Quantum Correlations Between Two Qubits via a Plasmonic Nanostructure

Andreas F. Terzis[1], Vassilios Yannopapas[2], Evangelos Voutsinas[3] and Emmanuel Paspalakis[4]

[1]*Department of Physics, University of Patras, Patras 265 04, Greece*

[2]*Department of Physics, National Technical University of Athens, Athens 157 80, Greece*

[3]*Technological and Educational Institute of Western Greece, Megalou Alexandrou 1, Patras 263 34, Greece*

[4]*Materials Science Department, University of Patras, Patras 265 04, Greece*

SCOPE OF THIS WORK: For practical applications in quantum computing and especially in quantum communication it is important to create entangled states between material qubits that are spatially separated. An important issue in the creation of entangled states is the presence of unavoidable decoherence that leads to irreversible destruction of entanglement. A major source of decoherence is spontaneous emission that occurs due to the interaction of the qubits with environment. Recent studies have shown that significant entanglement between distant qubits can occur when the qubits are placed near one-dimensional plasmonic waveguides [1-3].

It has also been shown that the spontaneous emission rate of quantum emitters near a two-dimensional lattice of metal-coated dielectric nanoparticles (see Fig. 1) can be significantly reduced for specific dipole direction [4,5]. In addition, the dipole-dipole interaction between two quantum emitters can be enhanced in the presence of the same two-dimensional lattice of metal-coated dielectric nanoparticles [6]. The combination of these two effects may lead to significant quantum correlations near this plasmonic nanostructure.

Here, we theoretically study the generation of quantum correlations between two distant quantum emitters (atoms or semiconductor quantum dots) in free space or mediated by a plasmonic nanostructure [1-3]. For the plasmonic structure we consider a two-dimensional lattice of metal-coated dielectric nanoparticles, shown in Fig. 1. We use the relevant density matrix equations for the two-qubit system, where the decay rates and the coupling coefficients are dependent on the plasmonic nanostructure. We first calculate the relevant coupling coefficients and decay rates by a rigorous electromagnetic Green's tensor technique [4-6]. We then report results for Entanglement of Formation (EoF) [1,2], which gives information about entanglement, Quantum Discord (QD) [3], which provides information for all possible quantum correlations, and Classical Correlations (CC) [3]. We have found that for proper initial state of the two-qubit system and distance between the two qubits we can produce quantum correlations that take significant values for a relatively large time interval.

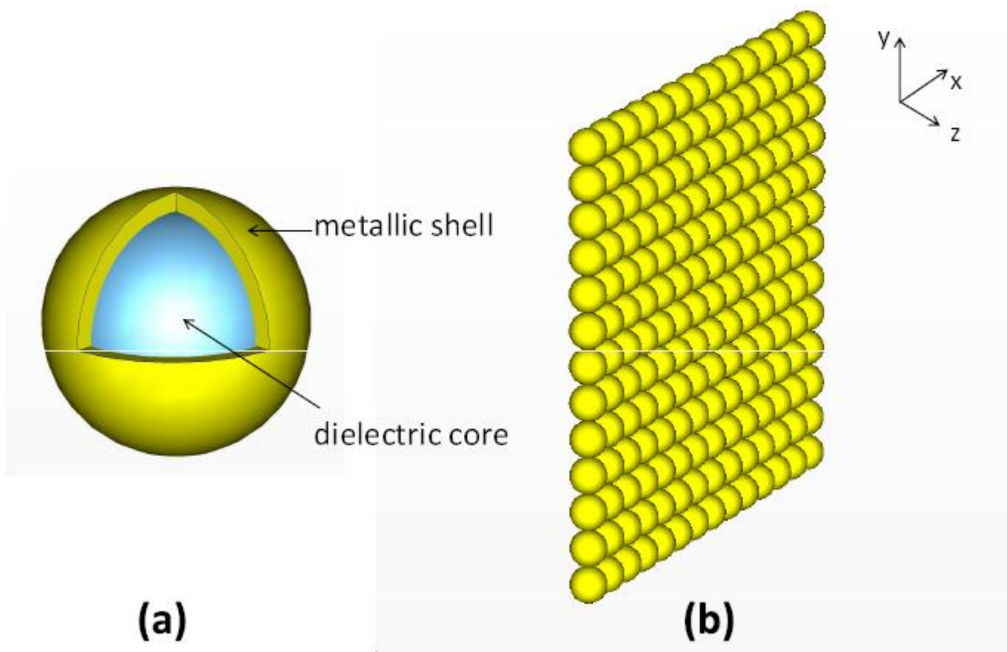

Figure 1: (Left) Schematic diagram of the plasmonic nanostructure which is mediated between the two qubits of our system. The two qubits are placed in same distances from the nanostructure. (a) A metal-coated dielectric nanosphere and (b) Square lattice (monolayer) of metal-coated dielectric nanospheres.

