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Contents

Biophotonics

1

Brain state modulation of cortical network

F. Resta [1,3], A. Scaglione[2,3], F. S. Pavone [3,2,1]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 Department of Physics and Astronomy, University of Florence (UNIFI), Sesto Fiorentino, Italy;
3 European Laboratory for Non-linear Spectroscopy (LENS), Sesto Fiorentino, Italy.

Large-scale cortical dynamics are crucial for various cognitive functions, including goal-directed behavior, motor learning, and sensory processing. Different brain states—such as wakefulness, sleep, and anesthesia—profoundly alter the spatiotemporal patterns of neuronal activity across multiple brain regions. While the effects of brain states on overall neuronal firing and synchronization have been extensively studied, the specific topography of networks engaged during these states remains less understood.
This study aimed to identify the cortical networks influenced by varying levels of anesthesia. To achieve this, we utilized Group Independent Component Analysis (GroupICA) on widefield mesoscale imaging data. This approach allowed us to uncover spatial independent components (ICs), which represent elements of cortical networks that are consistently observed across subjects as anesthesia levels decrease toward wakefulness.
Our findings highlight that ICs associated with the retrosplenial cortex exhibited significant brain state dependence, being most prevalent during deep anesthesia and least represented in the awake state. Further analysis revealed that deeper anesthesia was characterized by a strong correlation between retrosplenial components, which weakened as subjects approached lighter anesthesia and wakefulness. These results suggest that deeper anesthesia favors the coactivation of posterior-medial cortices, while lighter anesthesia and wakefulness allow for a more diverse range of dynamic connectivity patterns.

2 Mapping neuronal populations with Light-Sheet Fluorescence Microscopy

G. Mazzamuto[1,2,3], I. Costantini[4,2], D. Di Meo[5], F. Cheli[2], M. Sorelli[2], S. Bradley[3], J. Ramazzotti[2], C. Checcucci[3], A. Franceschini[3,2,1], L. Silvestri[2], F.S. Pavone[3,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy (LENS), Sesto Fiorentino, Italy;
3 University of Florence, Department of Physics (UNIFI), Sesto Fiorentino, Italy;
4 University of Florence, Department of Biology(UNIFI), Florence, Italy;
5 University of Florence, Department of Information Engineering (DINFO), Florence, Italy

Light-Sheet Fluorescence Microscopy (LSFM) is an excellent tool to study neuronal populations in large samples such as the whole mouse brain, thanks to its inherent three-dimensional nature and its high resolution down to the single cell. In this work we report on our latest technological developments in both hardware and software and their applications in several projects aiming at reconstructing the neuronal organization in both the human cortex and in whole mouse brain.

3 SERS-based sensors for early-stage disease diagnosis

C. Dallari[1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy, (LENS), Sesto Fiorentino, Italy

Early diagnosis of aggressive diseases (e.g., neurodegenerative disorders, cancer, sepsis) is essential to ensure timely treatments, slow progression and reduce burdens. The INO-CNR biosensing team focuses on optical targeting of diluted biomarkers in biofluids or biopsies using ad-hoc functionalized plasmonic nanoparticles, exploiting surface-enhanced Raman spectroscopy (SERS). We aim at developing new and reliable SERS-based sensors properly functionalized for bio/chemical sensing with improved sensitivity, implying a complex coordination of extremely interdisciplinary fields.

4

Single molecule imaging to track cellular proteins and follow drug release from nanoparticles

M. Calamai [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy,
2 European Laboratory for Non-Linear Spectroscopy (LENS), Sesto Fiorentino , Italy

Single molecule imaging with advanced microscopy approaches can be used to study the spatial distribution and trafficking of individual cellular proteins, allowing to reach nanoscale resolution and highlight potential heterogeneities within sample populations.
The application of single molecule imaging is not limited to study the cellular trafficking and interactions between candidate proteins in the field of neurodegenerative diseases, but can also be extended to monitor the release of biopharmaceuticals from nanoparticles embedded in hydrogels of different compositions.

5

Non-linear all-optical dissection of functional and effective connectivity in the larval zebrafish brain

L. Turrini [1,2], P. Ricci [2,3], M. Sorelli [5], G. de Vito [2], F. Vanzi [1,2,3], F. S. Pavone [2,4]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-linear Spectroscopy (LENS), Sesto Fiorentino, Italy;
3 Department of Physics and Astronomy, University of Florence (UNIFI), Sesto Fiorentino, Italy;
4 Department of Neuroscience, Psychology, Drug Research and Child Health, University of Florence (UNIFI), Florence, Italy;
5 Department of Biology, University of Florence (UNIFI), Sesto Fiorentino, Italy

Unraveling whole-brain neuronal population activity has become achievable with advances in optical methods and genetically encoded indicators. Applied to translucent larval zebrafish, these tools enable recording and manipulation of extensive neuronal populations. We present a custom two-photon system combining light-sheet imaging and 3D excitation with acousto-optic deflectors, to achieve noninvasive, crosstalk-free functional/effective connectivity mapping of the larval zebrafish brain.

6

Volumetric super-resolution of thick samples

L. Gardini [1]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy

Single-objective light sheet is an optical technique to reduce background fluorescence by illuminating a confined area within a sample. By using a linear slit, we obtained a 3 μm thick light sheet, while maintaining a 10 x 40 μm^2 field of view. In combination with super-resolution microscopy, we achieved a 3-folds increase in localizations. Thanks to the dramatic reduction of the background, we demonstrated volumetric super-resolution in thick samples, such as bacterial biofilms and plant roots.

7

Gold-based plasmonic nanocomposites for 3D laser-structuring of biocompatible scaffolds with built-in SERS-sensors

I. Ventisette [1], F. Mattii [2], C. Dallari [2,3], C. Capitini [2,4], M. Calamai [2,3], B. Muzzi [5], F. S. Pavone [2,3,4], F. Carpi [1], and C. Credi [2,3]

1 Department of Industrial Engineering, University of Florence, Florence, Italy;
2 European Laboratory for Non-Linear Spectroscopy (LENS), Sesto Fiorentino, Italy;
3 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
4 Department of of Astronomy and Physics, University of Florence, Sesto Fiorentino, Italy

To date, plasmonic gold nanoparticles (AuNPs) have gained significant attention in the biosensing sector due to their unique combination of chemical and physical properties. More recently, AuNPs have been explored as functional filler for photo-curable polymers, to obtain nanocomposites with intrinsic plasmonic properties that can be microstructured through laser-based 3D printing. Here, a gold-hydrogel photocomposite was developed to achieve high-resolution laser-based prototyping of biocompatible scaffolds with built-in optical sensors useful for in vitro real-time monitoring of 3D cells culture through surface enhanced Raman spectroscopy (SERS).

8

A novel all-optical stroke model of middle cerebral artery occlusion and recanalization in mice

E. Conti [1], A. Minetti [3], L. Turrini [1,2], C. Sarti [4,§], A.M. Gori [5,§], B. Giusti [5,§], M. Baldereschi [3,§], A.L. Allegra Mascaro [2,3,§†], and F. S. Pavone [1,2,6†]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non LInear Spectroscopy (LENS), Sesto Fiorentino, Italy;
3 Neuroscience Institute, National Research Council, Pisa, Italy;
4 Neurofarba Department, University of Florence, Florence, Florence, Italy;
5 Department of Experimental and Clinical Medicine, University of Florence (UNIFI), Florence, Italy;
6 Department of Physics and Astronomy, University of Florence (UNIFI), Sesto Fiorentino, Italy;
§ Translational REsEarch on Stroke (TREES) Working Group (in alphabetical order): Allegra Mascaro, A.L., Baldereschi, M., Conti, E., Di Carlo, A.S., Fainardi, E., Kennedy, J., Lombardo, I., Nencini, P., Palumbo, V., Piccardi, B., Sarti, C., Sodero, A., Tudisco, L.
† Equally contributing last senior authors.

