DAΦNE-Light Laboratory and Activity

M. Angelucci (Art. 23), A. Balerna (Resp.), M. Cestelli Guidi, R. Cimino, A. Conte (Dott.), G. Della Ventura (Ass.), A. Di Trolio (Ass.), A. Grilli (Tecn.), R. Larciprete (Ass.), A. Novelli (Dott.), M. Pietropaoli (Tecn.), L. Pronti (Ass. Ric.), A. Raco (Tecn.), M. Romani (Ass. Ric.), V. Sciarra (Tecn.), L. Spallino (Ass. Ric.), G. Viviani (Tecn.).

1 Summary

In 2021 the scientific activity at the DAΦNE-Light laboratory, was mainly performed using conventional sources and the DAΦNE synchrotron radiation beam only for alignments, tests and some measurements. Due to the COVID-19 pandemic, an to travel restrictions some Main Proposers of the approved proposals asked, when possible, to perform their measurements using the sample mail-in procedure with experiments undertaken by the beamline staff. About 35 experimental teams got access, in presence or mailing-in their samples, to the DAΦNE-Light laboratory coming from Italian and European Universities and Research Institutions and third parties. In 2021 two calls for proposals were opened and only the first one also to TNA (Trans-National Access) users related to the CALIPSOplus EU project that ended in October 2021. In 2021 the new website of the DAFNE-Light laboratory at the following link: **http://dafne-light.lnf.infn.it/** started working also for online proposal submission.
Concerning the beamlines, some alignment operations were performed in the last months of 2021, 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 through the CALIPSOplus EU project, that ended in October 2021. During the emergency related to the COVID-19 the Users' access were strictly reduced, in most cases the samples were mailed-in and the measurements were carried out by the beamline staff.
In 2021 the SINBAD-IR beamline has been involved in the following projects:

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 December 2022). 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 "Centro di Eccellenza Beni e Attività Culturali della Regione Lazio" DTC Lazio. The kickoff meeting was organized at the Laboratori Nazionali di Frascati on December 16th, 2021.

2. ***TRAINING CAMP, Regione Lazio***

   The Training Camp, *Dalla diagnostica alla fruizione museale: le opere del Museo del Colle del Duomo di Viterbo* has been organised in collaboration with: Università degli Studi della Tuscia, Archeoares s.r.l., C.R. ENEA Frascati, CHNet Sezione di Firenze. Project was financed by the Lazio Region in the field of DTC Lazio. The Training Camp was a training course divided into frontal teaching and practical exercises.
   The course aimed to provide participants with the necessary tools to design a multidisciplinary diagnostic approach for the analysis of artworks, through some of the most innovative portable investigation techniques made available by researchers coming from Research Institutions and Universities in order to disseminate the results in the museum set-up. The Training Camp was held in Viterbo (VT) at the Museo del Colle del Duomo of Viterbo from the 7th up to 13th of November 2021.
   During the opening of the call, 80 applications were received, and 20 participants were selected. All information regarding the Training Camp can be accessed on the dedicated website **https://www.trainingcampviterbo.it/**.

Figure 1: A patchwork of images giving information, views and showing some of the activities performed during the Training Camp 2021

3. ***Call TERA, INFN CSN5***

   The aim of the TERA project is to build a synergic interdisciplinary collaboration among different INFN sections with the final goal to push forward a strong R&D activity on THz technology with particular regard to THz acceleration. LNF is contributed to WP2 (Acceleration Beam Dynamics and Cavities) and WP3 (Detectors).

More than 14 experimental teams submitted their proposals for beamtime at the SINBAD-IR beamline. A selection of some scientific studies carried out in 2021 including experimental proposals, collaborations, standard access is summarized here:

1. **UVEOFTIR** - Infrared analysis of liquid biopsies (aqueous humor and serum) from patients with uveitis. S. Caldrer, IRCCS Sacro Cuore -Don Calabria Ospedale Classificato e Presidio Ospedaliero Accreditato -Regione Veneto, Negrar (VR).

2. **MAP**- Multi-analytical approach to monitoring the chemical alterations in Pteris seedlings exposed to arsenic for phytoextraction purpose – M.L. Antenozio - IBPM-CNR Dip. Biologia e Biotecnologie C.Darwin, Sapienza University of Rome.

3. **NESTER** - Neural Stem Cells Resistance to irradiation – R. Negri – Sapienza University of Rome.

4. **SpeChMet** - Spectral Characterization of (ungrouped) Meteorites: unraveling their origin and physicochemical evolution of their parental planetary bodies – E. Bruschini - INAF -IAFS

5. **DRAMA** - Study of ancient drugs materials and pigments from the Antica Spezzeria of Santa Maria della Scala (Rome) - Vàzquez de Ágredos Pascual Ma. Luisa, Department of History of Art/ Laboratory of Analysis and Diagnosis of Work of Art, Universidad de Valencia, Spain. (**CALIPSOplus**)

6. **VOOPS2**- High and Low temperature behaviour of confined H_2O and CO_2 in natural opaline silica, Rondeau Benjamin, University of Nantes, France. (**CALIPSOplus**)

7. **INSPECTOR**- INtracellular acidification: SPectroscopic search for vECTORs - M. Carbone, University of Rome Tor Vergata

8. **ATTIA** - Analysis of the distribution of titanium oxide layer deposited on panting for self-cleaning and protective sake – S. Pasquale – University of Catania (CT).

9. **YMPR** - Optical transmittance measurements were carried out on the CrI_3 (single crystal) and $MnBi_2Te_4$ (film) samples on silicon as the temperature varied - L. Tomarchio, Sapienza University of Rome.

