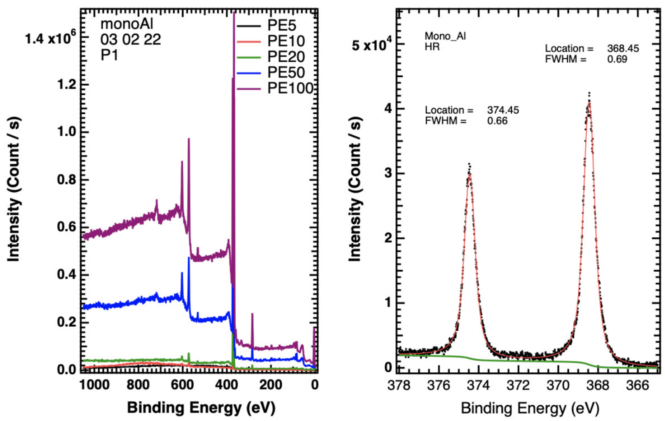

Figure 11: XPS survey spectra (left) and high-resolution spectra (right) in the region of 3d of Ag sample acquired with the new analyzer and monochromatic source.

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. The characterization of the materials' outgassing represents a fundamental measurement. This is one of the tasks of the ET-ITALIA@LNF project, carried out within the WP2 (Material Properties) in collaboration with the LATINO Vacuum Laboratory in Frascati.

Concurrently, since ice formation can be reduced but not avoided, active mitigation methods are mandatory to remove the unavoidable frost formation on the optics. Within the WP1 (Frost Mitigation and Electrostatic Charging), totally carried out in our laboratory, we intend to investigate 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 our recent papers, we have shown that 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. The concept of the method, considering two prototypical materials (Si and 20 nm SiO_2/Si) as representative for mirror surfaces, has been recently published. Being SEY=I_{out}/I_{in} (where I_{out} is the electron current leaving the surface once irradiated with a primary electron current I_{in}), irradiating a surface with electron energy such that SEY<1 (that is $I_{out}<I_{in}$), a negative charge will form on the surface; if the electron irradiation energy is such that SEY>1 (that is $I_{out}>I_{in}$), the material will be depleted of electrons and the surface will be positively charged. Figure 12 shows both the SEY features of the two samples considered in the article as reference to explain the charging method; a graphical sketch of the charging mechanism in the case of SiO_2 is also reported.

The same arguments reported for an initially neutral sample held in the case of an initially charged surface: knowing the SEY characteristics of the neutral material, it is possible to opportunely tune the irradiation electron energy up to neutralise it. These results have been also presented in different national and internal conferences.

In order to pass from a a proof of principle to a quantitative validation of neutralisation

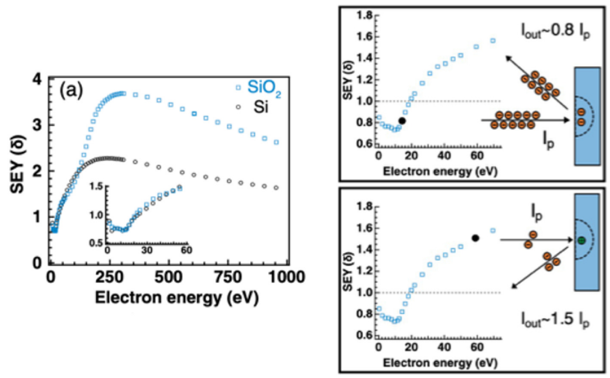

Figure 12: Left: SEY curves from a Si and SiO_2 samples in the energy range 0-1000 eV. The inset shows the low energy part of the spectrum for both samples. Right: Schematic view of the negative charging (top) and positive charging (bottom) process of a neutral 20 nm SiO_2 layer.Figure adapted from: L. Spallino et al., PRD 2022.