Stroke is the leading cause of adult disability and the third cause of death worldwide. To better retrace clinical processes, the development of a preclinical stroke model resembling the ischemic progression is really urgent. Here we developed a novel mouse model of all-optical occlusion and recanalization of a large blood vessel of the brain, we characterized the lesion volume, the emergence of cerebral edema and the insurgence of the inflammatory reaction.

9

Delineation of gastrointestinal tumors biopsies via autofluorescence lifetime imaging

D. Suraci [1], L. Tirloni [2], E. Baria [3], J.L Lagarto [4], C. Gatto [2], S. Pillozzi [5], L. Antonuzzo [1], A. Taddei [5,6], and R.Cicchi [2,6]

1 National Institute of Optics, National Research Council (CNR-INO) Sesto Fiorentino, Italy;
2 European Laboratory for Non LInear Spectroscopy (LENS), Sesto Fiorentino, Italy;
3 Neuroscience Institute, National Research Council (CNR-IN), Pisa, Italy;
4 Neurofarba Department, University of Florence (UNIFI), Florence, Italy;
5 Department of Experimental and Clinical Medicine, University of Florence (UNIFI), Florence, Italy;
6 Department of Physics and Astronomy, University of Florence (UNIFI), Sesto Fiorentino, Italy;
§ Translational REsEarch on Stroke (TREES) Working Group (in alphabetical order): Allegra Mascaro, A.L., Baldereschi, M., Conti, E., Di Carlo, A.S., Fainardi, E., Kennedy, J., Lombardo, I., Nencini, P., Palumbo, V., Piccardi, B., Sarti, C., Sodero, A., Tudisco, L.
† Equally contributing last senior authors.

Liver cancer is a global health challenge and its incidence is growing worldwide, with more than 1 million cases per year by 2025. While hepatocellular carcinoma (HCC) is the most common form of liver cancer, hepatic metastases of colorectal carcinoma (CRC) are the natural disease evolution in almost 50% of patients with CRC. For both HCC and CRC liver metastases, surgical resection represents the only chance of long-term survival. In this context, a label-free optical diagnostic and/or surgical guidance tool would be highly suitable to reduce possible positive margin and improve the patient disease outcome. In this study, we used a custom-made autofluorescence lifetime fiber-based imaging instrumentation1 to provide real-time discrimination of tumor from perilesional tissues in freshly excised liver samples. The proposed approach allowed discriminating tumor from perilesional tissue, reporting the fluorescence lifetime decay of cellular metabolic markers, i.e. NADH and FAD(H). In particular, we reported about the characterization and delineation of tumor against healthy margin in different clinical cases of gastrointestinal tissues2, demonstrating the capability of our method. The approach was further validated on a larger statistic by examining around 30 surgical specimens of both HCC and CRC hepatic metastases, demonstrating that this approach is a powerful method for delineating tumor borders as well as for differentiating HCC from CRC metastases to the liver. The obtained results, together with the capability to acquire and process images in real time under bright background enables our methodology to be translated into surgical and clinical instrumentation for label-free tissue diagnostics and surgical guidance.

10

Fine tuning of nanoparticles dynamics for sensing and delivery

E. Tognoni [1], B. Adinolfi [2], M. Ballestri [3], G. Varchi [3], M. Pellegrino [1]

1 National Institute of Optics, National Research Council (CNR-INO), Pisa, Italy;
2 Istituto di Fisica Applicata "Nello Carrara", Consiglio Nazionale delle Ricerche (CNR-IFAC), Sesto Fiorentino, Italy;
3 Istituto per la Sintesi Organica e la Fotoreattività, Consiglio Nazionale delle Ricerche (CNR-ISOF), Bologna, Italy

Nanoparticles dispersed in solution can be individually detected, characterized and captured/released by electrokinetic methods. Fluid flow and electrokinetic forces are applied to guide the nanoparticles toward the desired target. We study the experimental parameters that influence their dynamics, aiming at precision applications such as single-particle delivery in biomedicine.

Cold matter and quantum simulation

11

A new dipolar quantum gas machine

P. Lombardi, P.P. Sekhar, G. Ferioli, L. Tanzi, G. Modugno

National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy

We present a new setup for the realization of dipolar quantum gases targeting the study of many-body quantum phases in the strongly correlated regime. The apparatus has been design in the perspective of merging some of the most innovative technical approaches developed in the last years, and is currently under construction. Numerical simulations and references in literature envision the creation of a 10^5-atom dipolar Bose-Einstein condensate with a cycle time of few seconds.

12

Ultracold LiCr and the quest for quantum gases of doubly-polar molecules

S. Finelli , A. Ciamei, B. Restivo, M. Schemmer , A. Cosco, M. Inguscio, A. Trenkwalder , K. Zaremba-Kopczyk , M. Gronowski , M. Tomza , and M. Zaccanti

National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy

Quantum gases of doubly polar molecules, possessing both an electric and a magnetic dipole moment, have been proposed for a number of applications. Here, we explore a novel system composed of lithium (alkali metal) and chromium (transition metal). We produce up to 50x10^3 molecules at phase-space densities exceeding 0.1. We identify favorable transitions for the coherent optical transfer to the rovibrational ground-state, which features large electric (3.3D) and magnetic (5 μB) dipole moments.

13 Dynamical formation of multiple quantum droplets in a Bose-Bose mixture

L. Cavicchioli[1,2], C. Fort[1,2], F. Ancilotto[3,4], M. Modugno[5,6,7], F. Minardi[1,2,8]and Alessia Burchianti [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy (LENS) and University of Florence (UNIFI), Sesto Fiorentino, Italy;
3 Dipartimento di Fisica e Astronomia "Galileo Galilei" and CNISM, Università di Padova (UNIPD), Padova, Italy;
4 Istituto Officina dei Materiali, National Research Council (CNR-IOM), Trieste, Italy;
5 Department of Physics, University of the Basque Country UPV/EHU, Bilbao, Spain;
6 IKERBASQUE, Basque Foundation for Science, Bilbao, Spain;
7 EHU Quantum Center, University of the Basque Country UPV/EHU, Leioa, Biscay, Spain;
8 Dipartimento di Fisica e Astronomia, Università di Bologna, Bologna, Italy

We report on the formation of multiple quantum droplets in a heteronuclear 41K-87Rb mixture released in an optical waveguide. We initially form a single droplet in an excited mode, which axially expands up to a critical length and then splits into two or more smaller droplets; their number increases with decreasing interspecies attraction and increasing atom number. This is consistent with capillary instability, which causes the breakup of the droplet due to the surface tension.

14 Shapiro steps in a 6Li Fermi superfluid Josephson junction

M. Frometa [1,2], G. Del Pace [2], D. Hernandez-Rajkov [1,2],
N. Grani [1,2], G. Nesti [2], and G. Roati [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy (LENS) and University of Florence (UNIFI), Sesto Fiorentino, Italy

Josephson junctions represent a powerful tool to probe macroscopic phase coherence in different systems. They are also fundamental for atomtronics circuits, thanks to their well defined current-chemical potential and currentphase. In our experimental system, we create atomic Josephson junctions using Fermi superfluids of lithium-6, realized by coupling two quasi-twodimensional atomic clouds with a tunneling barrier. By moving the tunneling barrier across the junction while modulating the position at a given frequency, we are able to inject an alternate current. Then, measuring the chemical potential imbalance developed across the junction after a few modulation periods, we can study the dynamics resulting in the system. Our experimental results show that the AC driving of the barrier introduces a step-like behavior in the current-chemical potential curve, with a number of plateaus at a chemical potential value that is an integer multiple of the driving frequency. This behavior is the analog of Shapiro steps observed in superconducting Josephson junctions illuminated by an external electromagnetic field. We studied the AC response for a molecular BEC and a unitary Fermi gas junction, finding that in both cases the plateaus in the current-chemical potential characteristic coincides with the emission of a well-defined number of vortices, suggesting that the stabilization of the current in the plateaus is operated by phase slippage processes.