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

11. **Collaboration** - Marco Mangano, collaboration between C.R. ENEA of Frascati and EURESARTE s.r.l., characterisation of painting cross section by FT-IR and SEM-EDX analyses.

12. **Collaboration** - Centro Restauro e Conservazione la Venaria Reale (TO), characterisation of resins using during restoration treatments of a Kandinsky painting by FT-IR analyses.

13. **Collaboration** - Istituto Superiore per la Conservazione e il Restauro (ICR), monitoring the presence of resins during the restoration treatments of two Antonello da Messina's paintings by FT-IR analyses.

14. **Short access** - Confined volatiles (H_2O and CO_2) in amorphous silica: implications for terrestrial and extraterrestrial materials- A. Conte, University of Roma Tre, Rome.

15. **Short access** - Environmental monitoring of gaseous and solid pollutants via spectroscopy - F. Radica, Dept. of Science, University of Roma Tre, Rome.

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*** here included as highlight:

1. **Disordered photonics behavior from terahertz to ultraviolet of a three-dimensional graphene network** - *S. Lupi, Dept. of Physics, Sapienza University, Rome*
   Due to the advances of nanotechnology and the discovery of various 2D functional materials, in recent years there has been a growing interest for extending their extraordinary properties to three-dimensional (3D) ordered and disordered structures.
   The diffusion of light by random materials is a general phenomenon that appears in many different systems, spanning from colloidal suspension in liquid crystals to disordered metal sponges and paper composed of random fibers. Random scattering is also a key element behind mimicry of several animals, such as white beetles and chameleons. Here, random scattering is related to micro and nanosized spatial structures affecting a broad electromagnetic region. In this work, how random scattering modulates the optical properties, from terahertz to ultraviolet light, of a novel functional material, i.e., a three-dimensional graphene (3D Graphene) network based on interconnected high-quality two-dimensional graphene layers has been investogated. Here, random scattering generates a high-frequency pass-filter behavior. The optical properties of these graphene structures bridge the nanoworld into the macroscopic world, paving the way for their use in novel optoelectronic devices.
   The transmission of light through the 3D graphene samples was measured using several different spectroscopic setups to span a very broad frequency range, from THz to UV.
   The transmittance of a single polygon of the 3D network was analyzed through a Vertex70 V FT-IR interferometer coupled with an Hyperion3000 IR microscope equipped with a 64 x 64 pixel Focal Plane Array (FPA) MCT detector at the SINBAD-IR beamline of the DAFNE-Light laboratory

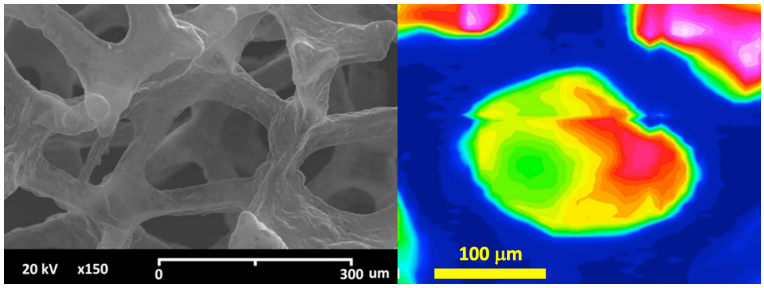

Figure 2: *Left* - SEM magnified image of a 3D graphene sample (S1). The 3D network is composed by several polygonal structures connected to each other. *Right* -Integrated infrared transmittance between 2000 and 3000 cm^{-1} of a single polygon of the undoped S1 sample, as taken by the FPA-MCT detector.

The SINBAD-IR beamline in 2021 was also involved in activities for third parties like:

1. **TECNO. EL s.r.l** - Diagnostic Analysis on colophony samples from marble statues.
2. **TECNO. EL s.r.l** - Diagnostic Analysis on samples of dark deposition patina sampled from a monument in the urban area of Rome.

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

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. **Stefania Pasquale**, *Synthesis and characterisation of nanostructured materials for the conservation of cultural heritage.* PhD Thesis, Dept. Physics and Astronomy "Ettore Majorana", University of Catania.

3. **Federica Attiani**, *Characterisation by FTIR spectroscopy in reflection mode of pictorial materials used in modern and contemporary art: the database of the "Centro Conservazione e Restauro La Venaria Reale (TO)*, Bachelor's Degree, Tor Vergata University of Rome, Rome.

Fixed and portable experimental equipments were upgraded in 2021 with the following instrumentation:

1. HeNe-LASERTUBE 0.9-1.3mW for the FT-IR Interferometer Bruker Vertex-70V.
2. Source MIR 12V for the FT-IR Interferometer Bruker Vertex-70V.
3. Detector SDD to realize a portable XRF scanner.
4. Scanner XYZ for the portable Bruker FT-IR ALPHA II (ARTEMISIA project).
5. Upgrade for experimental set-up for measurements with the Janis Cryostat for to perform refection and transmission analyses at low temperature (5K).

Concerning the upgrades of the experimental set-up to perform measurements using the Janis Cryostat at low temperatures the elements realised are listed below:

1. the realisation of a the sample holder to optimise the thermal contact between the sample holder and cold finger;
2. the placement of a SI diode on the sample holder to read the temperature near the sample, as well as on the cold finger;
3. the optimisation of the sample holder windows (CaF_2, polyethylene and TPX) in terms of transmittance and thickness.

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. 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 2021, some tests to control the beam alignment were performed in November. There is surely the need to move once again the experimental chamber but final movements will be performed in 2022.
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 Florence. 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. Using a conventional X-ray source and an old AMPETK SDD detector, some XRF measurements and tests were performed on different samples (see Fig. 3).

