Quantum processing and entanglement distribution in the Recife Quantum Network

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Abstract. *The Recife Quantum Network is a multipurpose infrastructure supporting the development of quantum technologies in the city of Recife, Brazil. Here we describe a small branch of the network, up to 10 km long, dedicated to the distribution and processing of quantum states of light at wavelengths compatible to an atomic quantum memory. We report the development and characterization of an efficient source of photon pairs, with pair generation rates up to MHz, and their distribution in the network. We also introduce our architecture for photonic quantum processing in the system and our first theoretical proposals for applications.*

1. Introduction

Quantum networks is a system composed of quantum channels connecting sites that are capable of processing this information aiming various applications in communication, computation, or sensing [Wei 2022]. Their numbers have multiplied around the world in the last decade, with a good portion of them dedicated to quantum key distribution [Liu 2025]. The Recife Quantum Network (RQN), one of the first quantum networks implemented in Brazil, has broad goals to serve as a testbed for quantum communication protocols and the development of national quantum hardware [Oliveira 2026]. A branch of the RQN is particularly designed to explore quantum protocols involving atomic quantum memories and processing. Its small size, of up to 10 km, allows for the exchange of quantum information through optical fibers at the wavelength of 780 nm, compatible to previously-developed local quantum memories [Ortiz-Gutiérrez 2018]. Here we discuss the development of such network branch particularly suitable to deeper quantum technologies. We introduce first its planned basic structure of sites and quantum channels, with a photonic quantum processor capable of coupling to the network. Then we describe the quantum hardware being developed to operate the network, with emphasis on a new source of photon pairs delivering quantum-entangled photons at MHz rates. Finally, we report on the first proposals to use the network's photonic quantum processor to find the ground-state energy of small molecules.

2. Quantum hardware and network structure

Figure 1(a) shows a map of Recife with the quantum channels of our network plotted as solid blue lines. Presently, they connect two laboratories at UFPE (located at the CCEN and CTG buildings) with a third laboratory at UFRPE. The connection between UFPE and UFRPE is provided by a collaboration with the RNP (*Rede Nacional de Ensino e Pesquisa*). The telecom fiber-optic pathway connecting the CCEN building and UFRPE is about 10 km long. Such a distance still allows for quantum information to be transmitted between the two sites even at wavelengths around 800 nm [Townsend 1996], following the scheme shown in Fig. 1(b). The critical element in this scheme in to use single-mode fibers for 780 nm at the input and output to eliminate the mode hoping responsible for polarization dispersion. An example of polarization control in our system is shown in Fig. 1(c). We are presently working on the synchronization of photo-detections between different sites of the network. This control is necessary to distribute and use photons carrying polarization entanglement [Oliveira 2026] or even to realize simpler quantum-key-distribution protocols. Besides the connection to quantum memories, another advantage of working close to the visible is the considerably better efficiency and lower noise of single-photon avalanche detectors for these wavelengths.

In order to be able to process quantum information at the network's sites, we are setting up a photonic quantum computer at the CCEN site. This computer will be later transferred to the site of the QUANTA institute, under construction at UFPE. The scheme for our photonic quantum computer is shown in Fig. 1(d). It is a combination of three modules: a quantum light source, an universal quantum processor, and a Superconducting Nanowire Single-Photon Detection (SNSPD) system. Three quantum light sources produced by the group are going to be used as input for the computer: photon pairs from spontaneous parametric down conversion (SPDC) [Oliveira 2026], synchronizable single photons from atomic memories [Ortiz-Gutiérrez 2018], and single photons from nanoemitters [Sánchez 2020]. A 20-modes universal photonic processor is commissioned and under production by EPHOS (https://ephos.io/), being optimized for use around 780 nm. The photo-detection system consists of 32 SNSPDs purchased from Quantum Opus (https://www.quantumopus.com/web/), also optimized for 780 nm. This modular structure allows for the use of the quantum computer as a stand-alone machine or connected to the RQN.

3. Efficient source of quantum entanglement

The first light source to be used to distribute quantum entanglement at the RQN and as input to our photonic quantum computer will be an SPDC source produced by the local startup QWeb. Its basic scheme is shown in Fig. 2(a). A blue cw diode laser excites a 1-cm PPKTP crystal, producing photon pairs with ortogonal linear polarizations.

