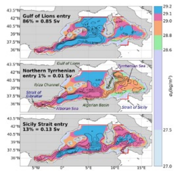
DEPARTMENT OF PHYSICS AND ASTRONOMY "AUGUSTO RIGHI"

Open Physics Hub

ADVANCED SENSING LABORATORY



HIGH PERFORMANCE COMPUTING CLUSTER

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

OPH NEWSLETTER

FOCUS. Exploring the Mediterranean Sea: dynamical downscaling, Lagrangian analysis and hazard mapping

The complex geometry of the Mediterranean Sea leads to a peculiar circulation of different water masses throughout the basin, and the resulting dynamical structures influence the development of both routine and exceptional events over the sea. The Oceanography research group is actively involved in several projects aimed at understanding the basin's circulation and using this knowledge to improve risk assessment and hazard mapping. In the following, some of these research lines are described.

Ocean dynamical downscaling

Ocean circulation occurs over a wide range of scales. From thousands of kilometers, the "planetary" scale related to the ocean general circulation, to the "microscale" ranging from less than a kilometer up to the millimeters. Kinetic energy is continuously transferred from large to small scales where it is dissipated as heat. The main actors in this energy cascade are "mesoscale" eddies and "sub-mesoscale" flows, on scales of hundreds and a few kilometers, respectively.

Usually, ocean global models exploit a coarse grid covering the world ocean, capable to reproduce planetary and meso-scales. On the other hand, resolving sub-mesoscales using a world-wide fine resolution grid, would not be sustainable in terms of computational effort. However, resolving smaller scales is key towards a complete understanding of ocean dynamics, therefore in the last years the dynamical downscaling approach has been developed. It consists in generating local, high-resolution, nested "child" models based on large-scale information from a global "parent" mo-

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del. Fields from the parent model are interpolated (Fig. 1) and provided to the child as initial and boundary conditions, allowing to keep reasonable, yet still significant, computational cost.

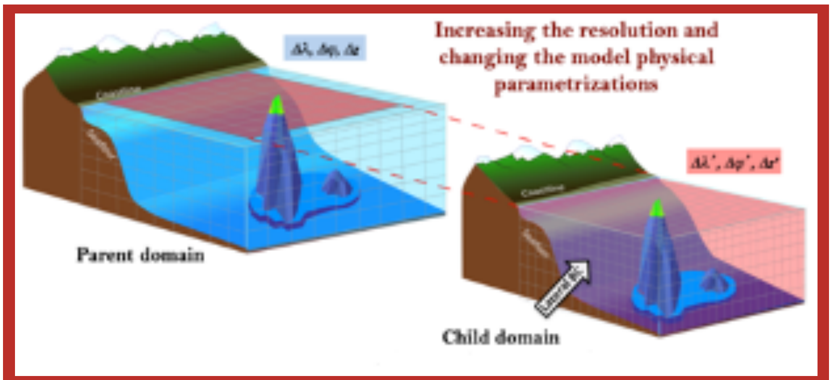

Figure 1. Scheme of dynamical downscaling approach.

At DIFA, the "Structured and Unstructured grid Relocatable ocean platform for Forecasting" (SURF), is used to carry out dynamical downscaling simulations. This is running on the OPH cluster "Matrix", which allows SURF to exploit parallel computing much more efficiently than common personal computers, offering significant benefits in terms of computing resources and storage capabilities.

Estimate of the Mediterranean outflow's origin

Lagrangian analysis is a powerful way to evaluate pathways of water masses at both global and regional scale. It employs a large set of virtual parcels of zero spatial extent whose trajectories are determined by the Eulerian velocity field. Statistics of the trajectories then define parcel pathways and their associated time scales.

We apply this method to the Western Mediterranean Sea to offer a complementary approach to estimating the fractional composition of the Mediterranean Outflow exiting the Gibraltar Strait at depth. The origin of the Outflow has been traced by advecting millions of parcels backward in time from the Strait of Gibraltar to the areas where deep and intermediate waters form: the Gulf of Lions, the Tyrrhenian Sea, and the Strait of Sicily. The velocity advecting parcels is an estimate combining observations with an ocean circulation model that conserves mass, momentum, temperature, and salinity.