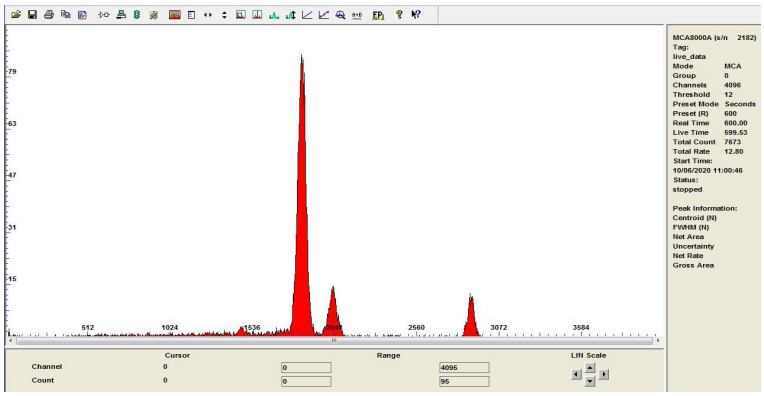

Figure 3: XRF spectrum of a Cu foil measured using an old AMPEK SDD detector.

Another activity performed was related the INFN CYGNO experiment. Using the Bruker SDD detector tests have been performed on the emission yield of several samples like Cr, Ti,Ca and Cl irradiated with a ^{55}Fe source (see Fig. 4).

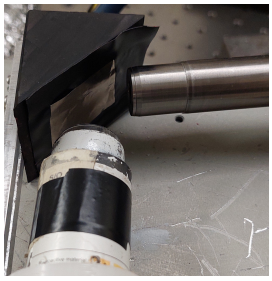

Figure 4: Test of a Ti film using the ^{55}Fe source and the a Bruker SDD detector.

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).

In 2021, a large part of the activity, more than ten users, was related to the use of the Scanning Electron Microscope (SEM) and of the Energy Dispersive X-ray spectroscopy (EDX) analysis. The SEM and EDX measurements were preformed on different kind of samples like graphene, polymers with impurities and many samples related to cultural heritage studies.
Between the different activities performed there was a direct collaboration within the CSN5 LLMCP project:

- **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.

2.4 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 2021, 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 the CSN5 founded ARYA project 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 (LHCspin). Furthermore, the laboratory has been involved in national and international collaborations with several groups (from CNR, Sapienza University, Roma Tre University, INFN-Ge and EGO, Virgo, ONERA, Universidade Nova de Lisboa, ET- International collaboration, EIC, etc) on different topics requiring the expertise and experimental equipment available in the laboratory. All these activities, which have been performed in the spirit of opening some of our resources to external users, are set out below.

1. ***ARYA***

   The laboratory hosts the CSN5 funded activity ARYA. This funding has significantly contributed to substantial implementations and hardware upgrades that have been launched in 2021 and will be finalised during 2022. A new experimental chamber has been set up, equipped with the necessary instrumentations to perform surface studies by Secondary Electron Yield (SEY), X-ray Photoelectron spectroscopy (XPS) and desorption investigations (stimulated by electrons, photons and by thermal variations) with a Quadrupole Mass Spectrometer (QMS). At the end of the year all the system has been mounted in the laboratory to proceed with the final commissioning. A picture of the set-up is reported in Fig. 5 were the new custom-designed μ-metal experimental chamber, a flood electron gun, a non-monochromatic source (with Al and Mg anodes), a monochromatic source (Al and Ag anodes) and an electron analyser can be observed.

The ARYA project is organised in four different WPs and two of them, WP1 and WP2, are under the LNF responsibility.

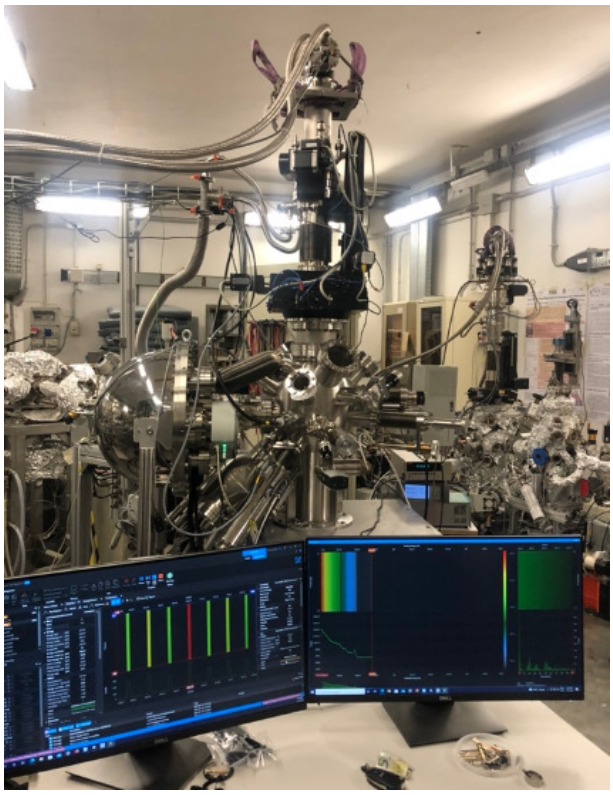

Figure 5: New experimental chamber equipped with a series of instruments to perform surface studies.