15 Local temperature measurement inside a magneto optical trap using doppler thermometry

K.N. Trivedi [1], B. Bégoc [1], M. Carminati [1], R. Donofrio [1],
T. Bonaccorsi [1], O. Morsch [1,2]

1 Dipartimento di Fisica, University of Pisa (UNIPI), Pisa, Italy;
2 National Institute of Optics, National Research Council (CNR-INO), Pisa, Italy

We present a technique to measure the local temperature inside the Rb magneto optical trap. Temperature in the MOT is found to increase as we go from the center to the edge of the MOT. The minimum measured temperature (in the center) is found to be 200+/-50 uk and the maximum measured temperature is 600+/-100 uk at 650 um away from the MOT center. We extract the temperature from the measured doppler broadening from the frequency scan of Rydberg state 70S1/2.

16 Spatially resolved temperature measurements on ultra-cold atoms using Rydberg Doppler broadening spectroscopy

K. N. Trivedi [1,2], M. Carminati [1], B. Bégoc [1,2], T. Bonaccorsi [1],
R. Donofrio [1], O. Morsch [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Pisa, Italy;
2 Dipartimento di Fisica, Università di Pisa (UNIPI), Pisa, Italy

We present experimental results on temperature measurements in ultra-cold clouds of rubidium atoms using Doppler broadening spectroscopy on a two-photon Rydberg transition. Thanks to the small intrinsic linewidth of that transition, temperatures in the micro-Kelvin regime can be accurately measured. By tightly focusing and intersecting the excitation beams at right angles we achieve a spatial resolution of the temperature measurements of around 20 micrometers.

17 Optical repulsive potential for Dy BEC and supersolid in the blue region

C. Gabbanini [1], N. Preti [1,2], N. Antolini [1,2], G.Biagioni [1,2], A.Fioretti [1], L. Tanzi [1] and G.Modugno [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Pisa, Italy;
2 European Laboratory for Non-Linear Spectroscopy and University of Florence, (LENS), Sesto Fiorentino, Italy

We present the realization of repulsive optical potentials for dysprosium atoms at wavelengths close to 400 nm. We employ a spectrally filtered diode laser to measure both scalar and tensorial polarizabilities of Dy, finding a good agreement with the theoretical predictions. The potential strength is appropriate to manipulate Dy BECs, with lifetimes above 1 s. We will use this potential to realize the annular geometry and test the differences between superfluids and supersolids under rotation.

18 Quantum superfluids as analog models of gravity: a fruitful synergy of gravity and quantum optics

I. Carusotto

Pitaevskii BEC Center, National Institute of Optics, National Research Council (CNR-INO), Trento, Italy

I will present the state of the art and the new perspectives in the theoretical and experimental study of analog models of quantum field theories on curved spacetimes.
After a brief presentation of milestone results on Hawking emission from acoustic horizons, I will outline recent results of the Trento team on back-reaction phenomena, quasi-normal modes of black holes, and false vacuum decay. The potential interest of these results for gravitation and cosmology will be finally highlighted.

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False vacuum decay in a quantum spin mixture

G.Lamporesi, A.Zenesini, R.Cominotti, A.Berti, C.Rogora, I.Carusotto, A.Recati, G.Ferrari

Pitaevskii BEC Center, National Institute of Optics, National Research Council (CNR-INO), Trento, Italy

Some systems in nature are hard to study because they cannot be changed at will. Ultracold gases can be highly manipulated up to having them acquire the properties of other physical systems.
In Trento, we create a quantum mixture with atoms in two spin states, which behaves as a ferromagnet. By initializing it in a metastable configuration, we study the decay to the ground state through the formation of macroscopic spin domains, in agreement with false vacuum decay of quantum field theory.

20

Quantum thermodynamics of long-range interactions

N. Defenu

National Institute of Optics, National Research Council (CNR-INO), Trieste, Italy

Quasi-static transformations, or slow quenches, of many-body quantum systems across quantum critical points create topological defects. The Kibble-Zurek mechanism regulates the appearance of defects in a local quantum system through a classical combinatorial process. However, long-range interactions disrupt the conventional Kibble-Zurek scaling and lead to a density of defects that is independent of the rate of the transformation. In this study, we analytically determine the complete full counting statistics of defects generated by slow annealing a strong long-range system across its quantum critical point. We demonstrate that the mechanism of defect generation in long-range systems is a purely quantum process with no classical equivalent. Furthermore, universality is not only observed in the defect density but also in all the moments of the distribution. Our findings can be tested on various experimental platforms, including Rydberg gases and trapped ions.

Extreme light and matter

21 Laser-driven Very High Energy Electrons (VHEE) for radiobiological applications at the Intense Laser Irradiation Laboratory

M. Salvadori [1], F. Avella [1,2], F.Baffigi [1], G. Bandini [1], G. Benincasa [1], F. Brandi [1], G. Cristoforetti [1], M. Ezzat [1], A. Fregosi [1], L. Fulgentini [1], D. Gregocki [1], E. Hume [1], P. Koester [1], L. Labate [1,2], D. Palla [1], M. C. V. Panaino [1], S. Piccinini [1], S. G. Vlachos [1] and L. A. Gizzi [1,2]

1 Intense Laser Irradiation Laboratory, National Institute of Optics, National Research Council (CNR-INO), Pisa, Italy;
2 also at Department of Physics, University of Pisa (UNIPI), Pisa, Italy

Very High Energy (100-250 MeV) Electron beams are being considered for the next generation of medical accelerators. We use plasma acceleration driven by intense lasers to produce Ultra-high dose rate VHEE beams to enable the investigation of radiobiological effects of VHEE. Electrons are extracted from the plasma ions via ionization induced injection and accelerated by the so-called Laser Wakefield Acceleration. Such electron bunches are then transported to the sample for biological studies.

22 Laser-plasma acceleration of very high energy electron (VHEE) beams: using ultra high dose rate pulses for in vitro radiobiology studies

S. Piccinini [1], M. Salvadori [1], G. Bandini [1], A. Borghini [4], M.G. Andreassi [4], F. Baffigi [1], A. Fregosi [1], L. Fulgentini [1], D. Gregocki [1,3], P. Koester [1], L. Labate [1,2], D. Palla [1], S. Vlachos [1,3], C. Panaino [1], F. Avella [1,3], F. Brandi [1] and L.A. Gizzi [1,2]

1 Intense Laser Irradiation Laboratory (ILIL), Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche, (CNR-INO), Pisa, Italy;
2 Istituto Nazionale di Fisica Nucleare (INFN), Pisa, Italy;
3 Università di Pisa (UNIPI), Pisa, Italy;
4 Istituto di Fisiologia Clinica, Consiglio Nazionale delle Ricerche (CNR-IFC), Pisa, Italy

VHEE beams (100-250 MeV) are being considered for treating deep-seated tumors using FLASH radiotherapy. Laser-plasma acceleration (LPA) through the Laser Wakefield Acceleration (LWFA) mechanism enables acceleration gradients orders of magnitude higher than conventional RF accelerators, making LPA an ideal candidate for compactly generating VHEE for clinical use. We present recent results on the dosimetric characterization of an LWFA-based VHEE source at ILIL and its application to in vitro radiobiology.