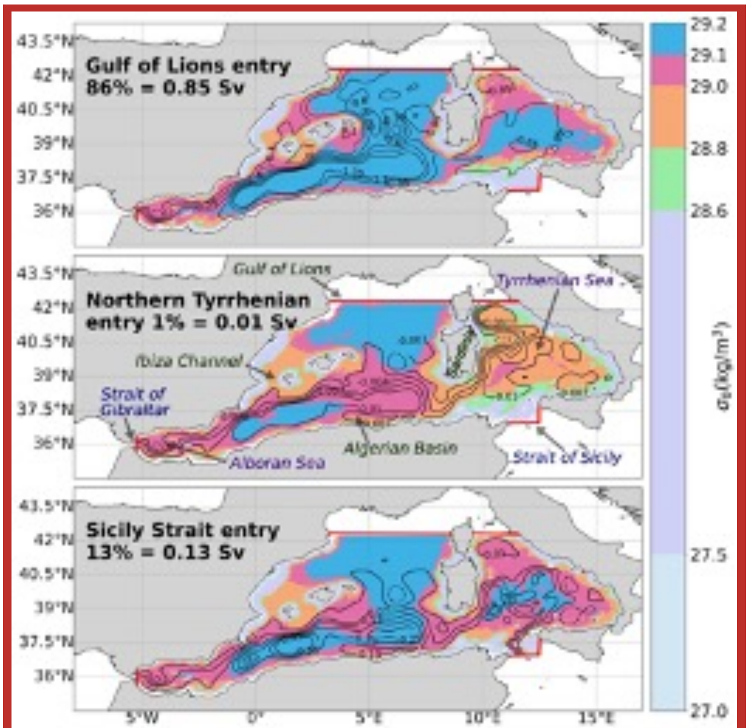

Figure 2. Lagrangian streamlines quantifying volume transport pathways in the Mediterranean outflow: (top) 86% of the parcels originate from the Gulf of Lions, (middle) 1% is associated to Northern Tyrrhenian Sea, (bottom) 13% originates from the Strait of Sicily. In the background, color shading shows transport-weighted ensemble-average potential density.

Three-dimensional trajectories are calculated using the offline tracking software "Ariane" on the OPH cluster. One drawback is that the software cannot be run in parallel, thus failing to benefit from the cluster computing power. As an exercise, we forced parallelization of the software by running it several times

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on the same node using different CPUs. In this way, detailed trajectories of hundreds of parcels were obtained, and further questions can be addressed in the future

Reference: Vecchioni, G., Cessi, P., Pinardi, N., Rousselet, L., Trotta, F. (2023). *A Lagrangian estimate of the Mediterranean outflow's origin*. Geophysical Research Letters, 50, e2023GL103699. https://doi.org/10.1029/2023GL103699.

Hazard Mapping of the Mediterranean Sea

Risk assessment is a critical procedure in many scientific fields, including hazard identification and risk analysis: the first action consists in identifying and characterizing the hazards; the second one tends to comprehend the nature of the hazards and to estimate the level of the risk. In Oceanography, risk assessment represents an open field of research with the scope to limit and reduce the impact as of routinary and of exceptional events. Hazard mapping in the Mediterranean Sea is therefore essential since the basin is prone to various natural and human-induced hazards, including earthquakes, tsunamis, volcanic activity, coastal erosion, pollution, and biodiversity threats.

Within this framework, our research work focuses on human-related activities and on oil slicks forecast, distribution and evolution. The goal is to provide two different products to the oceanographic community: the first one consists of an average of the forecasted evolution of the slicks starting from hypothetical but meaningful release points; the second one is an index describing the level of vulnerability of the coast to oil releases for the whole Mediterranean Sea (Fig. 3). To achieve that, we employ, upgrade and maintain a Lagrangian oil slick numerical model named "Medslik-II". To perform the hazard mapping, the model is employed in ensemble simulations, where many different release points are considered with fixed suitable parameters configuration, e.g., the mean of the trajectories and the probability distribution of the amount of the oil impacting the coastal segments.