(a) **ARYA WP1 - Comparative study and characterisation of the stimulated desorption induced by electrons and photons.**
Within ARYA we have continued the studies on the properties of materials of interest to accelerators' technology. The main activity consists in investigating the effects induced by the interactions of such materials with photons and electrons, in terms of Secondary Electron Yield (SEY) and vacuum behaviour. The studies have been done both at room and cryogenic temperatures (mimicking the real operational temperatures in various accelerators like LHC, EIC etc.). We focused on a class of surfaces morphologically modified by laser ablation. This kind of materials are of particular interest due to their porous structuring (at sub-micrometric length scale) that confers characteristics appealing for accelerators applications. In particular, Cu substrates morphologically modified by laser ablation technique (LASE-Cu) have turned out to be good materials to mitigate electron cloud phenomena due to their impressive low Secondary Electron Yield (SEY<1). However, a rigorous evaluation of the consequences on vacuum stability is required when such porous surfaces are exploited in cryogenic conditions. Thermal variation, photon and electron irradiation indeed can cause the desorption of residual gas adsorbed in their complex structures. Our previous studies on thermal desorption of

gases from a LASE-Cu substrate have highlighted that the morphological structural features confer non-negligible effects on the gas-substrate interaction, resulting in a vaster and higher desorption temperature with respect to what observed from a flat substrate. This means not only that desorption can occur from porous substrates in an unexpected temperature range, but also that cryosorbed gas can be foreseen at a temperature at which no adsorbed gas should be on the surface.
The gas adsorbed on the surface can participate to other desorption mechanisms, such as electron desorption. Quantitative evaluation of the electron desorption yield (η) is a non-trivial task, especially for porous surfaces for which the morphology plays a crucial role. η is defined as the number of desorbed molecules per incident electron and is experimentally derived by performing Electron Stimulated Desorption (ESD) measurements. By using Ar as calibration gas, during this year we have refined our capabilities to estimate η from porous surfaces considering the LASE-Cu sample as a representative porous material.
Performing ESD of Ar from a flat and a LASE-Cu substrate, we have observed that η increases with Ar dose for both surfaces. For all gas dose η_{LASE} is lower than η_{FLAT}. All these results can be explained considering two main effects of the morphological features. First, since the porous material has a high specific surface respect to its flat counterpart, the same gas dosing determines a different coverage on the two different substrates. This explains the differences in the total amount of gas desorbed by electron irradiation from the two substrates. The porous nature of LASE-Cu sample acts like a "trap" for gas and electrons. Since the transport of secondary electrons is the main mechanism governing ESD, a dependence of η on SEY is expected. Considering the lower SEY, this could explain the lower electron stimulated desorption from the LASE-Cu respect to the flat sample. This topic is still under investigation.
These results have been presented in different conferences and has been particularly appreciated at the 107° *Congresso Nazionale della Società Italiana di Fisica* (SIF2021). The oral contribution has been judged one of the best presentations of the congress.
During 2021 this study was extended also to realistic gases composing accelerator's vacuum (as CO, CH_4, CO_2 ...) and is still ongoing. Part of the activity of the laboratory was also dedicated the study of the effects of electrons in modifying the chemistry of ices condensed on flat and porous surfaces in use for accelerators. SEY measurements have been performed on CO condensed on a flat substrate as a function of the cumulated electron dose. Within the ARYA collaboration, at the end of November, the laboratory has hosted colleagues from INFN-Na to carry out a joint campaign of SEY measurements on another class of porous materials, called LIPSS (Laser Induced Periodic Surface Structures), also produced by laser ablation of Cu surface. The laser parameters used to ablate the substrate give rise to morphological porous structures less pronounced then LASE-Cu, with impedance properties appealing for the accelerator technology. A first characterisation of the SEY properties of selected samples have been done both at room and cryogenic temperature. Further developments of this first measurement campaign will be considered for the next year.
During this year, the limited availability of SR at LNF allowed the conduction only of some preliminary tests to calibrate photodesorption of CO from small samples at cryogenic temperature. The short working time and the DAΦNE beam orbit instability have limited our activity and the completion of any conclusive study. Acquired data have to be confirmed by a new experimental campaign obtained in stable working conditions.
The activity done within the ARYA project are of particular interest not only for accelerators applications but also for astrochemistry. Porous or very rough materials are also

found as small dust particles in the cold interstellar medium. They host molecular ices which, in turn, interact with photons, electrons and cosmic rays all-around in the space. Their study is fundamental to understand the formation (and abundance) of molecules in the space. Although along decades many laboratory studies have been made on molecular ices analogues, poor attention has been given to the possible role of substrate morphology in intermediating those interactions. Flat substrates are usually considered as references in laboratory studies. The study done (and ongoing) in our laboratory on porous materials can be powerful to predict the relative amount of gas finally delivered from a porous surface under electron irradiation, whether it is exploited as cryogenic component in accelerators or is a small dust particles in the cold interstellar medium. Our results obtained on thermal, and electron stimulated desorption from porous substrates (whose morphological features closely mimic the structure of interstellar grains) have been presented at the *European Conference on Laboratory Astrophysics* (ECLA).

(b) **ARYA WP2 - LHCspin: Validation of the surface properties of the storage cell with atomic H.**
The activity related to this WP, in close collaboration with LHCspin working group, is focused on the R&D for the construction of a storage cell to be installed in front of the LHCb detector. This new vacuum chamber will be filled with various gasses, with polarised atomic Hydrogen and Deuterium. This will bring, for the first time, polarised physics at the LHC. The storage cell and its surface coating must ensure minimal impact to the machine in terms of gas load, impedance and electron cloud related instabilities. The key parameter governing electron cloud formation is the SEY (δ). Due to a very low SEY ($\delta \sim 1$), carbon coatings have been proposed as the material to choice for the walls. However, the interaction between polarised atoms and the walls can cause depolarisation effects. To avoid this, it has been suggested to let a thin H_2O ice layer to cryosorb on the wall carbon coating. The thickness, the cryosorption temperature (which, in turn, determines the ice morphology) and its impact to the electron cloud budget are all crucial issues to be investigated. During this year of activity, a preliminary study has been done to test the experimental system and optimise the measurement parameters for the specific case of H_2O. SEY of a known Cu substrate held at T=10 K has been measured as a function of water ice thickness adsorbed onto it and Fig. 6 shows some selected results.