23 Development of direct diode pumped amplifiers for high rep rate, high average power, ultrashort and ultraintense lasers

L. Labate [1,†], F. Baffigi [1], F. Brandi [1], G. Cellamare [1,‡], M. Ezzat [1], A. Fregosi [1], D. Palla [1], G. Toci [2], L.A. Gizzi [1,†]

1 Intense Laser Irradiation Laboratory (ILIL), Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche, (CNR-INO), Pisa, Italy;
2 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
† Also at National Institute of Nuclear Physics (INFN), Pisa, Italy;
‡ Now at CISAM, San Piero a Grado (PI), Italy

Scaling the technology currently in use for generating ultrashort and ultraintense laser pulses to the rep-rate and average power required to drive future laser-driven particle accelerators is hindered by thermal management and complexity issues. We report on the development of a novel concept kW-class average power, J-class energy, ultrashort laser amplifier, based on the direct diode pumping of long-lifetime, Tm-based materials, and exploiting the so-called Multi-Pulse Extraction concept.

24 Perspectives of laser fusion after NIF Ignition: direct drive and LPI

E. Hume, G. Cristoforetti, P. Koester, L. A. Gizzi

Intense Laser Irradiation Laboratory (ILIL), Istituto Nazionale di Ottica, Consiglio Nazionale delle Ricerche, (CNR-INO), Pisa, Italy

In inertial confinement fusion (ICF) lasers are used to rapidly compress and heat a fuel pellet to nuclear fusion conditions to generate energy. Recent remarkable results from NIF demonstrated that ICF can produce more energy than is initially put into the fuel. However, there are still challenges to overcome before ICF reactors become a reality. We will present our work at ILIL investigating how the laser interacts with fusion plasmas and how to improve the absorption efficiency.

Heritage science, vision science, technical optics and materials for renewable energies

25 Coloring zirconium oxide for low-cost solar absorbers at high temperature

E. Sani, L. Mercatelli, L. Silvestroni

National Institute of Optics, National Research Council (CNR-INO), Florence, Italy

The exploration of new ceramics for use as absorbers in Solar Towers operating at temperatures higher than the SoA is a key to boost technology penetration. The most advanced material used to date is SiC, a non-oxide semiconductor with complex production technique and high cost.
Refractory oxides, like ZrO_2, have a great technological interest and mature production techniques. Usually they are whitish, but dopants or secondary phases drastically change the color. Here we report on a systematic study on colored ZrO_2 in view of the application as solar absorber.

26 Ceramics from regoliths for in-situ resource utilization

E. Sani [1], A. Dell'Oro [2], R. Licheri [3], R.o Orrù [3], G. Cao [3]

1 National Institute of Optics, National Research Council (CNR-INO), Florence Italy;
2 Istituto Nazionale di Astrofisica (INAF), Osservatorio Astrofisico di Arcetri, Florence, Italy;
3 Dipartimento di Ingegneria Meccanica, Chimica e dei Materiali, Unità di Ricerca del Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali (INSTM) - Università degli Studi di Cagliari (UNICA), Cagliari, Italy

The exploitation of resources available in-situ represents a crucial issue for human and robotic space explorations on planetary objects like Moon, Mars and asteroids. In this work we studied optical properties of ceramics obtained by sintering of the JSC-1A lunar regolith simulant, to assess the potential of processed regoliths for solar energy harvesting and thermal energy storage for future lunar colonies.

27 UV-LED system for in-vitro fluorescence analysis in a portable biomedical device

D. Jafrancesco, F. Francini, L. Mercatelli, P. Sansoni, D. Fontani, Lucia Veronica Rossi, Giuseppe Ferorelli

National Institute of Optics, National Research Council (CNR-INO), Florence, Italy

In the field of fluorescence analysis, the challenge is to have affordable results with low power consumption of the source and low setup costs, in order to utilize it in portable and battery-supplied devices. The proposed methodology achieves this objective substituting a 1000 W Xe lamp with an UV LED with 68 mW of electric power consumption and utilizing a suitable electronic conditioning system. The system has been optimized using an optical CAD.

28 Hybrid images as an instrument for evaluation of visual acuity

A. Farini, E. Baldanzi, F. Cosseddu, P. Grasso, A. Giorgetti, M. Gurioli, F. Tommasi

National Institute of Optics, National Research Council (CNR-INO), Florence, Italy

A hybrid image is one that can be perceived in two distinct ways depending on the viewing distance, leveraging the way humans process different spatial frequencies. In our study, we developed new hybrid images and employed them as tools for testing visual acuity. The resulting test demonstrated high specificity and sensitivity, making it a promising option for use with non-verbal individuals.

29

New activities in Naples in the field of Cultural Heritage Diagnostic field

A. Rocco[1], V. Di Sarno [1], P. Maddaloni [1], R. Fontana [2] and L. Pezzati [2]

1 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy;
2 National Institute of Optics, National Research Council (CNR-INO), Firenze, Italy

In this work, we present an overview of the new activities in the field of Cultural Heritage Diagnostic. Accordingly, in the Strengthening of the Italian node of E-RIHS (SHINE) the infrastructure has been equipped with cutting-edge instruments in Pozzuoli, too. Preliminary results are presented collected both in field campaigns and lab activities. Interesting perspectives were born from strict collaborations with the CH Group in Florence and new promising partnership in the Neapolitan area are in progress (i.e. Superintendence and Universities).

30

Optical Techniques and Software development for Non-Invasive Artwork Analysis

S. Innocenti, V. Righetti, A. Chaban, D. Quintero Balbas, R. Fontana, E. Pampaloni, L. Pezzati, and J. Striova

National Institute of Optics, National Research Council (CNR-INO), Firenze, Italy

Non-invasive optical techniques are highly demanded in Heritage Science. Among the different methods available at CNR-INO, Raman spectroscopy and Optical Coherence Tomography are amongst the most frequently exploited techniques to study the chemical and morphological characteristics of artefacts. This work exemplifies our analytical capabilities developed through the years both from the optical setup and the tailored software development by showing cases of study of renowned artworks and innovative projects.

31

New frontiers in wall painting diagnostics: potentials of holographic interferometry

A. Chaban [1], A. Rocco [2], V. Di Sarno [2], R. Fontana [1], J. Striova [1]

1 National Institute of Optics, National Research Council (CNR-INO), Florence, Italy;
2 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy

This contribution presents new achievements and challenges in on-site wall painting diagnostic procedures. Using holographic interferometry, infrared thermography, THz imaging, and other methods, our approach goes far beyond the only defect detection, enabling in-depth subsurface analysis and uncovering future risks. We illustrate the contribution of these techniques to current conservation campaigns on renowned wall paintings in Florence, supporting our research by laboratory simulation studies.

32

A Performance Comparison of 3D Survey Instruments for Their Application in the Cultural Heritage Field

E. Vannini [1], I. Lunghi [1], A. Dal Fovo [1], V. Di Sarno [2], A. Rocco [2] and R . Fontana [1]

1 National Institute of Optics, National Research Council (CNR-INO), Florence, Italy;
2 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy

In this work, we compared the performance of four 3D instruments based on different working principles by measuring four samples representative of artworks. We verified the accuracy and technical specifications in the suppliers' datasheets by computing the point density and evaluating both the lateral and axial resolution. The comparison between the nominal and calculated values from measuring the former samples was used to predict the performance of the instruments in real-case scenarios.

33 Women studying women: non-invasive and non-contact optical analysis on the painting Allegory of Inclination by Artemisia Gentileschi

I. Lunghi, A. Dal Fovo, E. Vannini, S. Innocenti, J. Striova, R. Fontana

National Institute of Optics, National Research Council (CNR-INO), Firenze, Italy

In this work, we present the results of the non-invasive and non-contact optical analysis on the painting Allegory of Inclination by Artemisia Gentileschi, one of the most famous female painters of all time. The analysis, carried out by a female team, allowed to identify the pigments, to document the state of conservation of the painting, to study the artist's technique and to reveal the Allegory's original nudity, which was later covered by a drape painted by Volterrano due to its perceived immorality.

