Fellow	Giacomo Sorelli
Host Organisation	Fraunhofer IOSB
Scientific coordinator	Szymon Gładysz

I – SCIENTIFIC ACTIVITY DURING YOUR FELLOWSHIP

My scientific activity during the fellowship focused on two distinct research directions: 1) the development of quantum-inspired super-resolution methods, 2) space-division multiplexing for telecommunications through free-space channels. What connects the two research lines is the use of optical-mode decompositions as a tool for extracting information more efficiently. A short description of the results achieved along these two research lines in the past two years is presented in the following.

1) The goal of this research line is to use mathematical tools from quantum information theory to identify optical-mode decompositions that allow to resolve point sources below the diffraction limit. I started this research line during my post-doc at Sorbonne University, in Paris. During the past two years, I maintained the collaboration with Sorbonne active and investigated the role of optical coherence (references 4 and 10 below) and that of optical imperfections (references 5 and 9) below. Moreover, I have developed a general quantum theory for the estimation of parameters encoded into the shape of optical modes (reference 3). Finally, I provided theoretical assistance in analysing the data in an experiment where we estimated the separation between two incoherent sources with a sensitivity 5 order of magnitudes below the diffraction limit (references 6 and 12). Even though these works have been conducted independently from the host institution, their results are extremely valuable for Fraunhofer IOSB. Moreover, the collaboration with the University of Gdansk that lead to publications 5 and 9 was strengthened by a tour of various Polish Universities that my scientific coordinator at Fraunhofer IOSB, Dr. Szymon Gładysz, organized for me in January 2023.
2) The second research line I pursued during my fellowship focused on the study of the transmission properties of structured modes of light through atmospheric turbulence with the goal of enhancing the performance of free-space communication networks. These works align with the activities of my host group, the Adaptive Optics group at Fraunhofer IOSB, and have been conducted in collaboration with them. In this context, I identified, in collaboration with the University of Freiburg, optical modes that transmit information with minimal losses through time-dependent turbulent channels (reference 8). For this work, we also developed a more accurate algorithm for the numerical simulation of light propagation and data transmission (reference 1). In a collaboration with the universities of Freiburg and Witwatersrand (Johannesburg), we obtained a universal decay law for the crosstalk of orbital-angular-momentum-carrying transmission modes in arbitrary random media (reference 7). Together with my host group at Fraunhofer IOSB, we are working on the online estimation of the transmission matrix of a turbulent channel (reference 11) with the goal of enhancing data transmission and decrease bit error rate in communications networks

II – PUBLICATION(S) DURING YOUR FELLOWSHIP

Preprint:

1) D Bachmann, M Isoard, V Shatokhin, G Sorelli, A Buchleitner, *Accurate Zernike-Corrected Phase Screens for Arbitrary Power Spectra*, arXiv:2402.04826 (2024)

Published Journal papers:

2) D Barral, M Isoard, **G Sorelli**, M Gessner, N Treps, M Walschaers, *Metrological detection of entanglement generated by non-Gaussian operations,* New J. Phys. 26 (8), 083012 (2024)
3) **G Sorelli**, M Gessner, N Treps, M Walschaers, *Gaussian quantum metrology for mode-encoded parameters*, New J. Phys. 26 073022 (2024)
4) I Karuseichyk, **G Sorelli**, V Shatokhin, M Walschaers, N Treps, *Exploiting separation-dependent coherence to boost optical resolution*, Phys. Rev. A 109 (4), 043524 (2024)
5) K Schlichtholz, T Linowski, M Walschaers, N Treps, Ł Rudnicki, **G Sorelli**, *Practical tests for sub-Rayleigh source discriminations with imperfect demultiplexers*, Optica Quantum 2 (1), 29-34 (2024)
6) C Rouvière, D Barral, A Grateau, I Karuseichyk, **G Sorelli**, M Walschaers, N Treps, *Ultra-sensitive separation estimation of optical sources*, Optica 11 (2), 166-170 (2024)
7) D Bachmann, A Klug, M Isoard, V Shatokhin, **G Sorelli**, A Buchleitner, *Universal crosstalk of twisted light in random media,* Phys. Rev. Lett. 132 (6), 063801 (2024)
8) D Bachmann, M Isoard, V Shatokhin, **G Sorelli**, N Treps, A Buchleitner, *Highly Transmitting Modes of Light in Dynamic Atmospheric Turbulence*, Phys. Rev. Lett. 130 (7), 073801 (2023)
9) T Linowski, K Schlichtholz, **G Sorelli**, M Gessner, M Walschaers, N Treps, Ł Rudnicki, *Application range of crosstalk-affected spatial demultiplexing for resolving separations between unbalanced sources*, New J. Phys. 25 103050 (2023)
10) I Karuseichyk, **G Sorelli**, M Walschaers, N Treps, M Gessner, *Resolving mutually-coherent point sources of light with arbitrary statistics,* Phys. Rev. Res. 4 (4), 043010 (2022)

Published Conference Papers:

11) **G Sorelli**, D Bachmann, M Isoard, V Shatokhin, D McDonald, S Gladysz, N Treps, A Buchleitner, *Transmission Matrix Approach to Turbulence Profiling*, Optica Imaging Congress (pcAOP), paper PTu5F.1. (2023)
12) C Rouvière, D Barral, A Grateau, **G Sorelli**, I Karuseichyk, M Walschaers, N Treps, *Experimental separation estimation of incoherent optical sources reaching the Cramér-Rao bound*, Conference on Lasers and Electro-Optics/Europe (CLEO/Europe) and European Quantum Electronics Conference (EQEC), paper eb_8_3 (2023)

III – ATTENDED SEMINARS, WORKHOPS, CONFERENCES

- 16-18/02/2023 - Taiwanese-German Young Researchers Forum on Quantum Information Science, Tainan, Taiwan (Invited Talk)
- 19 – 22/06/2023 - Optica Quantum 2.0 Conference, Denver, USA
- 09/08/2023 - Second Workshop on Quantum-Inspired Superresolution (Online)
- 14 – 17/08/2023 - Optica Imaging Conferece, Boston, USA (Invited Talk)
- 03 – 04/10/2023 - NATO IST-SET-198 Research Symposium (RSY) on Quantum Technology, Amsterdam, Netherlands
- 08 – 12/01/2024 - The Winter Colloquium on the Physics of Quantum Electronics (PQE), Snowbird, USA (Invited Talk)
- 21-22/05/2024 – Kick off Meeting of the NATO SET Working group on Quantum Sensing, Paris, France
- 27 – 28/06/2024 – London Imaging Meeting, London, UK
  (participation as chair of the conference “Quantum Technology for Security and Defence”)

IV – RESEARCH EXCHANGE PROGRAMME (REP)

In May 2023, I visited for one week Dr. Ulysse Chabaud at INRIA in Paris.
I had previously met Dr. Chabaud when we were both working at Sorbonne University.
We are both active in Quantum Information, but I come more from a statistics and metrology background, while Dr. Chabaud has more a computer science background. Before our meeting, we had both worked on the characterization of non-Gaussian states (see reference 2 above). During the REP, we attempted to derive an expression for the Quantum Fisher Information (a fundamental quantity in quantum metrology) for this class of states. We were able to make significant progress on the subject, but further work is needed to arrive at publishable results. After the REP I didn't find much time to devote to this extremely fundamental line research. This is partly due to the fact that I prioritized more applied research directions, that are more aligned with the Fraunhofer mission.