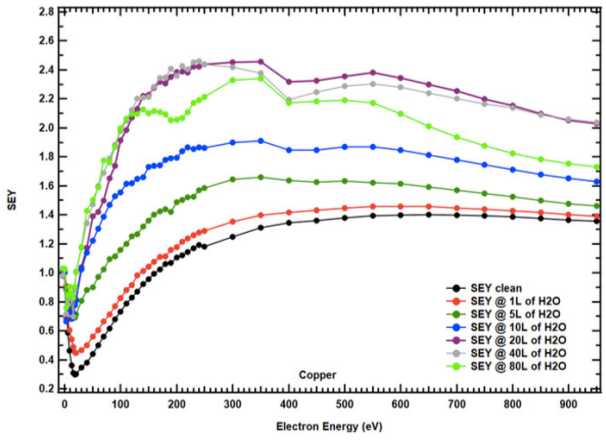

Figure 6: SEY curves obtained dosing different quantities of water on a clean Cu substrate.

On increasing the water dose, the SEY increases from $\delta_{max}\sim$ 1.4 (clean Cu) to $\delta_{max}\sim$ 2.5. Moreover, after $\sim$ 20 L the maximum value saturates to a stable value. The same study has been done dosing water on a graphite substrate. The results confirm the same trend, indicating that the water overlayer dominates the SEY properties of the system already after few nm of ice condensed on the surface. These results have been presented in different working group meetings and will be also presented at the IPAC22 conference and will be part of future publications. Once available, SEY of C-coated Cu samples provided by CERN will be analysed as a function of a water ice layer condensed on such substrates. This will allow to perform a representative case study on a realistic scattering chamber surface wall. During this year also the atomic hydrogen source has been installed (see Fig. 7) and is ready to test the water coating behaviour under atomic hydrogen bombardment.

Figure 7: Hydrogen source (in the blue circle) mounted in the UHV chamber.

2. ***CERN-LNF MoU: WINDY***

In 2017, a Memorandum of Understanding (MoU) between CERN and INFN-LNF has been signed. The general purpose of the MoU is the extract quantitative information about the reflectivity, photo-yield and photo induced desorption on small samples and on real 2-3 meters beam-pipes, using the Synchrotron Radiation White Light (WL) of DAΦNE. These parameters have a fundamental role in the optimisation of existing particle accelerator, like LHC and its upgrade (HL-LHC and HE-LHC), and in the realisation of the Future Circular Collider (FCC). A new beamline WINDY (White lIght liNe for Desorption Yields) is ready to take data once SR will become available. Given the last years performances of DAΦNE, it was not possible to honour the contract with the requested final measurements. In agreement with CERN and in line with their interest in obtaining the foreseen results, the MoU has been extended and will expire at the end of 2023.

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

During this year, the laboratory has been actively involved in the ET international collaboration. The future ET detectors will present a series of complex challenges where our material

and surface science laboratory and our longstanding vacuum and cryogenic experience could be relevant. Among others, cryogenically cooled mirrors to reduce thermal noise (T$\sim$10 K) present several extraordinary challenges, one being 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. Depending on such ice layer thickness, various unwanted detrimental effects may occur affecting mirror performances. A paper has been published on this topic in 2021 to analyse the consequences of hosting a cryogenically cooled mirror in a vacuum system. New limits have been set for an acceptable operating pressure to avoid frost formation in each period of continuous data taking. Since ice formation can be reduced but not avoided, a new potential mitigation method has been proposed to actively remove frost from mirrors' optics. It consists in the use of low energy electrons (below $\sim$200 eV) to induce ice desorption. Such defrost method will clearly cause electrostatic charging, which has been already shown to affect gravitational wave detection on running interferometers. In a paper that will appear online at the beginning of 2022 it will be shown that electrons not only can induce ice desorption but can also mitigate charging issues by properly tuning their kinetic energy. This method is strongly based on the knowledge of the SEY characteristics of mirrors materials. This activity has been also presented in different national and internal conferences and has been particularly appreciated, so that at the 107° *Congresso Nazionale della Società Italiana di Fisica* (SIF2021), the given communication has been awarded as best second-best presentation in Section 3: Astrophysics.

4. ***Collaboration with "EGO-Virgo"***

   In the field of gravitational wave detectors, the capability to perform surface studies has been relevant also for the EGO-Virgo scientific community. The understanding of the origin of charges in gravitational wave detectors is one of the many issues to be solved also in view of the incoming third generation of detectors. A possible source is the presence of ion pumps along the laser beam vacuum chamber. After some interactions with the chamber walls, charges released by an ion pump could reach the mirror vacuum chamber, thus leading to mirror charging. An estimate of the propagation/attenuation path of charges along the laser beam chamber can allow to understand in which position ion pumps could be installed, thus limiting mirror charging effects. To perform such estimates, the knowledge of the SEY of the wall surfaces is fundamental. A SEY measurement campaign has been done at room temperature on 304L stainless steel small samples (obtained from the Virgo beam pipe) under different thermal treatments (meaning different oxidation degrees). Such measurements have been used by Virgo vacuum group to simulate the migration path of the charges escaped by an ion pump installed along a 3 km pipe.