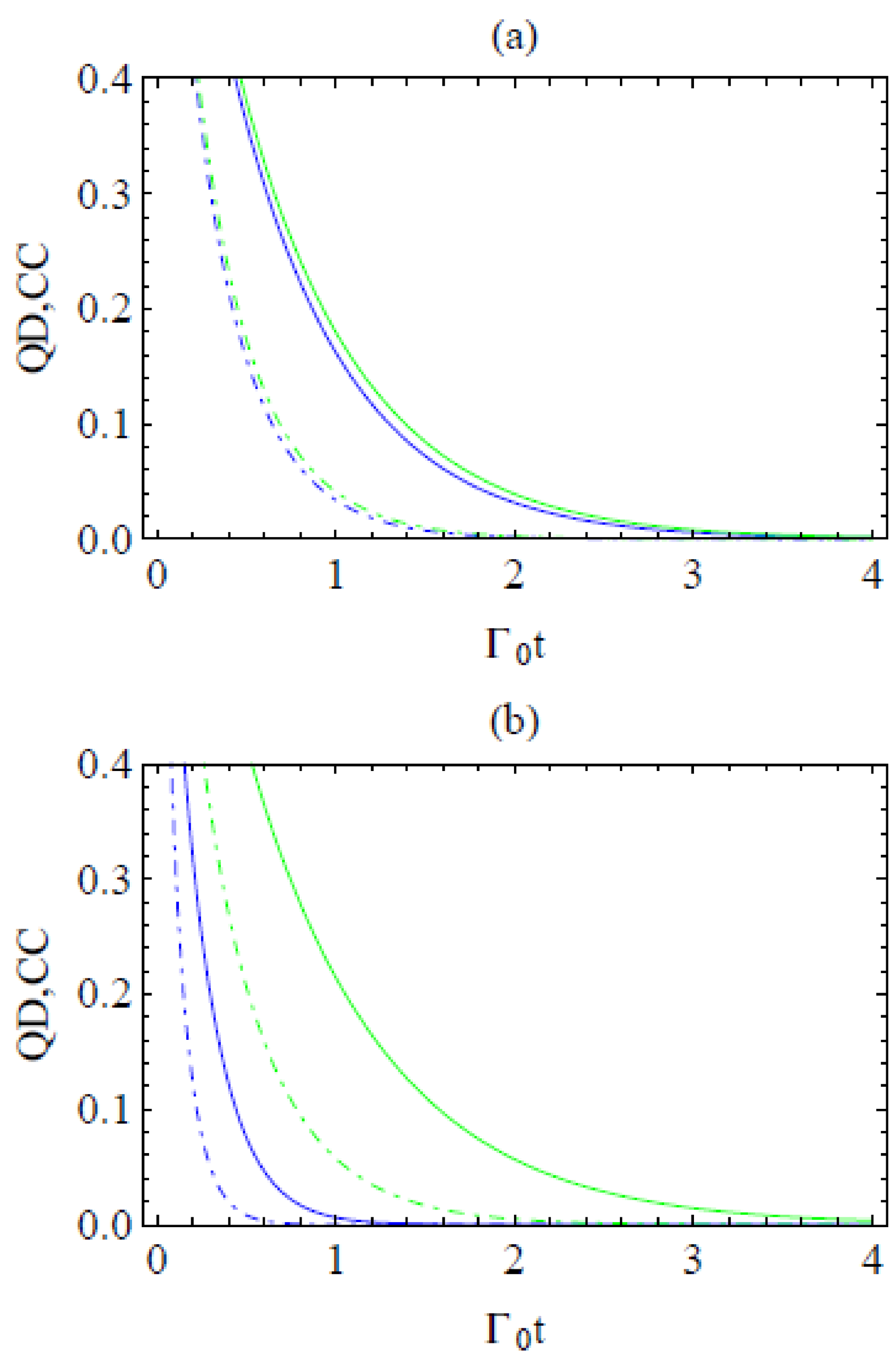

Figure 3: (Right) Plots of QD (solid curves) and CC (dashed curves) as a function of time for a maximally entangled Bell state. We use blue and green curves for representing results for distances d=0.4c/ω_p and d=0.7c/ω_p, respectively. In (a) the results are for qubits in the free space and in (b) are for qubits in the presence of the plasmonic nanostructure.