method by using electrons, during this year the laboratory has been equipped with a non-contact electrostatic voltmeter (ESV 1000) to measure the voltage induced on a surface upon electron irradiation. The electrostatic voltmeter has been integrated in our experimental set-up so as to measure the sample voltage from outside the UHV chamber. As shown in Fig. 13, the sample (electrically insulated) is connected by a BNC to a metallic plate. Then, when the sample is under electron irradiation, an image charge is formed on the metallic plate. The voltage generated by such a charge is revealed by the voltmeter sensor, faced to the metallic plate and held at a distance from it for about 2.5 mm. The analog output of the voltmeter is sent to a digital multimeter (HP34401A) that, connected to the PC, allows one to choose data acquisition parameters (resolution and acquisition rate) by an on purpose LabView acquisition program. The work is ongoing to validate the charging/neutralisation method on other materials representative for the mirror optics.

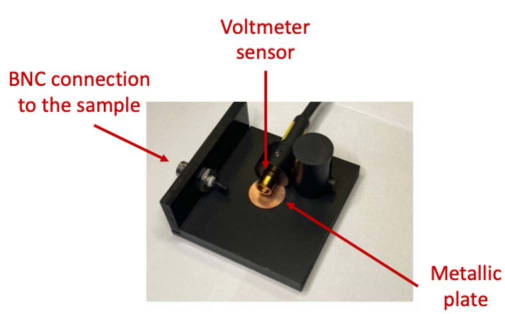

Figure 13: Picture of the homemade holder for the voltmeter sensor. The sensor is held at $\sim$2.5 mm far from a metallic plate on which the image charge of the sample is formed upon electron irradiation. The metallic plate receives the sample signal through a BNC directly connected to the sample. This system allows to measure from outside the charge accumulated on the sample placed inside the UHV experimental chamber. During measurement the whole holder is screened with an aluminum foil to reduce unwanted spurious noises.

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

   The laboratory has been actively involved in the ET-ISB Division IV (Vacuum and Cryogenics) collaboration to contribute to the future TDR for ET. Our work on "Electrostatic charge mitigation" is part of the Technical Report in the TDS of ET-ISB Division IV.

4. ***Collaboration with EIC (Eelectron Ion Colllider) at FermiLab (USA)***

   Following the collaboration already established last year with FermiLab (USA), during this year we have operatively contributed to the EIC (**Electron Ion Collider**) project carrying out a SEY measurement campaign to qualify selected C-coated copper substrates. The samples were produced at FermiLab, stored in air or in vacuum, and sent in our laboratory. The characterisation of surface coatings and surface conditions to mitigate electron cloud issues (while being compliant with vacuum and impedance related constrains) is indeed an area where the LNF expertise could be beneficial to the study and construction of the EIC. During this year, the interaction with the working group studying and designing the new accelerator have been strengthen at INFN/DOE level. A MoU is about to be signed among EIC and INFN to formalise this collaboration. Future news will be available during 2023.

5. ***Collaboration with ONERA - The French Aerospace Lab***

   This collaboration has been carried out since 2021 with ONERA to extend our work on SEY of thin amorphous carbon (a-C) coatings on Cu. The numerical simulations done in the contest of this collaboration have confirmed our experimental observations also to other substrates (i.e. Ag). The work has been presented in an international conference and two papers written in collaboration have been published in 2022.

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

   This collaboration is based on the interest of carbon based 2D materials. During this year the laboratory continues to collaborate with colleagues from the Roma Tre University to perform growth of graphene films on crystalline Ge substrate by Chemical Vapor Deposition. The experiments have been performed with the CVD furnace on varying physicochemical conditions.

7. ***Organization of E-cloud'22 and GWDVac'22 Workshops***

   The laboratory has been actively involved in the organisation of E-cloud'22 and GWDVac'22 Workshops, that took place at La Biodola (Isola d'Elba), 25th – 28th September 2022. (see Fig. 14 and the link: **https://agenda.infn.it/event/28336/**). Following the series of previous e-cloud workshops, E-cloud'22 workshop has been devoted to present, discuss, and compare many recent and new electron-cloud observations and to showcase and examine electron-cloud mitigation measures.