In addition to a large ensemble dimension, memory resources are also crucial: technically, our work is focused on setting up the system for the single simulation, optimizing and parallelizing it to reduce the execution time, decreasing the memory occupation with specific data format and/or optimizing the management of the stored data.

By employing these technologies and approaches, hazard mapping in the Mediterranean Sea aims to reduce risks, enhance safety, and promote sustainable use of marine resources. Our research work is funded by the European Digital Twin Ocean (EDITO) project whose aim is to build a European Community "Digital Twin of the Ocean".

Figure 3. ***(A)*** *in red, the sampling release points;* ***(B)*** *in light green, the sampling belt (10 to 50 km from the coast, 10 km sampling rate) together with a mean trajectory of the spill (red pin-point);* ***(C)*** *hazard mapping of the Med. Sea: different colors denote the different hazard levels for each coast segment.*

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Teaching and outreach

The 6th edition of the DIFA International Summer School on Physical Sensing and Processing

From 8 to 12 July 2024, the the Department of Physics and Astronomy has hosted the **sixth edition of the Summer School on Physical Sensing and Processing – “Physics for a better planet”** focused on interdisciplinary applications of Physics impacting our society like Biomedicine, Climate, Material science, Artificial Intelligence, Geophysics and management of EU policies https://site.unibo.it/school-physical-sensing-and-processing/en.

Invited talks have been provided by National and International speakers such as Pietro Lió (Cambridge University UK), Fabio Monforti (Joint Research Center EU), Guido Sanguinetti and Angelo Rosa (SISSA Trieste) and Matteo Della Porta (HUMANITAS Milano).

The school, conceived for Master's and Ph.D students, had XXX participants. The program was articulated (from Tuesday to Thursday) in frontal lectures in the morning (3 lectures per day, 1 hour each) and computational laboratories in the afternoon (2 laboratories per day, 2 hours each) related to the lecture topics. Monday and Friday were dedicated to invited speakers, including a question time to discuss on the proposed interventions. Students had the possibility to get informed on state-of-the-art research topics from the researchers involved, and to get a taste of how research is performed by hands-on laboratories presenting some of the commonly used procedures and tools.

The School aimed to help Physics students to become more aware of the active role they can have in improving our society, by increasing knowledge and providing useful support in many research areas with a direct impact on every-day life.

The School was funded by the Physics and Astronomy Department funds and the ERA-HDHL SYSTEMIC European project n. 696295, aiming to the analysis of challenges for human society (particularly food production and consumption) related to climate change.

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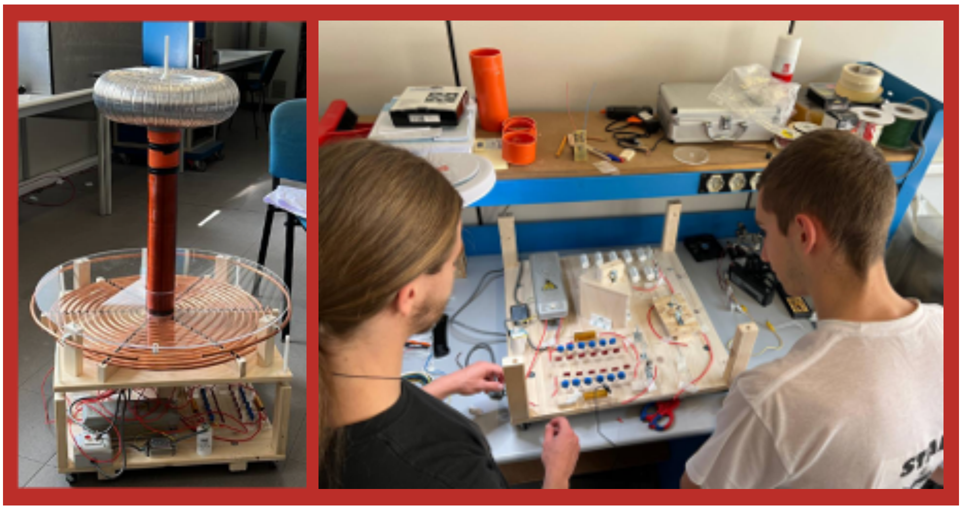
Advanced sensing laboratory