5. ***Collaboration with the "Institute for Photonics and Nanotechnologies (IFN) - CNR"***

   During the year, a collaboration started with IFN addressed to the surface properties of thin SiO_2 coatings on Si substrates. The purpose is focused mainly on the SEY characteristics of insulating materials, compositionally close to the mirrors of gravitational wave detectors, to test our electrostatic charge neutralisation method by using electrons. A first investigation, combining SEY and XPS measurements, has been conducted at room temperature on SiO_2/Si samples produced at IFN with different oxide thickness. Conductive and semiconductive materials can be easily measured since they do not incur in charging issues that may invalidate the measurements. To measure SEY of an insulating surface, two different methods can be applied: i) pulsing the impinging electron flux to minimise the flux reaching the sample and, eventually, measuring with a heterodyne technique the very low current emerging from the sample; ii) measuring the very thin film of the insulating layer deposited on a conductive

surface and use an incident electron current as reduced as possible. Adopting this second approach, the range of the possible conditions (oxide film thickness and primary electron current) to avoid charging during SEY measurements, has been investigated. Some of the results will be reported in a dedicated paper containing the characterisation of all samples.

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

   This collaboration with ONERA has been carried out in 2021 to extend the work on SEY of thin amorphous carbon (a-C) coatings on Cu. a-C is a well-known coating apt to reduce SEY to $\sim$1. The numerical simulations done in the contest of this collaboration have confirmed our experimental observations showing that already a $\sim$5 nm thin carbon coating can significantly affect the emission yield of an irradiated material. Such work has a great relevance also for satellites. A paper written in collaboration has been submitted for peer review in an international journal and will appear in 2022.

7. ***Collaboration with Roma Tre University***

   This collaboration is based on the interest on carbon based 2D materials. In 2021 the laboratory has hosted colleagues from UniRoma3 to perform the growth of graphene on crystalline Ge substrates by Chemical Vapor Deposition. The experiments have been performed with the CVD furnace in varying physicochemical conditions.

8. ***Collaboration with Universidade Nova de Lisboa (Portugal) – GRACE project***

   During this year the laboratory collaborated to the presentation of an international project (Graphene Coatings Meet Challenges of Future Accelerators - GRACE) with the Universidade Nova de Lisboa (Portugal). The main goal of this project is getting a proof of concept of coating inner walls of vacuum pipes by graphene (and/or its derivatives) using electrophoretic deposition, which will meet restrictive demands of future accelerator technologies. The laboratory has been involved in the investigation of the SEY characteristics of such materials at different temperature conditions and to study their vacuum behaviour, thermal variation and electrons and photons irradiations.

9. ***Collaboration with EIC (Electron Ion Collider) at Fermilab (USA)***

   In 2021 the laboratory collaborated to establish potential areas where the LNF expertise could be beneficial to the study and construction of the EIC (Electron Ion Collider). Close interactions with the working group studying and designing the new accelerator have allowed to identify a series of topics where the EIC/LNF collaboration is strongly envisaged. One is indeed the characterisation of surface coatings and surface conditions to mitigate electron cloud issues while being compliant with vacuum and impedance related constrains. The potential collaboration will be discussed at INFN/DOE level and future news will be available in 2022.

The Laboratory is also routinely hosting students to perform their thesis or PhDs but also Summer Students getting a direct experience with some *state of the art* experimental activities:

1. **Armando Novelli**, *Studies on carbon coating deposition methods and surface treatments for electron cloud mitigation inside particle accelerators* - Sapienza University of Rome, PhD Thesis in Accelerator Physics (November 2019 - November 2021).

2. **Jacopo Bilotto**, *SEY and XPS characterisation of SiO_2/Si* - INFN Summer Student Grant-Sapienza University of Rome (October-November 2021).

3 Acknowledgments

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

4 List of Talks and Posters

1. R. Fantoni, V. Lazic, V. Spizzichino, M. Romani, L. Pronti, G. Viviani, M. Angelucci, *LIBS Stratigraphy a powerful tool for in situ and laboratory investigation of multilayered Cultural Heritage surfaces*, 11th EMSLIBS - Gijón Nov. 29 – Dec. 2, 2021 (Invited)

2. M. Romani L. Pronti, G. Viviani, M. Cestelli-Guidi, Ma. L. Vázquez de Ágredos Pascual, *Drugs and Colors in Santa Maria della Scala, Rome: tradition and innovation*, 1st European Symposium on Drugs & Colors in History: from the past to the present Revisiting ancient Pharmacies, Apothecaries, Spezierias & Workshops, 20, 21 and 22 October 2021, València, Spain.

3. S. Pasquale, G. Politi, L. Pronti, M. Romani, G. Viviani, M. Cestelli Guidi, M. Angelucci, A.M. Gueli, *Analysis of the distribution of titanium oxide nanoparticles on paintings*, METRO Archeo, 2021 International Conference, Milano, ltaly - October 20-22, 2021.

4. A. Balerna, *Electronic and structural investigation on gold monometallic and bimetallic nanoparticles using X-ray absorption fine structure spectroscopy.* High precision X-ray measurements 2021 Conference, LNF, Online Talk, 8 - 10 June 2021

5. F. Stellato et al. *Plasma-generated X-ray pulses: betatron radiation opportunities at EuPRAXIA @ SPARC_LAB.* High precision X-ray measurements 2021 Conference, LNF, online talk, 8 - 10 June 2021

6. R. Cimino, *EIC and INFN accelerator experts: update on possible perspectives*, Giornata Nazionale EIC_NET Torino, 20th December 2021

7. L. Spallino, *Electron and (photo) stimulated desorption at cryogenic temperatures*, EIC Accelerator Partnership Workshop 2021 (EIC2021), online talk, 26 -29 October 2021

8. M. Angelucci, *SEY properties of electron cloud mitigators at cryogenic temperatures*, EIC Accelerator Partnership Workshop 2021 (EIC2021), online talk, 26 -29 October 2021

