Correlations Between Two Qubits via a Plasmonic Nanostructure

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SCOPE OF THIS WORK: A novel trend in the field of quantum computing and communication is the creation of entangled states between material qubits that are spatially separated. However the unavoidable decoherence, present in any realistic entangled system, usually leads to irreversible destruction of entanglement. The interaction of the qubits with environment, resulting in spontaneous emission is a major source of decoherence. Recent studies have shown that significant entanglement between distant qubits can occur when the qubits are placed near quasi 1D plasmonic waveguides [1-3]. Actually, in these investigations it was revealed that the dissipative dynamics plays in some cases a positive role in the creation of the entangled states.

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 along with the proper control of the individual and collective decay rates [1-3] may lead to significant quantum correlations near this plasmonic nanostructure.

We theoretically study the generation of classical and quantum correlations between two distant quantum emitters (atoms or semiconductor quantum dots) in free space or mediated by the surface plasmons of a metallic nanostructure [1-3]. For the plasmonic structure we consider a two-dimensional array of metal-coated dielectric nanospheres and calculate the relevant coupling coefficients and decay rates by a rigorous electromagnetic Green's tensor technique [4-7]. We report results for both Entanglement of Formation (EoF), which gives information about entanglement, and Quantum Discord (QD) which provides information for all possible quantum correlations as well as Classical Correlations (CCs). The estimation of correlations is achieved by solving the master equations of the density matrix of the quantum system. Analytical, closed forms of the density matrix were derived for the pure quantum states. We have found that for a 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, so that they can be useful in quantum information and computation processes.

For maximally entangled initial states we have found a monotonic decay of all correlations, except for initial state where both qubits are excited. In the latter case a revival of the correlations is found. The results for non-entangled initial states are reported in the figures below.