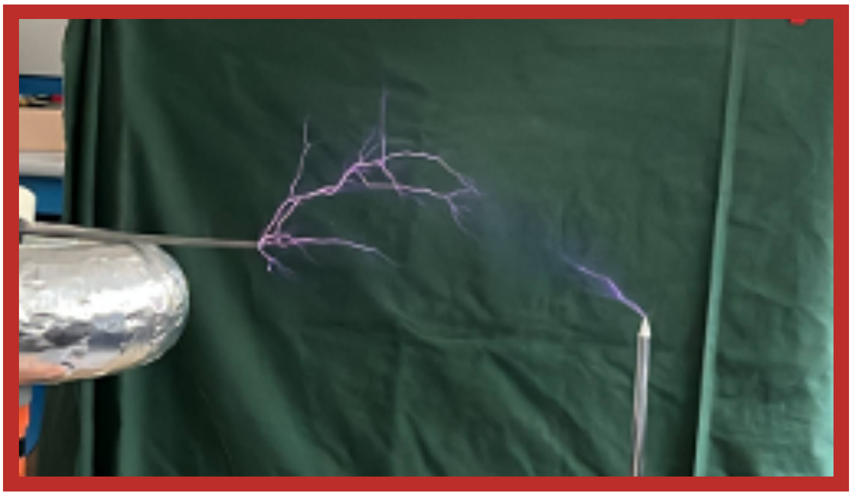
Sparky, the lightning machine in Bologna

Few things inspire wonder for science as much as lightnings, embodiment of the electromagnetic force ! And what about the thrill of recreating it in lab through a legendary machine created at the end of the nineteenth century by the renowned Serbian-Croatian scientist Nikola Tesla!? This instrument exists and is called the Tesla Coil. Capable of generating electric discharges of over a million volts and alternating currents of gigahertz frequencies, it helped its inventor in the study and development of the first concepts of alternating current. Recently, it has perhaps become more famous in pop culture for its spectacular ability to reproduce music at the rhythm of the generated electrical sparks.



Charmed by this fascinating machine, two brilliant students from our Physics degree course, Simone Naglieri and Martino Garelli, decided to study this device in depth for their bachelor thesis, investigating the theory behind its operation and discovering the necessary details for its construction. It might seem like a simple exercise of electromagnetism, but it hides numerous theoretical and technical details that go far beyond the topics covered al lessons, such as the behaviour of currents at very high frequencies and inductive damping cycles (and how to avoid them).

However, Martino and Simone did not stop at theoretical study: they succeeded in building a working model of the Tesla Coil, obtaining funding thanks to the interest and generosity of the company RENCO Srl in Pesaro and they assembled all the pieces with the support of the OPH laboratory. Thus, after a long process of testing and optimisation, Sparky came to life, the largest amateur-built Tesla Coil in Italy, capable of generating “lightning” approximately 40 cm long!



This work is particularly noteworthy as it represents one of the rare practical implementations of experiments carried out by students during their bachelor thesis, this a fundamental characteristic of an experimental physicist who investigates nature through observation and validation.

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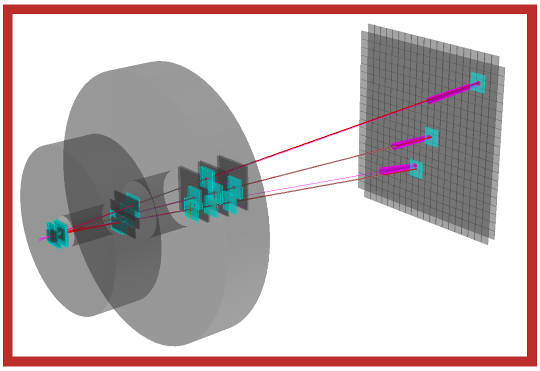
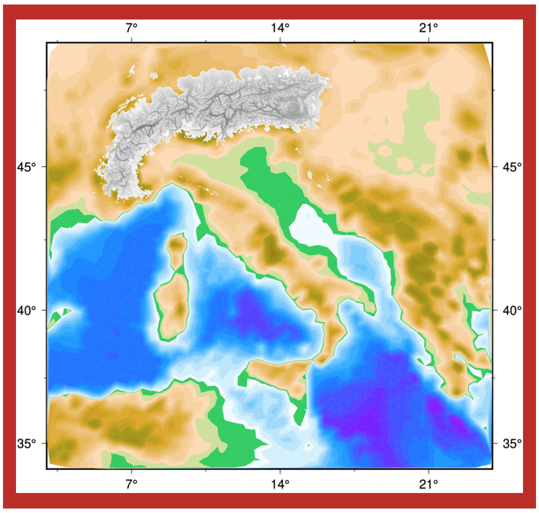
OPH Ph.D. students - 36th Cycle

