

# Quantum Artificial Intelligence: from theoretical physics foundations to real-world applications

**Filippo Caruso**<sup>1</sup>

<sup>1</sup>Physics and Astronomy Department, Florence University, Italy

Physics-inspired foundations of AI are at the core of the 2024 Physics Nobel Prize. Would it be possible to design novel, more powerful, explainable and sustainable AI models that are triggered by quantum physics, running on real quantum hardware?

Indeed, Quantum AI is rapidly emerging as a very promising, extremely powerful while more sustainable, but still challenging avenue to be integrated with more traditional HPC, AI and GPU energy-hungry resources, especially when dealing with highly demanding global challenges the world does urgently need to face. In the last years the first prototypes of quantum processors have reached the market, are sometimes available via cloud, and can be used to test novel quantum physics-inspired learning models. Quantum neural networks usually require much less training parameters, hence may be more interpretable, still work with small training datasets, and can be benchmarked on energy-saving quantum hardware.

Here, we will provide a broad-audience, historical overview on Quantum AI, together with a discussion of our theoretical and experimental works where quantum learning models are applied in different contexts while dealing with various types of data, including images and time-series. In particular, we will show our first quantum generalization of generative AI diffusion models that are today the most powerful tools to infer complex and unknown data distributions from a finite number of training samples in order to produce new synthetic data. More specifically, our counter-intuitive idea is to exploit quantum noise not as an issue to be detected and solved, as usually done for quantum technologies, but instead as a very remarkably beneficial key ingredient to generate much more complex probability distributions that would be difficult or even impossible to express classically, and from which a quantum processor might sample more efficiently than a classical one.

Therefore, we strongly believe that these results pave the way for the foundations of a novel physics-inspired theory of Generative Quantum AI towards future widespread real-world applications exploiting both HPC and quantum processors, in several practical domains such as, among others, healthcare, cybersecurity, finance, and energy.