   The E-cloud'22 workshop have shared a joint section - "GWD vacuum meets accelerator vacuum"- with the GWDVac'22. This latter workshop has been lunched in its first edition to present, discuss, and compare the status of recent GWD around the world (as LIGO, Virgo and KAGRA). Specific focus of the workshop has been to present and discuss the vacuum and cryogenic challenges 3rd generation GWD will have to tackle in projects like Einstein Telescope, Cosmic Explorer, etc. LNF personnel was co-chairing the event and all the group was involved in the local organising committee and in the program committee, with the fundamental help of Laura Natoli.

Figure 14: Group photo at E-cloud'22 and GWDVac'22 Workshops (thanks to V. Tullio).

3 Acknowledgments

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4 List of Talks and Posters

1. A. Balerna, M. Cestelli Guidi, E. Gorga, **L. Pronti**, M. Romani, G. Viviani, V. Sciarra, G. Verona Rinati, G. Bonifazi, G. Capobianco, S. Serranti, F. Aramini, E. Giani, M. Ioele, B. Lavorini, S. Brandalesi, A. Mantoan, S. Tamascelli, M. Simeone, *NUOVE TECNOLOGIE PER IL MONITORAGGIO DEI PROCESSI DI DEGRADO SULLE SUPERFICI DIPINTE: Spettroscopie integrate al servizio dei restauratori e conservatori*, III Convegno annuale DTC Lazio, Sapienza University of Rome, 30/11/2022.

2. A. Balerna, M. Cestelli Guidi, E. Gorga, L. Pronti, **M. Romani**, G. Viviani, V. Sciarra, G. Verona Rinati, G. Bonifazi, G. Capobianco, S. Serranti, F. Aramini, E. Giani, M. Ioele, B. Lavorini, S. Brandalesi, A. Mantoan, S. Tamascelli, M. Simeone, *ARTEMISIA: ARTificial intelligence Extended-Multispectral Imaging Scanner for In-situ Artwork analysis*, Nanoinnovation 2022, Sapienza University of Rome, 22/09/2022.

3. **E. Bruschini**, C. Carli, M. Romani, T. Cuppone, M. Cestelli Guidi, G. Viviani, G. Pratesi, *Multiscale spectroscopic charcaterization of ungouped achondrites*, EUROPLANTES SCIENCE CONGRESS, Palacio de Congresos de Granada, Spain, 18-23/09/2022.

4. **M. Romani**, M. Angelucci, L. Pronti, A. Balerna, G. Viviani, M. Cestelli Guidi, *Ultraportable system for LED-induced fluorescence spectroscopy coupled on a multi-technique scanner for the characterization of pictorial materials: a feasibility study*, Convegno Tematico AIAR , Padova, Italy 29 June - 1 July 2022.

5. **L. Pronti**, M. Romani, G. Capobianco, A. Balerna, G. Verona Rinati, G. Bonifazi, M. Iole, B. Lavorini, F. Aramini, M. Angelucci, G. Viviani, V. Sciarra, S. Serranti, M.Cestelli Guidi, *Broad spectral range reflectance spectroscopy (from VIS SWIR to Mid IR) for in situ analyses*

of the painting "Mobili nella stanza" painted by Giorgio De Chirico, pictorial materials: a feasibility study, Convegno Tematico AIAR , Padova, Italy 29 June - 1 July 2022.