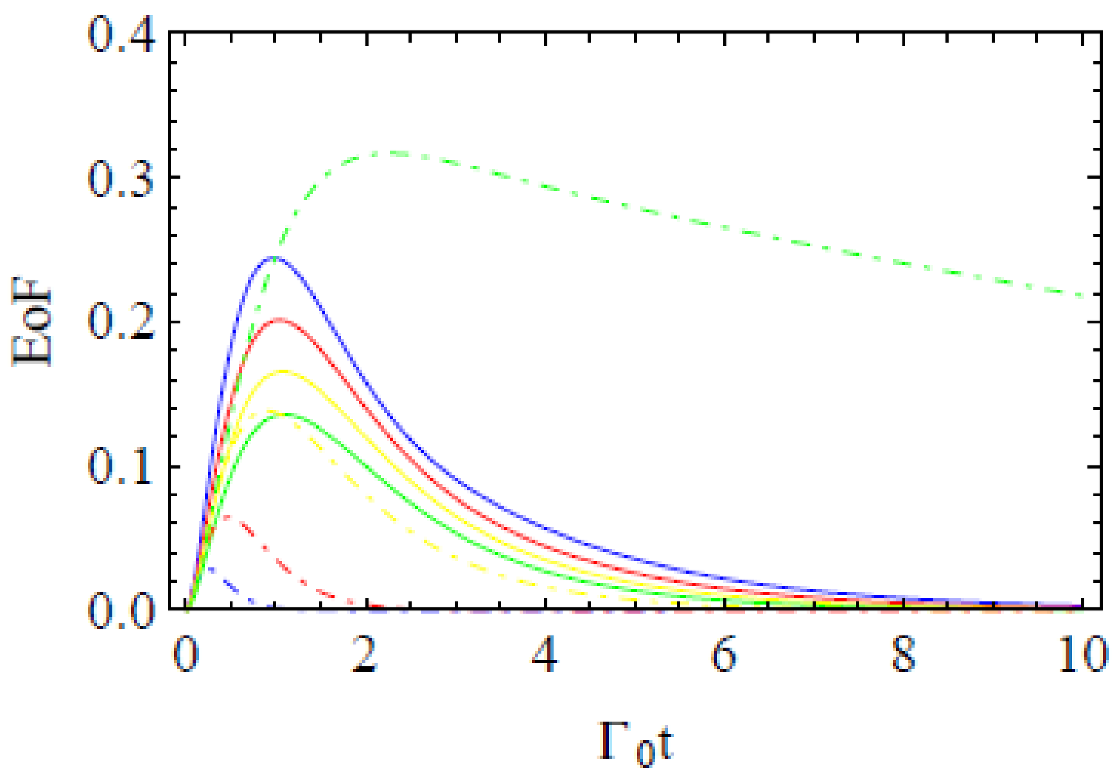

Figure 4: (Above) Plots of EoF as a function of time for a completely non-entangled initial state (one qubit is excited while the other un-excited). The conventions for the different curves are the same as in Fig. 2.