34 THz Time-Domain transmission and reflection imaging for art material analysis

V. Di Sarno [1], S. Zappia [2], E. Vannini [3], A. Dal Fovo [3], A. Rocco [1], P. Maddaloni [1], R. Fontana [3], I. Catapano [2]

1 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy;
2 Institute for Electromagnetic Sensing of the Environment, National Research Council of Italy (CNR-IREA), Naples, Italy;
3 National Institute of Optics, National Research Council (CNR-INO), Florence, Italy

This contribution for non-contact methodologies in cultural heritage studies, provides a brief overview of the available THz systems and presents preliminary results obtained on ad-hoc prepared specimens.
Specifically, transmission imaging results on painted canvas samples with hidden drawings and time of flight reflection imaging results on wood samples covered by different material layers are presented.

Quantum optics, information and metrology

35

Entanglement manipulation through multicore fibres

C. Marconi [1], E. Fanella [1,2], D. Bacco [3], and A. Zavatta [1]

1 National Institute of Optics, National Research Council (CNR-INO), Firenze, Italy;
2 Università degli Studi di Napoli Federico II (UNINA), Napoli, Italy
3 Department of Physics and Astronomy, University of Florence (UNIFI), Firenze, Italy

Multicore fibres are recently gaining considerable attention in the context of quantum communication tasks, where their capability to transmit multiple quantum states along different cores of the same channel makes them a promising candidate for the implementation of scalable quantum networks. For this reason, such devices have been used, so far, mostly in the context of quantum communication protocols such as quantum key distribution. Recently, it was shown how MCFs can be used not only for quantum communication purposes but also as multi-port beamsplitters, an application that has made possible their use as a tool for entanglement generation.
Here, we follow this latter approach and show that multicore fibres can be effectively used not only for the scope of communication but also for the manipulation of entangled states. First, exploiting the formalism of completely-positive trace-preserving maps, we describe the action of a multicore fibre as a quantum channel and investigate the propagation of a transmitted quantum state under the effect of decoherence and inter-core crosstalk. Then, we propose a novel protocol for the manipulation of the entanglement where, starting from a maximally entangled state of two qudits, we use a multicore fibre to create new families of mixed entangled states, including examples of bound entangled states, whose implementation is typically a cumbersome task. Remarkably, detrimental effects like decoherence and inter-core crosstalk are fundamental for the realisation of such states.

36

Levitated quantum optomechanics

A. Pontin [1] , Q. Deplano [2,3], A. Ranfagni [2], F. Marino [1,3], F. Marin [1,2,3,4]

1 National Institute of Optics, National Research Council (CNR-INO), Florence, Italy;
2 Dipartimento di Fisica e Astronomia, University of Florence (UNIFI, Sesto Fiorentino, Italy;
3 National Institute of Nuclear Physics (INFN), Sezione di Firenze, Sesto Fiorentino, Italy
4 European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy

Levitated optomechanics explores interactions between optical fields and mechanical oscillators obtained by trapping mesoscopic nanoparticles in external fields. These systems are seen as optimal candidates to explore quantum mechanics in this high mass regime and have the potential to explore the quantum nature of gravity in future laboratory tests.
Here, we report the achievement of a 2D ground state in an optical tweezer with a final phonon occupation of nx=0.55±0.06 and ny= 0.74±0.08.

37

Intensity noise properties of mid-infrared cascade lasers: between classical and quantum operation regime

T. Gabbrielli [1,2], J. Pelinia [1,3], L. Consolino [1,2], I. La Penna [1,2], F. Cappelli [1,2], S. Borria [1,2], and P. De Natale [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Florence, Italy;
2 European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy;
3 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy;

Our work investigates the generation of nonclassical light by mid-infrared (MIR) cascade lasers. Using a MIR-balanced detector sensitive to the intensity noise below the shot-noise level, we unveiled shot-noise-limited operation of cascade lasers in the 1-100 MHz range. The same setup has been exploited to measure four-wave-mixing-induced correlations in harmonic combs emitted by these devices. These novel insights may enable laser sensing at unprecedented sensitivity levels.

38

Solid state spins for quantum thermodynamics

S. Hernández-Gómez [1,2], S. Gherardini [1,2], and N. Fabbri [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy

Spin-based diamond devices, thanks to exquisite quantum control and long coherence time of the spin state, and tailored interaction with its environment, disclose new possibilities for exploring how thermodynamics operates at the nanoscales, where fluctuations and quantum effects play a significant role. We employed different measurement schemes to quantify the contribution of quantum coherence, and nonclassical multi-time correlations in (thermo)dynamic processes.

39

Magnetic quantum imaging with spin defects in diamond

S. Hernández-Gómez [1,2], G. Bianchini [1,2], M. Barucci [1,2], S. Viciani [1,2], and N. Fabbri [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy

Nitrogen-vacancy (NV) centers in diamond have been established in the last decade as quantum sensors–sensors that take advantage of their quantum properties to detect weak signals. In our lab, we built a magnetomicroscope based on NV centers, with which we can study 2D and 3D magnetic properties of matter, including biological samples. In collaboration with UniFi and UCBM we aim at imaging magnetic fields of cardiac tissues, relevant to the study of cardiac arrhythmias.

40

Differential Mach-Zehnder interferometry with trapped Bose Einstein condensates

T. Petrucciani [1] , A. Santoni [2] , C. Mazzinghi [1] , D. Trypogeorgos [1] , F. S. Cataliotti [1,2], A. Smerzi [1] ,M. Inguscio [2], L. Pezzé [1] , G. Modugno [1,2], and M. Fattori [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy

We report on the first realization of a gradiometric sensor based on Mach-Zehnder trapped atom interferometers. By using innovative Beat Note Superlattices, we create an array of double-well traps loaded with BEC of atomic potassium. Using a broad Feshbach resonance, we can operate the beam splitters with simple control of the tunneling probability of the atoms through the central barrier. With this, we determine the phase of each interferometer without releasing the atoms and measuring the final atoms in the two modes. The simultaneous operation allows us to perform a differential analysis and cancel the common phase noise of the sensors. A coherence times of several hundred milliseconds is reported.

41

Advantages of entangled in distributed quantum sensing

L. Pezzè

National Institute of Optics, National Research Council (CNR-INO), Firenze, Italy

Distributed quantum sensing is an emerging topic in quantum metrology where quantum states are distributed spatially in a network of sensor nodes in order to allow the simultaneous estimation of multiple parameters. This protocol opens to several innovative technological applications. In this talk, I will discuss multiparameter sensitivity bounds of a sensor made by an array of spatially-distributed Mach-Zehnder interferometers (MZIs). I will show that local measurements, independently performed on each MZI, are sufficient to provide a sensitivity saturating the quantum Cramer-Rao bound. The analytical comparison with a separable scheme using independent MZIs will directly clarify advantages of the entangled strategy when using different constraints on resources.

42

Enhanced control of organic molecules for quantum technologies

R. Duquennoy[†,//], S. Landrieux[‡,//], D. De Bernardis[†,//], J. Mony [†], M. Colautti[†,//], L. Jin[¶,⊥], W.H.P. Pernice[¶,⊥] and Costanza Toninelli [†,//]

† National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
‡ Laboratoire Charles Fabry, Institut d'Optique Graduate School (CNRS), Université Paris-Saclay, France;
¶ Kirchhoff-Institute for Physics, Heidelberg University, Heidelberg, Germany;
§ Physics Department, University of Naples (UNINA), Fuorigrotta , Italy;
// European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy;
⊥ Institute of Physics, University of Muenster, Muenster, Germany

Distributed quantum sensing is an emerging topic in quantum metrology where quantum states are distributed spatially in a network of sensor nodes in order to allow the simultaneous estimation of multiple parameters. This protocol opens to several innovative technological applications. In this talk, I will discuss multiparameter sensitivity bounds of a sensor made by an array of spatially-distributed Mach-Zehnder interferometers (MZIs). I will show that local measurements, independently performed on each MZI, are sufficient to provide a sensitivity saturating the quantum Cramer-Rao bound. The analytical comparison with a separable scheme using independent MZIs will directly clarify advantages of the entangled strategy when using different constraints on resources.