6. **M. Szubka**, P. Zajdel, M. Fijałkowski, E. Talik, A. Balerna, M. Cestelli-Guidi, M. Romani, J. Łażewski, P.T. Jochym, *Soft X-ray Absorption and IR reflectivity study of selected materials from* $CaCoSi_nO_{2n+2}$ *series*, International School and Symposium on Synchrotron Radiation in Natural Science, Krakow, Poland, 22-25 August 2022.
7. **L. Spallino**, M. Angelucci and R. Cimino, *Low Energy Electrons significance in gravitational wave detector technology*, LEE2022 - A brainstorming meeting on relevance of Low Energy Electrons in aerospace, ISM-CNR Roma, 15th November 2022.
8. **M. Angelucci**, L. Spallino and R. Cimino, *Low Energy Electrons relevance in accelerator technology*, LEE2022 - A brainstorming meeting on relevance of Low Energy Electrons in aerospace, ISM-CNR Roma, 15th November 2022.
9. **M. Angelucci**, invited talk, *SEY dependence on overlayer thickness and its relevance for e-cloud studies at various temperatures*, e-cloud'22 & GWDVac'22 Workshops, La Biodola (Isola d'Elba), 25th - 28th September 2022.
10. **L. Spallino**, invited talk, *Synergies between dynamic vacuum issues in accelerators and GW instrumentations*, e-cloud'22 & GWDVac'22 Workshops, La Biodola (Isola d'Elba), 25th - 28th September 2022.
11. **L. Spallino**, invited talk, *Morphology effects on desorption processes at cryogenic temperatures*, e-cloud'22 & GWDVac'22 Workshops, La Biodola (Isola d'Elba), 25th - 28th September 2022.
12. **L. Spallino**, *Can electrons neutralise the electrostatic charge on test mass mirrors in gravitational wave detectors?*, ET@TO Workshop, Dipartimento di Fisica di Torino, Jun 15-16, 2022.
13. **M. Angelucci**, L. Spallino, and R. Cimino *Electron stimulated desorption studies on porous material used in next generation accelerators as cryogenic vacuum component*, AIV XXV Conference, Napoli, May 10-12, 2022.
14. **L. Spallino**, M. Angelucci, and R. Cimino *Cryogenic Vacuum Constraints to Mitigate Frost Formation on the Optics of Future Gravitational Wave Detectors*, AIV XXV Conference, Napoli, May 10-12, 2022.
15. **L. Spallino**, M. Angelucci, and R. Cimino *Frost and electrostatic charge formation in mirrors of future gravitational wave detectors: mitigation strategies for two potential showstoppers*, 15th Pisa Meeting on Advanced Detectors, La Biodola - Isola d'Elba (Italy), May 22-28, 2022.

5 Lectures and outreach

1. **A. Balerna**, *Introduction to synchrotron radiation*, XVI School on Synchrotron Radiation "Gilberto Vlaic": Fundamentals, Methods and Applications, Trieste, 19-30 September 2022
2. **M. Angelucci and L. Spallino**, *Sviluppo di tecnologie e progettazione di acceleratori di particelle, studi di scienza dei materiali*, Corso di "Tecnologie degli acceleratori", organized by LNF-INFN and Università La Sapienza (Rome) in the framework of the "Corso di Eccellenza – Laurea Magistrale in Fisica e in Astronomia e Astrofisica - Università La Sapienza di Roma", LNF Frascati, 21-22 July 2022.

6 Publications

1. S. Lupi, L. Tomarchio, L. Mosesso, S. Macis, A. Grilli, M. Romani, M. Cestelli Guidi, K. Zhu, X. Feng, M. Zacchigna, M. Petrarca, K. He, ″ Electrodynamics of $MnBi_2Te_4$ intrinsic magnetic topological insulators″, NPG Asia Materials, **14(1)** (2022) 82. **https://www.nature.com/articles/s41427-022-00429-w**

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, online (2022) **https://doi.org/10.1016/j.sab.2022.106601**

3. M. Romani, L. Pronti, C. Ruberto, L. Severini, C. Mazzuca, G. Viviani, ... & M. Cestelli-Guidi, ″ Toward an assessment of cleaning treatments onto nineteenth–twentieth-century photographs by using a multi-analytic approach.″. European Physical Journal Plus, **137(6)** (2022) 1-12. **https://doi.org/10.1140/epjp/s13360-022-02948-5**