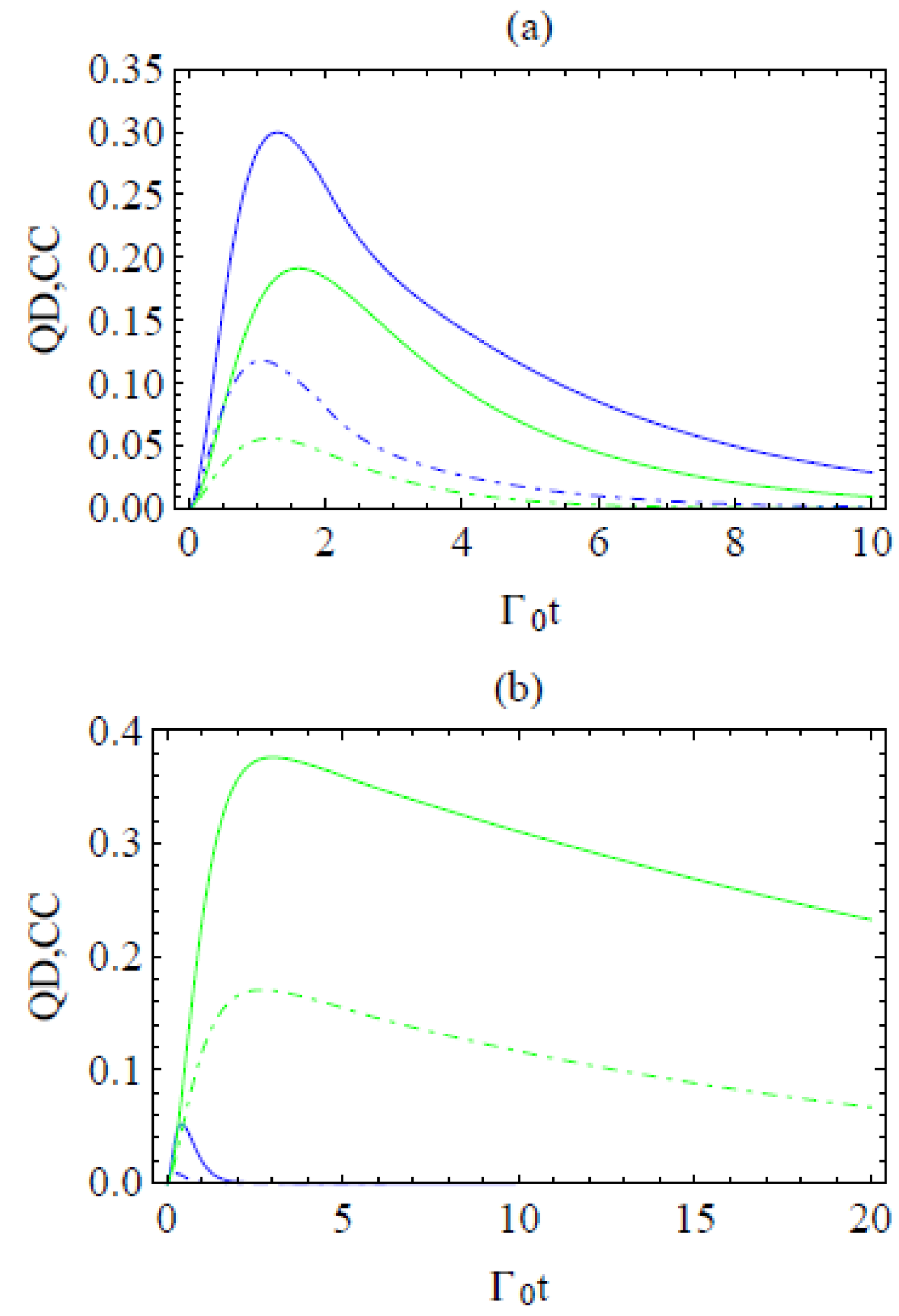

Figure 5: (Right) Plots of QD (solid curves) and CC (dashed curves) as a function of time for a completely non-entangled initial state (one qubit is excited while the other un-excited). The conventions for the different curves and plots are the same as in Fig. 3.