43

Large Activation Yields For Nitrogen-Vacancy and Silicon-Vacancy Diamond Color Centers by Proton Irradiation

Z. Rashid, S. Lagomarsino, N. Markesevic, S.o Hernanez-Gomez, G. Bianchini, M. Agio, N. Fabbri

National Institute of Optics, National Research Council (CNR-INO), Firenze, Italy

Nitrogen-Vacancy and Silicon-Vacancy color centers in diamond are fluorescent defects that emerged in the last decade for quantum technology applications. To realize high-performance quantum devices, we need high color centers densities and low concentration of different defects. In collaboration with Univ. of Siegen, INFN, and Fraunhofer, we investigate proton implantation to obtain high vacancy densities, and enhance N-to-NV (Si-to-SiV) conversion rates after annealing, demonstrating an improvement by a factor of 2 to 10 compared to standard electron beam irradiation.

44

Entangled photon pairs for quantum networks

Y. Mehmood, A. Zavatta, N. Bruno

National Institute of Optics, National Research Council (CNR-INO), Firenze, Italy

The key to enabling communication between quantum devices lies in establishing efficient communication channels among these quantum devices even over a long distance, which involves the exchange of qubits encoded in light at telecom wavelengths through optical fibers. We are building a source of polarization entangled photon pairs tuned to atomic transitions in the telecom and infrared band, with the goal of interfacing them with trapped atoms.

45

Topological photon pumping in quantum optical systems

M. B. M. Svendsen [1], M. Cech [1], M. Schemmer* [2,3] and B. Olmos [1]

1 Institut für Theoretische Physik, Universität Tübingen, Tübingen, Germany;
2 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
3 European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy

I will present a theoretical proposal on how to transport atomic excitations in quantum optics systems, like Rydberg atoms in optical tweezers, using topological protection. In our recent work, we show how the concept of topological pumping can be extended to long-range coupling. There, the counter-intuitive topological transport scheme of an excitation across an a 1D emitter chain achieves 99.9% fidelity and protection against local disorder.

46

Light Manipulation for Future Quantum Applications

V. Vicuña-Hernández, S. Golkar, M. Parisi and S. Mosca

National Institute of Optics, National Research Council (CNR-INO), Pozzuoli, Italy

The light manipulation at the quantum level is a key tool for technological applications and fundamental physics exploration. We will present achievable goals in quantum optics, tailoring structured light with orbital angular momentum modes and developing innovative squeezed light in telecom spectral range. We will discuss how light manipulation can respond to current request to interface different parts of a network and overcoming ultimate limits in high sensitivity devices.

47

Nonlinear OAM Near-Mid Infrared Link

S. Golkar [1], V. Vicuña-Hernández [1], A. Marino [2],
B. Piccirillo [3,4], M. Parisi [1] and S. Mosca [1]

1 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy;
2 National Institute of Applied Sciences and Intelligent Systems National Research Council (CNR-ISASI) c/o Physics Department, University of Naples Federico II (UNINA), Naples, Italy;
3 Dipartimento di Fisica "Ettore Pancini", Università degli Studi di Napoli Federico II (UNINA); Naples, Italy;
4 National Institute of Nuclear Physics, (INFN), Complesso Universitario di Monte Sant'Angelo, Naples, Italy

We present an activity aiming to achieve a hybrid fiber-free-space multiplex optical link based on orbital angular momentum (OAM). The link will operate in two different wavelength ranges connected through a coherent conversion process. We will focus on the design and implementation of a stable nonlinear cavity to transfer OAM from NIR spectral range to MIR spectral range, preserving the quality of optical modes of OAM.

48 Strong Optomechanical coupling with OAM in cavities

V. Vicuña-Hernández [1] , M. Parisi [1] , A. Marino [2] , B. Piccirillo [3,4], A. Borrielli [5] , M. Bonaldi [6] and S. Mosca [1]

1 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy;
2 National Institute of Applied Sciences and Intelligent Systems, National Research Council (CNR-ISASI) c/o Physics Department, University of Naples Federico II (UNINA), Naples, Italy;
3 Dipartimento di Fisica "Ettore Pancini", Università degli Studi di Napoli Federico II (UNINA); Naples, Italy;
4 National Institute of Nuclear Physics, (INFN), Complesso Universitario di Monte Sant'Angelo, Naples, Italy
5 Institute of Materials for Electronics and Magnetism, Nationale Research Council (IMEM-CNR), Trento unit c/o Fondazione Bruno Kessler, Trento, Italy;
6 Fondazione Bruno Kessler, Trento, Italy

We present the study and experimental optomechanical coupling of light Orbital Angular Momentum and vibrational modes of a mechanical membrane, to realize transducers of linear and orbital angular momentum of light (Spin and OAM). We obtained a frequency splitting for the mechanical modes, demonstrating that two spatial optical modes couple differently with the lower and higher frequencies. The strong coupling will be carried out in the quantum regime with a cavity optical field and the membrane in the middle of it.

49 Quantum technology for Gravitational waves Detectors: SMART_Q_ET Project

S. Mosca [1] , A. Marino [2] , R. De Rosa [3] , M. De Laurentis [3] , F. Garufi [3] , V. Vicuña-Hernández [1] and M. Parisi [1]

1 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy;
2 National Institute of Applied Sciences and Intelligent Systems, National Research Council (CNR-ISASI), Naples, Italy;
3 Physics Department, University of Naples Federico II (UNINA), Naples, Italy.

Recently, Gravitational-Wave (GW) observatories have implemented optical schemes for the injection of squeezed vacuum states, further increasing the detections sensitivity.
Here, we present SMART_Q_ET project that aims to carry out efficient generation of squeezed states in a compact device fused silica based.
In view of the upcoming third-generation GW detector, Einstein Telescope, the development of cutting-edge nonlinear optical devices will open up new interesting perspectives in this field.

50 Quantum Correlated Twin Beams in Cascaded Quadratic Processes

S. Castrignano, P. Bosso, I. Ricciardi, P. Maddaloni, P. De Natale, S. Wabnitz, M. De Rosa

National Institute of Optics, National Research Council (CNR-INO), Naples, Italy

Squeezed light represent a key resource for quantum information protocols, for fundamental tests of quantum mechanics, and for pushing metrological limits. We report the observation of squeezing in the intensity difference of twin beams generated by cascaded quadratic processes in a single optical resonator: a primary process of second harmonic generation of the pump laser triggers an optical parametric oscillation, giving rise to two parametric modes around the pump frequency. A reduction of noise of -5.0 ± 1.3 dB below shot noise is achieved.

51 Circuit Quantum Electrodynamics with Semiconductor Quantum Dots

G. Rastelli

Pitaevskii Center on Bose-Einstein Condensation, National Institute of Optics, National Research Council Trento, Italy;
and Dipartimento di Fisica dell'Universitá di Trento (UNITN), Trento, Italy

Circuit quantum electrodynamics (cQED) with semiconductor quantum dots (QDs) coupled to microwave cavities enables studying light-matter interactions. A key aspect is the transfer of entanglement between electrons and photons. I present proposals for generating entangled photons using: [1] A double QD device operating as a single-electron splitter interferometer, and [2] a BCS superconductor-based Cooper pair splitter to generate frequency-entangled photons in microwave transmission lines.

Our proposal holds promise as a powerful resource for quantum technologies, enabling the on-demand generation of quantum entangled photons in the microwave domain.