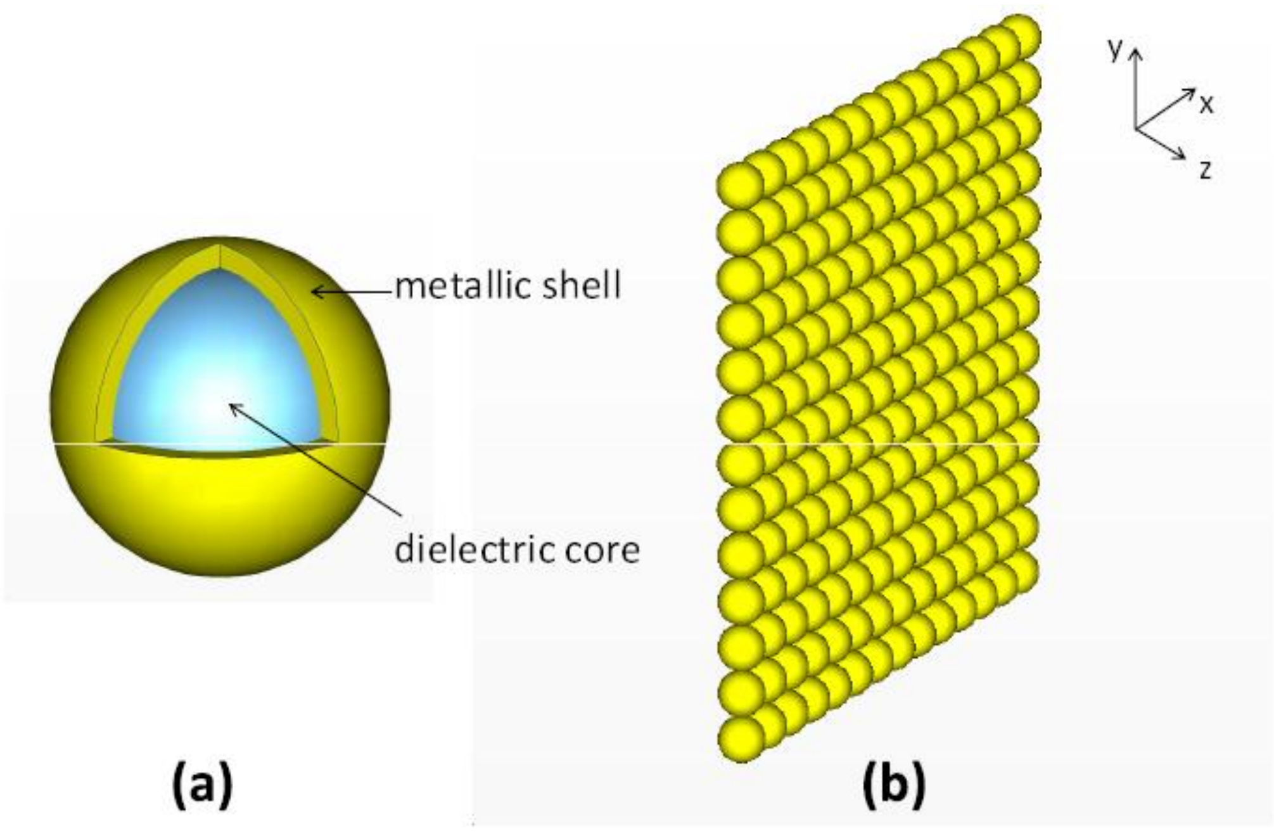

Figure 3: (Right) Plots of QD (solid curves) and CC (dashed curves) as a function of time for a non-entangled initial state as in Fig.2. We use blue and green curves for representing results for distances d=0.4c/ω_p and d=0.7c/ω_p, respectively. In (a) the results are for qubits in the free space and in (b) are for qubits in the presence of the plasmonic nanostructure.

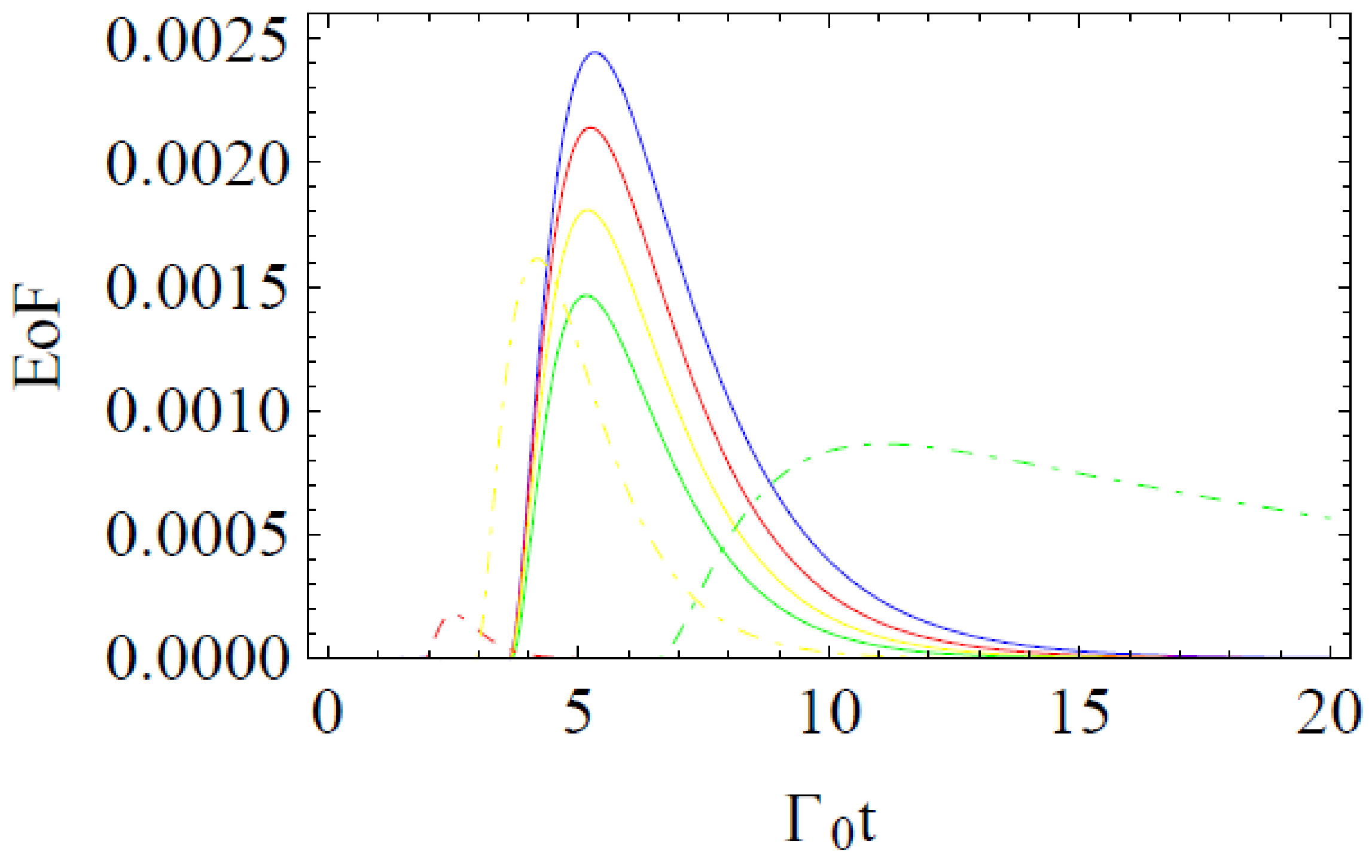

Figure 4: (Above) Plots of EoF as a function of time for a completely non-entangled initial state (both qubits are excited). The conventions for the different curves are the same as in Fig. 2.