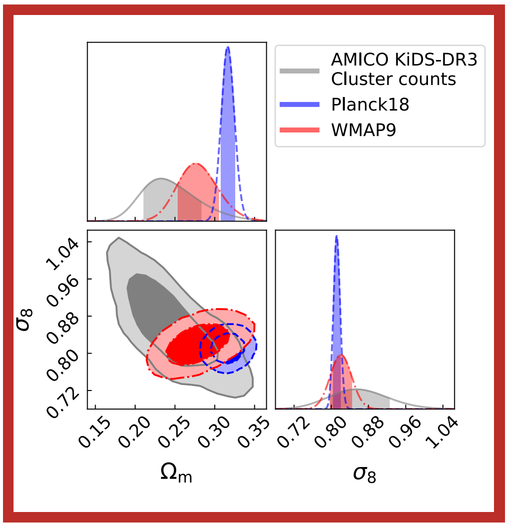
The Ph.D. students enrolled during the second year of OPH activity (A.Y. 2020/2021, XXXVI Cycle) are going to discuss their thesis. Hereafter the short reports describing their research.



Roberto Zarrella worked in the FOOT project, an applied nuclear physics experiment aiming at the characterization of nuclear fragmentation reactions of interest for hadrontherapy and radiation protection. His research focused on the momentum measurement through particle track reconstruction in the magnetic spectrometer of FOOT and on the global analysis of data. In his PhD thesis work, he performed the first complete closure test on Monte Carlo simulated data, establishing a solid and reliable workflow for the calculation of nuclear fragmentation cross sections. The development and testing of the track reconstruction and analysis software used in this research has been carried out exploiting the Data Analysis Cluster of OPH.

Fernando Linsalata carried out his research in the fields of Geophysics and Geodynamics. He worked on the Glacial Isostatic Adjustments (GIA), the global, long-term process arising from interaction between the cryosphere, the solid Earth and the oceans in response to the melting of continental ice sheets. In the first part of his thesis, also in collaboration with Daniele Melini (INGV Rome), through high-resolution numerical simulations, he found that GIA is responsible for a complex pattern of geodetic signals across the Mediterranean region and the results indicates that needs to be considered for a correct interpretation of the observed geodetic variations. The numerical simulations were performed using the Data Analysis Cluster "BladeRunner" of OPH.





During his PhD in Astrophysics, **Giorgio F. Lesci** carried out several research projects in the field of observational cosmology, with a focus on the role of galaxy clusters. These cosmic objects are fundamental tools for the understanding of our Universe, providing information on the content of dark matter and on the nature of dark energy. In his thesis, Giorgio presented cosmological analyses based on galaxy cluster statistics, also introducing methods for deriving cluster masses from weak-lensing measurements and for the calibration of galaxy colour-redshift relations. Giorgio's research, based on the data collected by state-of-the-art telescopes, has benefited from the high-performance OPH cluster “Blade/Matrix”, which is indispensable for performing Markov chain Monte Carlo analyses.

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Publications related to OPH

SPEEDY-NEMO: performance and applications of a fully-coupled intermediate-complexity climate model

The study documents a fully-coupled general circulation model of intermediate complexity and presents an overview of the model climatology and variability, with particular attention to the phenomenology of processes that are relevant for the predictability of the climate system on seasonal-to-decadal time-scales. It is shown that the model can simulate realistically the general circulation of the atmosphere and the ocean and the major modes of climate variability on the examined time-scales. We discuss potential applications of the model, with emphasis on the possibility of generating sets of low-cost large-ensemble retrospective forecasts. Figure 1 shows an example of geophysical fields simulated by the model and compared with observational datasets. One is the sea-ice cover in the Arctic, which is typically challenging for this family of climate models and is here reproduced with a great level of detail. The other is the zonal mean precipitation, where we can see that the model lies broadly within the range of observational uncertainty. Downstream applications of the model are currently ongoing in national funded projects. The model is maintained and developed by the Atmospheric Physics Group of our department, by the Abdus Salam International Centre for Theoretical Physics and by the Meteorology group of the University of Barcelona. The set of simulations supporting the study were performed on the Cluster maintained by the Open Physics Hub.