Sensors, spectroscopy and communications

52 Development of a Cryogen-Free THz Wireless Communication Link based on Quantum Cascade Laser Technology

A. Sorgi [1,2], M. Meucci [1,2], M. A. Umair [1,2], F. Cappelli [1,2], G. Toci [1], P. De Natale [1,2], L. Viti [3], A. C. Ferrari [4], M. S. Vitiello [3], L. Consolino [1,2], J. Catani [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy;
3 NEST, Istituto Nanoscienze (CNR-IN) and Scuola Normale Superiore (SNS), Pisa, Italy;
4 Cambridge Graphene Centre, University of Cambridge, Cambridge , United Kingdom

Wireless networks are evolving to meet increasing demands for data rates up to Tbps and low latency (under 1 ms), essential for 6G applications. The THz band fulfills these requirements and is robust against atmospheric scattering1. We present a cryogen-free THz Wireless Communication link based on a 2.83 THz Quantum Cascade Laser and a room-temperature graphene-based FET receiver2, achieving a communication distance of 3 m, highlighting its potential for portable terrestrial and satellite use.

53 Performance investigation of cavity-enhanced photo-acoustic sensors

J. Pelini [1,2], S. Dello Russo [1,3], Z. Wang [4], I. Galli [1], P. Cancio Pastor [1], I. Lopez Garcia [1], M. Concetta Canino [5], A. Roncaglia [5], N. Akikusa [6], W. Ren [5], M. Siciliani De Cumis [1,3], and S. Borri [1], P. De Natale [1]

1 National Institute of Optics, National Research Council (CNR-INO), Naples, Italy;
2 Università degli Studi di Napoli Federico II (UNINA), Naples, Italy;
3 Agenzia Spaziale Italiana, (ASI), Matera, Italy;
4 Department of Mechanical and Automation Engineering, The Chinese University of Hong Kong, New Territories, Hong Kong SAR, China;
5 Istituto per la Microelettronica e Microsistemi, Consiglio Nazionale delle Ricerche (CNR-IMM), Bologna, Italy;
6 Hamamatsu Photonics K.K., Shizuoka, Japan

Our work proposes the development of an advanced trace-gas photo-acoustic sensor able to achieve the part-per-trillion level detection sensitivity. The system exploits a continuous-wave quantum cascade laser emitting in the mid-infrared as the excitation source, a Fabry-Perot optical cavity for power enhancement, a novel 7-kHz resonant “racket-shaped” cantilever as the transducer coupled with a custom-made acoustic resonator, and a balanced Michelson interferometer for the voltage readout.

54 The detection of the volatile phase emitted by TSWV virus infected tomatoes plants by means of a portable electronic nose

C. Pennacchio [2], N. Miotti [1], M. Turina [1], C. Baratto [2], G. Faglia [3], L. Pandolfi [2], M. Ciuffo [1], E. Gobbi [4], A. Ponzoni [2]

1 Institute for Plants Sustainable Protection, Narional Research Council (CNR-IPSP), Turin, Italy;
2 National Institute of Optics, National Research Council (CNR-INO), Brescia, Italy;
3 Information Engineering Department, University of Brescia (UNIBS), Brescia, Italy;
4 Molecular and Translational Medicine Department, University of Brescia (UNIBS), Brescia, Italy

The quasi real time and early detection of infected plants inside a greenhouse through a distributed network of sensors would be a great technological advancement. This would allow to drastically reduce the crop damage by removing the infected plants before the spread of infection. An electronic nose based on a single semiconductor gas sensor working with temperature modulation has been investigated as a potential instrument for tracking the volatile emissions by infected tomatoes plants.

55 Sensing plant pathogens via in-field Raman spectroscopy for precision agriculture

L. Pandolfi [1], G. Faglia [1], C. Pennacchio [1], A. Ponzoni [1], N. Miotti [2], M. Turina [2], M. Ciuffo [2], E. Gobbi [3] and C. Baratto [1]

1 National Institute of Optics, National Research Council (CNR-INO), Brescia, Italy;
2 Institute for Plants Sustainable Protection, Narional Research Council (CNR-IPSP), Turin, Italy;
3 Molecular and Translational Medicine Department, University of Brescia (UNIBS), Brescia, Italy

Raman spectroscopy is a non-invasive technique that can be adopted for the in-field monitoring of crops and early detection of plant pathogens. Combining its sensing capabilities with chemometric analysis, it is possible to classify plants as healthy or infected by evaluating the leaf pigment content. The method is currently under investigation to characterize both abiotic stresses and biotic infections at the lab scale, while conducting in situ inspections of grapevines from a local vineyard.

56 Characterization of magnetic nanoparticles in polymeric matrices

F. Dinelli [1,2], M. Modestino [2], A. Galluzzi [2,3], T. Posati [4], M. Seri [5], R. Zamboni [4,6], G. Sotgiu [4,6], F. Corticelli [7], and M. Polichetti [2,3]

1 National Institute of Optics, National Research Council (CNR-INO), Pisa, Italy;
2 Dipartimento di Fisica, Università di Salerno (UNISA), Salerno, Italy;
3 Istituto Superconduttori, Materiali Innovativi e Dispositivi, National Research Council (CNR-SPIN), Salerno, Italy;
4 Istituto per la Sintesi Organica e la Fotoreattività, National research Council (CNR-ISOF), Bologna, Italy;
5 Istituto per lo Studio dei Materiali Nanostrutturati, National Reseacrh Council (CNR-ISMN), Bologna, Italy;
6 Kerline srl, Bologna, Italy;
7 Istituto per la Microelettronica e Microsistemi, National Research Council (CNR-IMM), Bologna, BO, Italy

Magnetic nanoparticles (MNP) are interesting for several applications. Although they have been characterized by many techniques, it is not yet possible to finely define their size distribution and local magnetic properties. We present a study of MNP embedded in polymeric matrices and shaped in thin films by spin coating. The analysis has been conducted using a set of techniques, namely AFM, Environmental-SEM, PPMS-Vibrating Sample Magnetometer, and spatially resolved Magneto-Optic Kerr Effect.

57 A new application of Saturated-absorption CAvity Ring-down (SCAR) laser spectroscopy to evaluate the inhibition of the G6PD enzyme by 14C-radiolabeling

L. Varricchio [1,2], S. Bartalini [1], P.Cancio [1], I. Galli [1], D. Mazzotti [1], P. De Natale [1], S. Rapposelli [2], A. Morandi [3]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 University of Pisa, Department of Pharmacy (UNIPI), Pisa, Italy;
3 Department of biomedical sciences, University of Florence (UNIFI), Florence, Italy

SCAR is an innovative laser spectroscopy technique we invented in 2010 aiming at obtaining very precise radiocarbon measurements. We developed a bioanalytical methodology in which a C14-SCAR analyzer is used to quantify 14CO2 produced by cells treated with 14C-radiolabeled glucose. The ultimate goal is to study pharmacologically relevant molecules capable of altering glucose metabolism, such as inhibitors of the G6PD enzyme, hypothesized to be a possible target of cancer treatment.

58 FORUM a new satellite to understand how Earth is losing its cool

C. Belotti, M. Barucci, G. Bianchini, F. D'Amato, G. Di Natale, M. Ridolfi, S. Viciani, and L. Palchetti

National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino e Firenze, Italy

The properties of the energy emitted from the Earth to space are essential for the study of global warming and climate change. The FORUM (Far-infrared Outgoing Radiation Understanding and Monitoring) satellite mission was proposed by INO to the European Space Agency and will be launched in 2027 to measure the Earth's outgoing radiation in the far-infrared, a part of the spectrum never systematically observed from space before. We will describe INO active support to the mission.