9. M. Angelucci, L. Spallino, and R. Cimino, *Cryogenic Vacuum behavior of Porous Materials of Interest for Future Accelerators*, 107° Congresso Nazionale della Società Italiana di Fisica (SIF2021), online talk, 13 -17 September 2021 - **Oral contribution chosen among the best presentations of the Congress**

10. L. Spallino, M. Angelucci, and R. Cimino, *Cryogenic Vacuum Issues Affecting Mirrors of Future Gravitational Wave Observatories*, 107° Congresso Nazionale della Società Italiana di Fisica (SIF2021), online talk, 13 -17 September 2021 - **Oral contribution awarded as second-best presentation in Sezione 3: Astrofisica**

11. R. Cimino, *Key Vacuum Surface Parameters for FCC-ee operation*, FCC WEEK 2021, online, 28th June - 2nd July 2021

12. L. Spallino, G. Costella, M. Angelucci and R. Cimino, *Electron Desorption from Porous Materials of Interest for Future Accelerators*, 12th International Particle Accelerator Conference (IPAC'21), online, 24-28 May 2021

13. M. Angelucci, A. Novelli, L. Spallino, A. Liedl, R. Larciprete, and R. Cimino, *Very Thin a-C Film as e- Cloud Suppressor*, 12th International Particle Accelerator Conference (IPAC'21), online, 24-28 May 2021

14. L. Spallino, M. Angelucci, A. Pasqualetti, K. Battes, C. Day, S. Grohmann, E. Majorana, F. Ricci, and R. Cimino, *Impact on Vacuum Requirements by Cryogenically Cooled Mirrors for Gravitational Wave Detection*, Gravitational Wave Advanced Detector Workshop (GWADW21), online, 17-21 May 2021

15. M. Angelucci, L. Spallino, G. Mazzitelli, R. Musenich, S. Farinon, A. Chincarini, F. Sorrentino, A. Pasqualetti, G. Gemme, and R. Cimino, *Mitigation of the electrostatic charge on test mass mirrors in gravitational wave detectors*, Gravitational Wave Advanced Detector Workshop (GWADW21), online, 17-21 May 2021

16. R. Cimino, *Coating with ARYA*, LHCspin 2nd General Meeting, online, 19th February 2021

17. M. Angelucci and R. Cimino, *R&D on storage cell coating for polarised targets at the LHC*, 26th Meeting of the PBC-FT working group, online, 27th May 2021

18. M. Santimaria, P. Di Nezza, M. Angelucci, R. Cimino, *ARYA for LHCspin*, 30th Meeting of the PBC-FT working group, online, 26th November 2021

5 Lectures and outreach

1. M. Romani *CHNet Fisica per i Beni Culturali*, Summer School 2021 INFN- Laboratori Nazionali di Frascati - 14-17 June 2021

2. M. Romani and L. Pronti, *Physics and Cultural Heritage. CHNet - The INFN network devoted to cultural heritage*, INSPYRE 2021, INFN-LNF 12-16 April 2021

3. M. Romani, *Physics and Cultural Heritage*, Lectures organized by Prof. S. Lupi, Course of Istituzioni di Fisica della Materia , Sapienza University, Rome, 14th May 2021

4. L. Pronti, *Physics and Cultural Heritage*, Lectures organized by Prof. S. Lupi, Course of Istituzioni di Fisica della Materia , Sapienza University, Rome, 21st May 2021

5. M. Romani, L. Pronti, Fermilab 2021 Summer Student School, INFN-LNF, 3-4 August 2021

6. M. Romani, *Fisica e Beni Culturali: Tecniche per la caratterizzazione dei materiali*, Progetto SUSA, Seminari INFN, 31st May 2021

7. M. Cestelli Guidi, L. Pronti, M. Romani, Mostra *... per fare notomia. Il Cristo anatomico di Raffaello*, Biblioteca Marucelliana, Firenze, 05 October 2021

8. M. Perino and L. Pronti, *Nuova Luce sul Graduale "D" da Badia a Settimo. Analisi non invasive e restauro*, online, 24 June 2021

9. M. Cestelli Guidi, *Indagini diagnostiche non distruttive per le opere d'arte*, OPEN LAB del DTC Lazio, 25 February 2021

10. A. Balerna, *Synchrotron Radiation and Cultural Heritage* Training Camp DTC Lazio, Museo del Colle del Duomo di Viterbo, Viterbo, November 10th, 2021

6 Publications

1. G. Della Ventura, F. Radica, F. Galdenzi, U. Susta, G. Cinque, M. Cestelli-Guidi, B. Mihailova, A. Marcelli, ″ Kinetics of dehydrogenation of riebeckite Na_2Fe_3+2Fe_2+3$Si_8O_22(OH)_2$: an HT-FTIR study″, American Mineralogist, **https://doi.org/10.2138/am-2022-8021**

2. Licursi, V., Wang, W., Di Nisio, E., Cammarata, F. P., Acquaviva, R., Russo, G., ... & Negri, R. ″Transcriptional modulations induced by proton irradiation in mice skin in function of adsorbed dose and distance″. Journal of Radiation Research and Applied Sciences, **14** (2021) 260-270

3. Paluszkiewicz, C., Roman, M., Piergies, N., Pieta, E., Woźniak, M., Guidi, M. C., ... & Kwiatek, W. M. ″ Tracking of the biochemical changes upon pleomorphic adenoma progression using vibrational microspectroscopy″. Scientific reports, **11** (2021) 1-11. **https://doi.org/10.1038/s41598-021-97377-2**