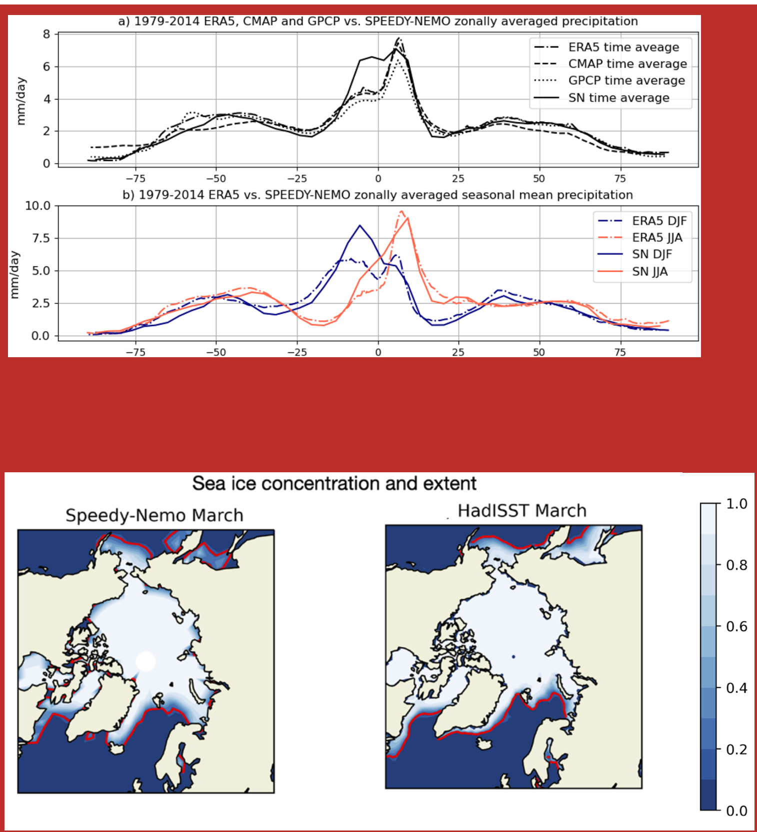

Figure 1 : Top) Climatology of zonal mean annual mean precipitation in units of mm day−1 in the SPEEDY-NEMO model (solid line), the ERA5 reanalysis (dashed-dotted line), the CMAP (dashed line) and GPCP (dotted line) gridded observations. b Climatology of zonal mean total precipitation in units mm day−1 in DJF (blue lines) and JJA (red lines) for the SPEEDY-NEMO model (solid lines) and the ERA5 reanalysis (dashed-dotted lines). Bottom) Climatology of March sea ice concentration (shading) and extent (red contour) for the Speedy-Nemo model and HadISST observational dataset in the Northern Hemisphere.

Reference

Ruggieri, P. et al. (2024) *SPEEDY-NEMO: performance and applications of a fully-coupled intermediate-complexity climate model.* Climate Dynamics: 1-19.

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Publications related to OPH

Can a capacitively coupled electrostatic field affect cell migration in-vitro?