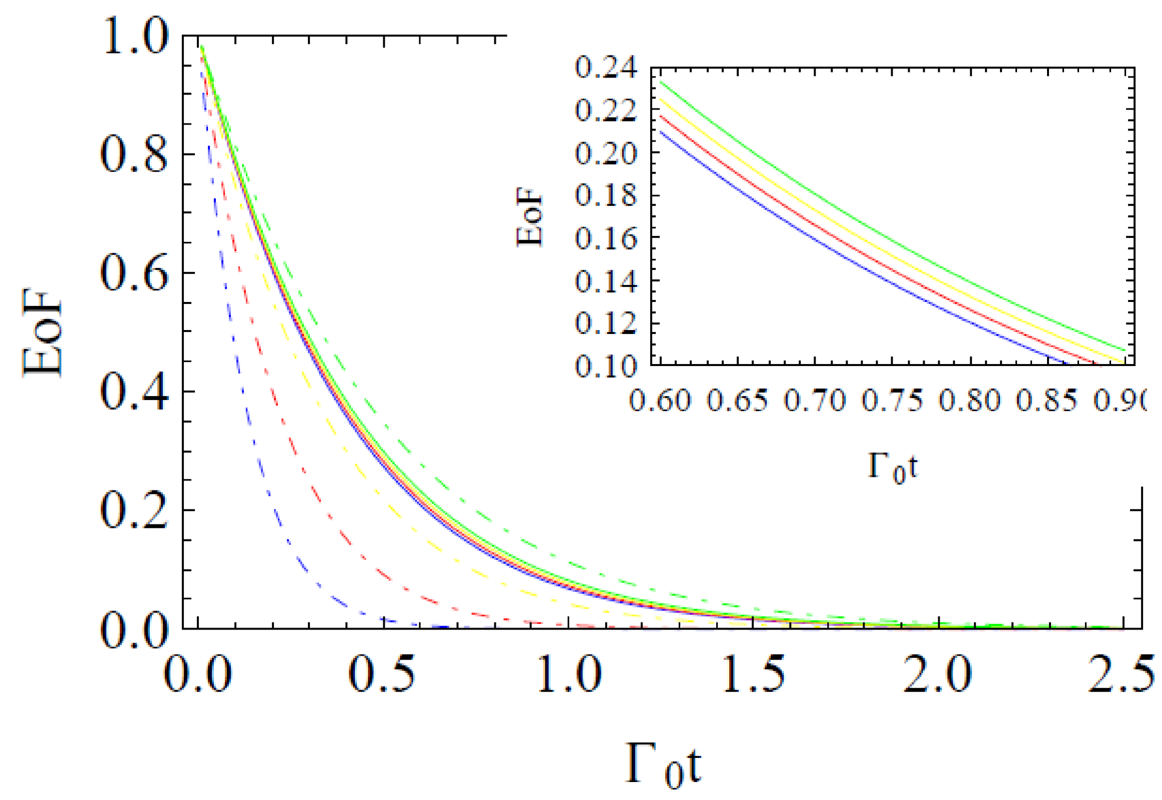

Figure 2: (Above) Plots of EoF as a function of time for a maximally entangled Bell state. We use blue, red, yellow and green curves for representing results for distances d=0.4c/ω_p, d=0.5c/ω_p, d=0.6c/ω_p, and d=0.7c/ω_p, respectively, where d is the distance between the qubits and the surface of the plasmonic nanostructure (the plasmonic nanostructure is placed between the two qubits). We have used silica as the dielectric core and a Drude-type dielectric function for the metallic shell [4-6]. Here, the solid curves are for qubits in the free space whereas the dashed ones are for qubits in the presence of the plasmonic nanostructure. In the inset we report the EoF for a smaller time region, so that the d-dependence of the solid curves becomes apparent.

ACKNOWLEDGMENTS: This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: Archimedes III.

REFERENCES

[1] A. Gonzalez-Tudela, D. Martin-Cano, E. Moreno, L. Martin-Moreno, C. Tejedor, and F. J. Garcia-Vidal, Phys. Rev. Lett. **106**, 020501 (2011).

[2] D. Martin-Cano, A. Gonzalez-Tudela, L. Martin-Moreno, F. J. Garcia-Vidal, C. Tejedor, and E. Moreno, Phys. Rev. B **84**, 235306 (2011).

[3] C. E. Susa, J. H. Reina, and L. L. Sanchez-Soto, J. Phys. B **46**, 224022 (2013).

[4] V. Yannopapas, E. Paspalakis, and N.V. Vitanov, Phys. Rev. Lett. **103**, 063602 (2009).

[5] I. Thanopulos, E. Paspalakis, and V. Yannopapas, Phys. Rev. B **85**, 035111 (2012).

[6] I. Thanopulos, E. Paspalakis, and V. Yannopapas, J. Phys. Chem. C **115**, 4370-4374 (2011).

Presentation in Condensed Matter in Paris 2014 (CMD 25 – JMC 14), Paris, France, 24-29 August 2014.

European Union
European Social Fund

OPERATIONAL PROGRAMME
EDUCATION AND LIFELONG LEARNING
investing in knowledge society
MINISTRY OF EDUCATION & RELIGIOUS AFFAIRS
MANAGING AUTHORITY

NSRF 2007-2013
programme for development
EUROPEAN SOCIAL FUND

Co-financed by Greece and the European Union