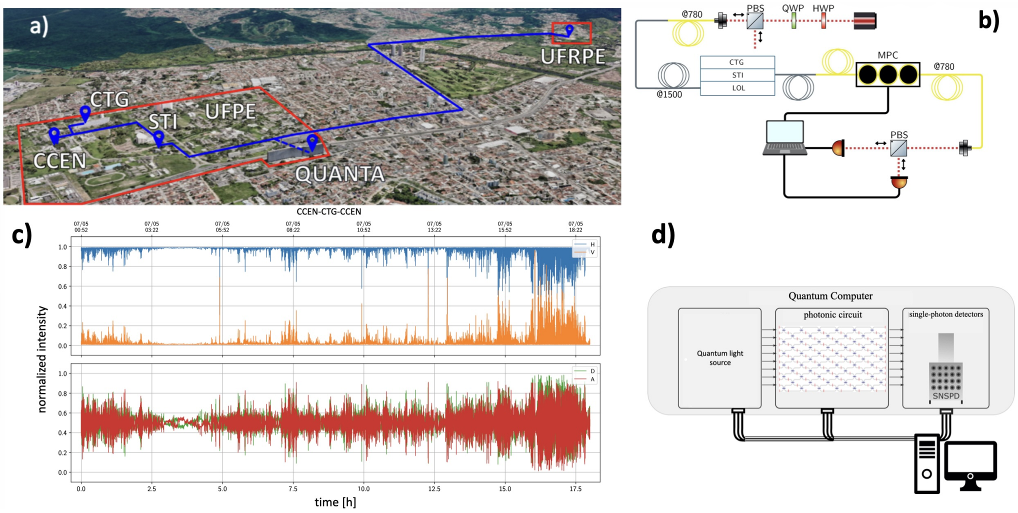

Figura 1. a) Channels and sites of the Recife Quantum Network [Oliveira 2026]. Fiber-optic pathways are drawn as solid blue lines, connecting UFRPE to the CCEN and CTG sites. The dashed blue line indicates a channel under construction to a new site. STI is a data distribution center for UFPE. b) Scheme for polarization control of light around 780 nm, with MPC for Motorized Polarization Controller. c) 18 hours of polarization control after 1.4 km propagation in the fiber with 780 nm vertically-polarized light at the input. (H,V) and (D,AD) indicate (horizontal,vertical) and (diagonal,anti-diagonal) polarizations. d) Scheme for UFPE's photonic quantum computer.

After passing through a beam splitter, these photon pairs can violate a CHSH Bell inequality [Oliveira 2026], demonstrating its utility for quantum cryptography or quantum teleportation. Such long crystals allow for high generation rates. In Fig. 2(b) we use the violation of a Cauchy-Schwarz inequality to characterize the nonclassical nature of the photon pairs emitted by the QWeb source. The quantity R is the ratio of the normalized cross-correlations by the normalized auto-correlations among the photons in the pairs [Clauser 1974]. The bound $R < 1$ is valid for classical light fields. We obtain $R \approx 500$ even for laser powers resulting in photon-pair generation rates above 1 MHz. Such a value of R allows for significant violation of the CHSH inequality. The violation of R decreases with the laser power due to the increase in the higher order components of the quantum fields. In [Oliveira 2026] we showed that the quantum correlations between photons at 800 nm can survive the absorption by the optical fiber for distances of over 5 km, and we should be able to reach the 10 km for our longest links.

4. Photonic quantum processing

We did not finish setting up the quantum computer of Fig. 1(b). However, we are already developing theoretical proposals for its use. In Fig. 3, we show our first results for a Variational Quantum Eigensolver (VQE) photonic algorithm to compute the dissociation profile of a CH_5^+ molecular system [see inset of Fig. 3(a)]. Our results show that the photonic path-encoded ansatz achieves competitive performance with a substantial reduction in entangling operations, particularly CNOT gates, which are major sources of circuit complexity and noise in conventional gate-based approaches. The energies obtained lie within chemical accuracy. Such approach offers a promising route toward the simulation of larger molecular systems.

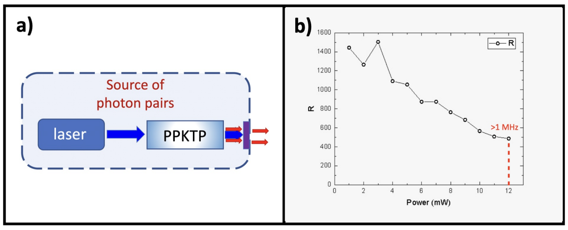

Figura 2. a) Basic elements of our photon pair source. A laser excites a PPKTP crystal with blue photons which are each converted to two photons in the near infrared. b) Violation of Cauchy-Schwarz inequality ($R < 1$) indicating strong quantum correlations of the photon pairs even for laser powers resulting in generation rates above 1 MHz.

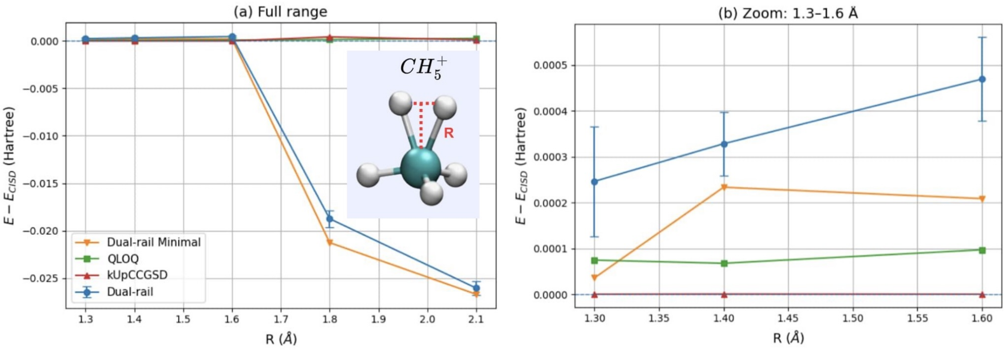

Figura 3. (a) Energy difference, in Hartree, between various ansätze and CISD as a function of the dissociation distance of the CH_5^+ molecule (shown as inset). Dual-rail and QLOQ are simulations of different methods of photonic quantum computation. (b) Zoom of panel (a) around dissociation distances of 1.3 to 1.6 Å.

5. Conclusion

We reported here our advances in the implementation of a quantum network in Recife with capability to distribute quantum entanglement and process quantum information. We described the overall infrastructure being built and its main elements. We specifically reported the first characterization of the source of quantum entanglement to be used in the first experiments over the network, demonstrating its high efficiency. We also reported our first calculations prospecting the use of our future photonic quantum computer for simulating molecular systems of increasing complexity.

6. References

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