4. A. Conte, G. Della Ventura, B. Rondeau, M. Romani, M. Cestelli Guidi, M., C. La ... & F. Lucci, ″Hydrothermal genesis and growth of the banded agates from the Allumiere-Tolfa volcanic district (Latium, Italy). ″Physics and Chemistry of Minerals, **49(10)** (2022) 1-21. **https://doi.org/10.1007/s00269-022-01214-5**

5. S. Pasquale, G. Politi, L. Pronti, M. Romani, G. Viviani, M.C. Guidi, ... & A. M. Gueli, ″Analysis of the distribution of titanium oxide nanoparticles on paintings″, Journal of Physics: Conference Series, **2204** (2022) 012070. **https://iopscience.iop.org/article/10.1088/1742-6596/2204/1/012070**

6. M. Szubka, P. Zajdel, M. Fijałkowski, E. Talik, A. Balerna, M. Cestelli-Guidi, ...& P. T. Jochym, ″Revisiting properties of $CaCoSi_nO_{2n+2}$.Crystal and electronic structure″. Journal of Magnetism and Magnetic Materials, **546** (2022) 168858. **https://doi.org/10.1016/j.jmmm.2021.168858**

7. F. Stellato, M.P. Annania, A. Balerna et al.,″Plasma-generated X-ray pulses: betatron radiation opportunities at EuPRAXIA@SPARC_LAB″, Condens. Matter **7** (2022) 23. **https://doi.org/10.3390/condmat7010023**

8. F. Orsini, S. Aplin, A. Balerna et al., ″XAFS-DET: a new high throughout X-ray spectroscopy detector system developed for synchrotron applications″. Nuclear Instrum. Meth. A: online October 2022. **https://doi.org/10.1016/j.nima.2022.167600**

9. M. Angelucci, K. Battes, L. Busch, R. Cimino, A. Cruciani, C. Day, J. Gargiulo, S. Grohmann, S. Hanke, X. Koroveshi, A. Liedl, X. Luo, E. Majorana, L. Naticchioni, A. Pasqualetti, P. Puppo, P. Rapagnani, F. Ricci, L. Spallino, A. Stahl, ″Status of the ET Tower Vacuum, ET-LF Cryostat and ET-LF Payload Cooling Design″. Technical Report in the TDS (ET-ISB Division IV, Vacuum & Cryogenics), **ET-0235C-22** (2022). **https://apps.et-gw.eu/tds/ql/?c=16423**

10. C. Inguimbert, Q. Gibaru, P. Caron, M. Angelucci, L. Spallino, and R. Cimino, ″Modelling the impact on the secondary electron yield of carbon layers of various thicknesses on copper substrate″. Nucl. Inst. Methods Phys. Res. B **526** (2022) 1. **https://doi.org/10.1016/j.nimb.2022.05.006**

11. C. Inguimbert, Q. Gibaru, P. Caron, M. Angelucci, L. Spallino, M. Belhaj, R. Cimino, and D. Payan, ″3. SEY Monte Carlo modelling of conditioned Ag and Cu substrates″. *MULCOPIM 2022*, Oct. 2022, Valence, Spain. **https://hal.science/hal-03931324**

12. L. Spallino, ″Cryogenic vacuum issues affecting mirrors of future gravitational wave observatories″. IL NUOVO CIMENTO C **45** (2022) 78. **DOI: 10.1393/ncc/i2022-22078-7**

13. L. Spallino, M. Angelucci, G. Mazzitelli, R. Musenich, S. Farinon, A. Chincarini, F. Sorrentino, A. Pasqualetti, G. Gemme and R. Cimino, ″Can electrons neutralise the electrostatic charge on test mass mirrors in gravitational wave detectors?″. Phys. Rev. D **105** (2022) 042003. **https://doi.org/10.1103/PhysRevD.105.042003**