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Supervisor Expression of Interest
MSCA - Marie Sklodowska Curie Action - (PF) Postdoctoral Fellowship 2024

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Department Name: Fisica (DFIS)

Research topic: Nonlinear optics and Nanophotonics

MSCA-PF Research Area Panels:

- ☐ ECO_Economic Sciences
- ☐ ENG_Information Science and Engineering
- ☐ ENV_Environmental and Geosciences
- ☐ LIF_Life Sciences
- ☐ MAT_Mathematics
- X PHY_Physics
- ☐ SOC_Social Sciences and Humanities
- ☐ CHE_Chemistry

Brief description of the Department and Research Group (including URL if applicable):
The Department of Physics focuses its scientific research in the field of Physics of Matter and Applied Physics, combining research and innovation, for the development of internationally advanced instrumentation and technologies with high social impact. It collaborates with national and international centers of excellence, including large Research Infrastructures. It is built on 5 research lines dedicated to different branches of Physics. The supra Nano-Optics Milan (sNOm) Lab, coordinated by Prof. Michele Celebrano, belongs to line 5: electronic, optical and magnetic properties of low-dimensional systems. The sNOm Lab is devoted to the investigation of light-matter interaction at the nanoscale when ultrashort and high-intensity pulses are employed. The team is currently composed of 4 PhD students, among which 1 PhD funded by through CSC and a shared PhD with the University of Troyes, 1 Assistant Professor (RTDA), 2 Associate Professors and 1 Full Professor. We investigated nonlinear optical properties in low dimensional systems such as nanostructures, metasurfaces and 2D materials for applications to sensing and optical signal processing.

TITLE of the project: Enhanced nonlinear optics in 2D hybrid systems based on transition metal dichalcogenides coupled to nanostructures.

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Brief project description:

The integration of transition metal dichalcogenides (TMDs) with nanostructures recently emerged in materials science and promptly fostered extensive investigations thanks to the vast realm of innovative applications associated. TMDs possess unique electronic, optical, and mechanical properties that make them attractive candidates for diverse applications. Molybdenum disulfide (MoS_2), and in particular its specific 3R configuration, recently attracted immediate attention thanks to the intrinsic broken symmetry of the material. This peculiar feature is associated with marked nonlinear optical properties, such as a record second order nonlinear susceptibility that can reach values above 1 nm/V in specific wavelength range.

The last decades witnessed major efforts in field of nanophotonics to attain efficient nonlinear optical effects in nanoscale volumes. This endeavor is driven by the utmost prospect to perform light conversion in extremely compact and integrated devices for optical information processing, sensing and nonlinear digital holography. The main limitation in this scenario is the perturbative character of nonlinear interactions, whose intrinsic weakness is compounded in nanoscale systems. Standalone single layers of MoS_2-3R were already demonstrated to promote strong nonlinear optical processes while multi-layered systems based MoS_2-3R were shown to be even more efficient than commonly employed nonlinear crystals in their bulk form. Another approach investigated in parallel to overcome the fundamental limits posed by the drop in efficiency of nonlinear processes associated dramatic decrease of matter is to boost light–matter interaction by leveraging the localized field enhancements associated with optical resonances in engineered nanoantennas and metasurfaces.

The aim of this project in a nutshell is to combine the strongly localized fields associated with optical resonances in nanostructures and metasurfaces with the strong nonlinear susceptibility of MoS_2-3R. The investigation and applications of hybrid systems based on TMDs and nanostructures represent a burgeoning field with significant potential for technological advancement. We believe the proposed hybrid systems will open new possibilities in nonlinear nanophotonics and we already predict a significant impact in fields such as optical sensing, optical information processing as well as quantum optics. In particular, regarding the latter field, one of the main tasks of the project will be the enhancement in the generation of entangled photons by these hybrid systems via spontaneous parametric down-conversion (SPDC), which is a second order parametric process that strongly benefit from the high nonlinear susceptibility of MoS_2-3R. While we plan to investigate a palette of novel hybrid architectures based on nanostructures combined with this specific TMD, the project is also thought to be a unique opportunity to explore hybrid systems based on other novel TMD systems displaying even more promising features.