The cellular motility is an essential process that underline and guarantee throughout life-span the architecture of multicellular organisms. Migrating cells can move either individually or collectively by a crawling movement which interconnects the cytoskeletal activity to the adhesion surface via generated traction forces at the extracellular matrix interface. The onset of a static potential of about 35 V between the externally placed positive and ground electrodes generated two different electric fields (E-Fields), which using a numerical dosimetry analyses based on a cell modelled as a semi-spherical non-conducting shell separating two conducting regions and in direct contact with a flat dielectric substrate, are identified as: i) a strong capacitive coupled (C-Coupled) E-field generated across dielectric substrates with a uniform intensity distribution of about 10^3 V/m; ii) a small continuous ionic current at the culture medium level due to a residual charge density fluxing through non-null conductivity of the humid air, having a spatial and material-dependent distribution ranging from 0.02 up to 0.12 V/m. Both the scratch assay and the free-to-move cell tracking, performed on a glioma cells line to test the effects of these electrical stimulations on cell's migration resulted on the clear evidence that the cells motility is boosted in those population crawling on polystyrene surfaces. Our results do not support the hypothesis of a directionality effect, nevertheless data indicates a slight cell motility increase in corresponding to the position of the cells near the Positive electrode, perfectly matching the spatial distribution of divergence gradients described by microdosimetry model. This work demonstrated that a C-Coupled system exposed to a direct current (DC) stimulus can generate forces capable of impacting cell behavior if dielectric materials such as polystyrene are present on which the cells are interfaced.

Reference

Zironi I. et al. (2024). Scientific Reports (accepted with request for revision)

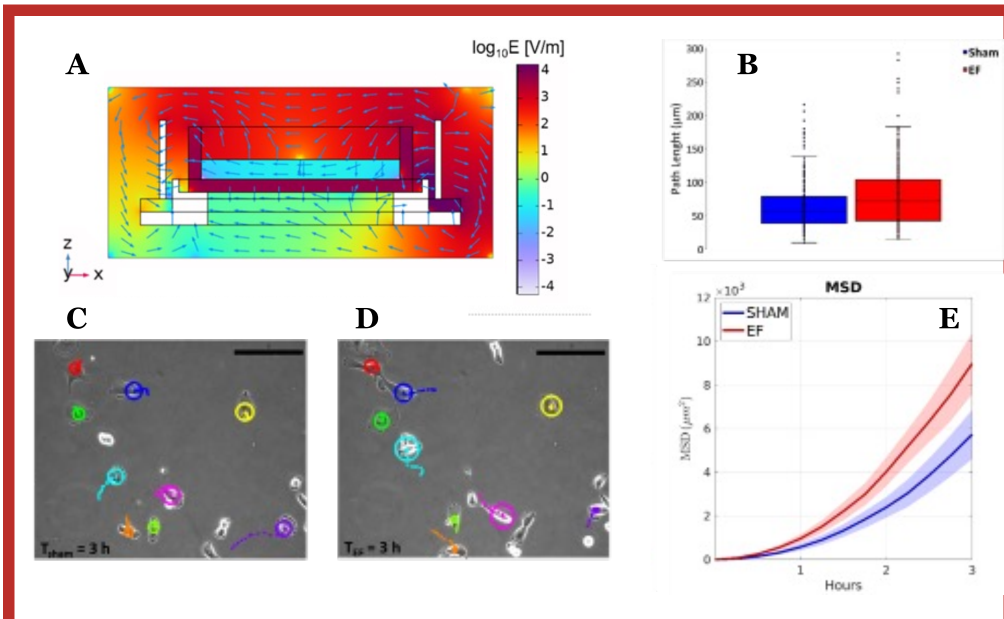

***Figure 1**. **A**) E-field distribution on the xz-cutplane passing through the center of the polystyrene Petri dishes sample holder. The E-field lines on the selected plane are reported as light blue arrows. Example of two visual fields acquired in phase contrast at 20× of magnification after 3 hours of SHAM conditions (T_{SHAM} = 3 h) (**B**) and after 3 hours of E-field exposure (T_{EF} = 6 h) (**C**) Sample cells and the relative tracked pathways are visualized by different colors. Scale bar is 100 mm. **D**) Box Plot analysis of the Path Length (mm) performed by each cell (n = 280) monitored during T_{SHAM} (Blue) and T_{EF} (Red). The non-parametric Kruskal-Wallis statistical test indicated a Chi-square distribution with 1 degree of freedom H = 42.346 that give a corresponding P < 0.00001. **E**) Mean Square Displacement (MSD; mm^2) performed by the cells population during T_{SHAM} (Blue) and T_{EF} (Red) and the relative interval of confidences (shadow areas).*

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Useful links

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OPH Newsletter: previous issues

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