59 Atmospheric science at CNR-INO

G. Di Natale, M. Barucci, C. Belotti, G. Bianchini, F. D'Amato, S. Menci, A. Montori, L. Palchetti, M. Ridolfi, and S. Viciani

National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino and Florence, Italy

The INO activity to investigate the global climate involves:
- the development of sensors for measuring the Earth or the Atmosphere emitted radiation and the concentration of gases in the atmosphere. These sensors are employed during campaigns on ground and onboard stratospheric aircraft and balloons or operate continuously in Antarctica
- development and implementation of inversion algorithms for the retrieval of atmospheric composition and surface parameters (temperature, emissivity) from remote sensing spectral radiance measurements

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Applied spectroscopy: a tool for (molecular) detection

F. D'Amato

National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy

The INO activity to investigate the global climate involves:

- the development of sensors for measuring the Earth or the Atmosphere emitted radiation and the concentration of gases in the atmosphere. These sensors are employed during campaigns on ground and onboard stratospheric aircraft and balloons or operate continuously in Antarctica
- development and implementation of inversion algorithms for the retrieval of atmospheric composition and surface parameters (temperature, emissivity) from remote sensing spectral radiance measurements

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Fluorescent Optical Antennas based on LSC for Hybrid Visible Light Communication (VLC) and Energy Harvesting

M. Meucci [1,2], M. Aresti [1], M. Ali Umair [1], J. Catani [1,2]

1 National Institute of Optics, National Research Council (CNR-INO), Sesto Fiorentino, Italy;
2 European Laboratory for Non-Linear Spectroscopy, University of Florence, (LENS), Sesto Fiorentino, Italy

We will report on the recent realization and test of novel fluorescent Optical Antennas (OAs) based on Luminescent Solar Concentrators (LSC) for white-light Visible Light Communication (VLC) [1], also known as LiFi, using ordinary white LEDs. We will also present the first PoC of a novel photovoltaic window enabled for simultaneous conversion of solar energy and VLC data conversion [2]. This is a key step towards the realization of hybrid devices for integration in zero-energy smart buildings.

62 Optical fiber based hydrophones within the SEAmPhonia project

F. Nobile, D. D'Ambrosio, S. Avino, P. Malara, G. Gagliardi, A. Giorgini

National Institute of Optics, National Research Council (CNR-INO), Naples, Italy

The marine environment constitutes a complex system on the physical, chemical and biological point of view. The SEAmPhonia project is focused on the study of this environment in term acoustical noise. Acoustical sensors are the fundamental element in this approach. A new generation of low cost Fiber Bragg Grating based optical hydrophone is under development. They are conceived for recover the spatial distribution of the noise pattern under the sea by means of the installation of a sensor network.

63 Multiple cascaded stimulated Brillouin scattering in a fiber-optic ring resonator

R. R. Sahoo, M. Capezzuto, D. D'Ambrosio, P. Malara, S. Avino, G. Gagliardi

National Institute of Optics, National Research Council (CNR-INO), Naples, Italy

We investigate stimulated Brillouin scattering (SBS) in a fiber-optic resonator. Locking the pump laser to the resonance, new optical components are observed due to resonant SBS. Several cascaded Stokes beams satisfy the resonance condition and phase matching, so that a first sideband is scattered backwards from the pump while subsequent components propagate opposite to the previous ones. Their beat note (≈11GHz) is a candidate for realizing a gyroscope where common-mode noise is rejected. Interestingly the system is an ideal analogy of spin-½ dynamics analysed with Berry's phase.

64 Noise Reduction and Performance Characterization of a High-Sensitivity Fiber-Optic Sagnac Gyroscope

F. D'Apice [1], R. Zahoor [1], M. Capezzuto [1,2], F. Sgobba [1,3], D. D'Ambrosio [1],
G. Gagliardi [1], L. Santamaria Amato [3] and S. Avino [1]

1 National Institute of Optics, National ResearchCouncil (CNR-INO), Naples, Italy;
2 Università degli Studi di Napoli Federico II (UNINA), Naples, Italy;
3 Agenzia Spaziale Italiana, (ASI), Matera, Italy

In this work we studied the performance of a gyroscope based on a fiber-optic Sagnac interferometer. We implemented advanced noise reduction techniques, focusing on the differential output analysis of both interferometer arms. We improved the signal to noise ratio, by manipulating the phase relationship between the two signals. An analysis of the noise sources provided a complete characterization of performance, highlighting its potential for high-precision rotational sensing applications.

65 A second-generation buffer-gas-cooling (BGC) molecular machine for spectroscopic tests of fundamental Physics

R. Aiello, M.G. Delli Santi, and P. Maddaloni

National Institute of Optics, National Research Council (CNR-INO), Naples, Italy

We report on the ongoing construction of a novel BGC source, based on a vacuum chamber with improved thermomechanical stability and a pulse-tube cryocooler in ultralow vibration mode [1]. Such an apparatus will be used in combination with the saturated-absorption cavity ring-down (SCAR) technique for placing new bounds on putative fifth forces beyond the Standard Model, by accomplishing sub-kHz-accuracy line-center frequency determinations for selected hydrogen deuteride (HD) ro-vibrational transitions in the (1,0) band at 2.7-mm wavelength [2].

Keywords

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3D laser-structuring
3D survey instruments
All-optical stroke model
Art material analysis
Autofluorescence lifetime imaging
Biocompatible scaffolds
Bose-Bose mixture
Brain state modulation
Buffer-gas-cooling molecular machine
Cavity-enhanced photo-acoustic sensors
Cellular proteins
Ceramics from regoliths
Circuit Quantum Electrodynamics
Cortical network
Cryogen-Free THz Wireless Communication
Cultural Heritage Diagnostics
Differential Mach-Zehnder interferometry
Dipolar quantum gas machine
Direct diode pumped amplifiers
Distributed quantum sensing
Doppler thermometry
Drug release
Dy BEC
Dynamical formation
Early-stage disease diagnosis
Energy Harvesting
Entangled photon pairs
Entanglement manipulation
False vacuum decay
Fiber-optic ring resonator
Fluorescent Optical Antennas
FORUM satellite
G6PD enzyme inhibition
Gastrointestinal tumors
Global climate
Gold-based plasmonic nanocomposites
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In-field Raman spectroscopy
In-vitro fluorescence analysis
Larval zebrafish brain
Laser fusion
Laser-driven Very High Energy Electrons (VHEE)
Levitated quantum optomechanics
Light Manipulation
Light-Sheet Fluorescence Microscopy
Magnetic nanoparticles
Magnetic quantum imaging
Magneto optical trap
Mid-infrared cascade lasers
Middle cerebral artery occlusion
Nanoparticles dynamics
Neuronal populations
NIF Ignition
Nitrogen-Vacancy centers
Non-Invasive Artwork Analysis
Non-invasive optical analysis
Non-linear all-optical dissection
Nonlinear OAM
Optical detection
Optical fiber hydrophones
Optical repulsive potential
Optomechanical coupling
Organic molecules

Plant pathogens
Portable electronic nose
Precision agriculture
Quantum Correlated Twin Beams
Quantum droplets
Quantum gases
Quantum networks
Quantum optics
Quantum spin mixture
Quantum superfluids
Quantum technologies
Quantum thermodynamics
Radiobiological applications
Recanalization
Rydberg Doppler broadening spectroscopy
Saturated-absorption CAvity Ring-down laser spectroscopy
SEAmPhonia project
Sensing and delivery
SERS-sensors
Shapiro steps
Silicon-Vacancy centers
Single molecule imaging
Solar absorbers
Solid state spins
Spectral radiance simulations
Stimulated Brillouin scattering
Stratospheric aircraft
Strongly-interacting Fermi gases
Supersolid
THz Time-Domain imaging
Topological photon pumping
Ultra-cold atoms
Ultracold LiCr
UV-LED system
Visual acuity evaluation
VLC
Volumetric super-resolution
Zirconium oxide

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