4. Tomarchio, L., Macis, S., Mosesso, L., Nguyen, L. T., Grilli, A., Guidi, M. C., ... & Lupi, S. ″Low energy electrodynamics of CrI_3 layered ferromagnet″. Scientific reports, **11** (2021) 1-8. **https://doi.org/10.1038/s41598-021-02918-4**

5. L. Pronti, G. Capobianco, M. Vendittelli, A. C. Felici, S. Serranti, G. Bonifazi, ″Optimized method for mapping inorganic pigments by means of multispectral imaging combined with hyperspectral spectroscopy for the study of Vincenzo Pasqualoni's wall painting at the Basilica of S. Nicola in carcere in Rome″, Minerals, **11** (2021) 839. **https://doi.org/10.3390/min11080839**

6. Tomarchio, L., Macis, S., D'Arco, A., Mou, S., Grilli, A., Romani, M., ... & Lupi, S. ″Disordered photonics behaviour from terahertz to ultraviolet of a three-dimensional graphene network″. NPG Asia Materials, **13** (2021) 1-8. **https://doi.org/10.1038/s41427-021-00341-9**

7. M. Perino, L. Pronti, L.G. Di Forti, M. Romani, C. Taverna, L. Massolo, ... & Felici, A. C. ″Revealing Artists' Collaboration in a 14th Century Manuscript by Non-Invasive Analyses″. Minerals, **11** (2021) 771. **https://doi.org/10.3390/min11070771**

8. N. Proietti, P. Calicchia, F. Colao, S. De Simone, V. Di Tullio, L. Luvidi, ... A. Tatì. ″Moisture Damage in Ancient Masonry: A Multidisciplinary Approach for In Situ Diagnostics″. Minerals, **11** (2021) 406. **https://doi.org/10.3390/min11040406**

9. F. Ripanti, A. Di Venere, M. Cestelli Guidi, M. Romani, A. Filabozzi, M. Carbonaro, M. C. Piro, F. Sinibaldi, A. Nucara, G. Mei, ″The puzzling problem of cardiolipin membrane- cytochrome c interactions: a combined infrared and fluorescence study″, International Journal of Molecular Science, **22** (2021) 1334. **https://doi.org/10.3390/ijms22031334**

10. F. Coletti, M. Romani, G. Ceres, U. Zamm, M. Cestelli Guidi ″Evaluation of microscopy techniques and ATR-FTIR spectroscopy on textile fibers from the Vesuvian area: A pilot study on degradation processes that prevent the characterization of bast fibers.″, Journal of Arch. Sci.: Reports, **36** (2021) 102794. **https://doi.org/10.1016/j.jasrep.2021.102794**

11. L. Giuntini, L. Castelli, M. Massi, M., Fedi, C., Czelusniak, N., Gelli, ... & F. Taccetti. ″Detectors and Cultural Heritage: The INFN-CHNet Experience″. Applied Sciences, **11** (2021) 3462. **https://doi.org/10.3390/app11083462**

12. Szubka, M., Zajdel, P., Fijałkowski, M., Talik, E., Balerna, A., Cestelli-Guidi, M., ... & Jochym, P. T. ″Revisiting properties of $CaCoSi_nO_{2n+2}$. Crystal and electronic structure″. Journal of Magnetism and Magnetic Materials, online (2021) .
https://doi.org/10.1016/j.jmmm.2021.168858

13. M. Angelucci, A. Balerna, R. Cimino, M. Cestelli-Guidi, A. Grilli, M. Pietropaoli, A. Raco, V. Sciarra, V. Tullio, and G. Viviani, ″DAΦNE-Light: The INFN-LNF Synchrotron Radiation Facility ″, Di Cicco A., Giuli G., Trapananti A. (eds) Synchrotron Radiation Science and Applications. Springer Proceedings in Physics, **220** (2021) 33-43. Springer, Cham.
https://doi.org/10.1007/978-3-030-72005-6_3

14. A. Balerna, ″DAΦNE-Light INFN″, Synchrotron Radiation News **34** (2021) 9.
https://doi.org/10.1080/08940886.2021.1902711

15. L. Spallino, M. Angelucci, A. Pasqualetti, K. Battes, C. Day, S. Grohmann, E. Majorana, F. Ricci, and R. Cimino, ″Cryogenic vacuum considerations for future gravitational wave detectors″, Phys. Rev. D **104** (2021) 062001.
https://doi.org/10.1103/PhysRevD.104.062001

16. R. Dupuy, M. Bertin, G. Féraud, X. Michaut, P. Marie-Jeanne, P. Jeseck, L. Philippe, V. Baglin, R. Cimino, C. Romanzin, and J.-H. Fillion, ″ Mechanism of Indirect Photon-Induced Desorption at the Water Ice Surface″, Phys. Rev. Lett. **126** (2021) 156001.
https://doi.org/10.1103/PhysRevLett.126.156001

17. R. Dupuy, M. Bertin, G. Féraud, C. Romanzin, T. Putaud, L. Philippe, X. Michaut, P. Jeseck, R. Cimino, V. Baglin and J.-H. Fillion, ″X-Ray induced desorption and photochemistry in CO ice″, Phys. Chem. Chem. Phys. **23** (2021) 15965.
https://doi.org/10.1039/D1CP02670D

18. D. Saranina, S. Pescetelli, A. Pazniak, D. Rossi, A. Liedl, A. Yakusheva, L. Luchnikov, P. Gostischev, S. Didenko, A.Tameev, D. Lizzit, M. Angelucci, R. Cimino, R. Larciprete , A. Agresti, A. Di Carlo, ″ Transition metal carbides (MXenes) for efficient NiO-based inverted perovskite solar cells″, Nano Energy **82** (2021) 105771.
https://doi.org/10.1016/j.nanoen.2021.105771