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

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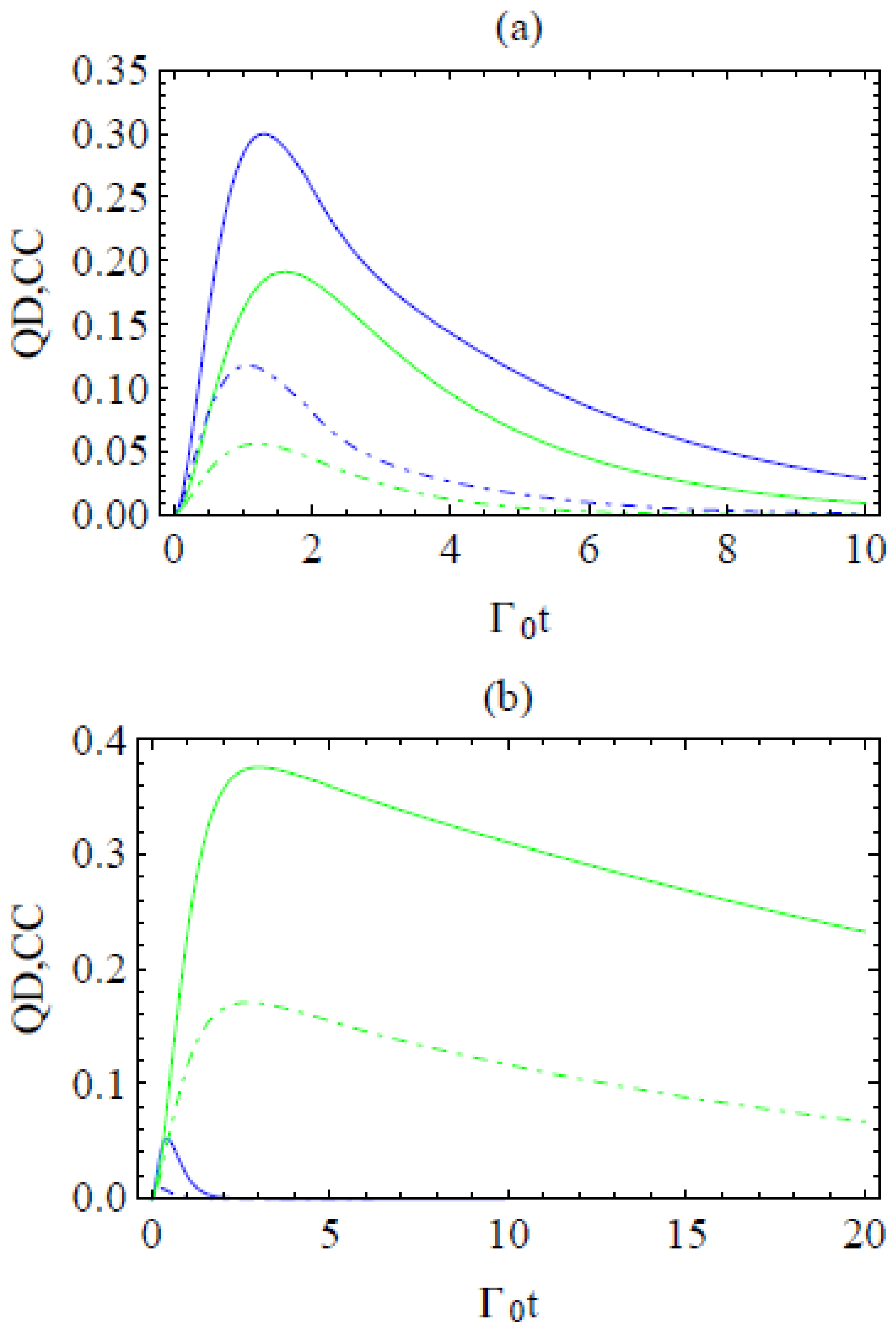
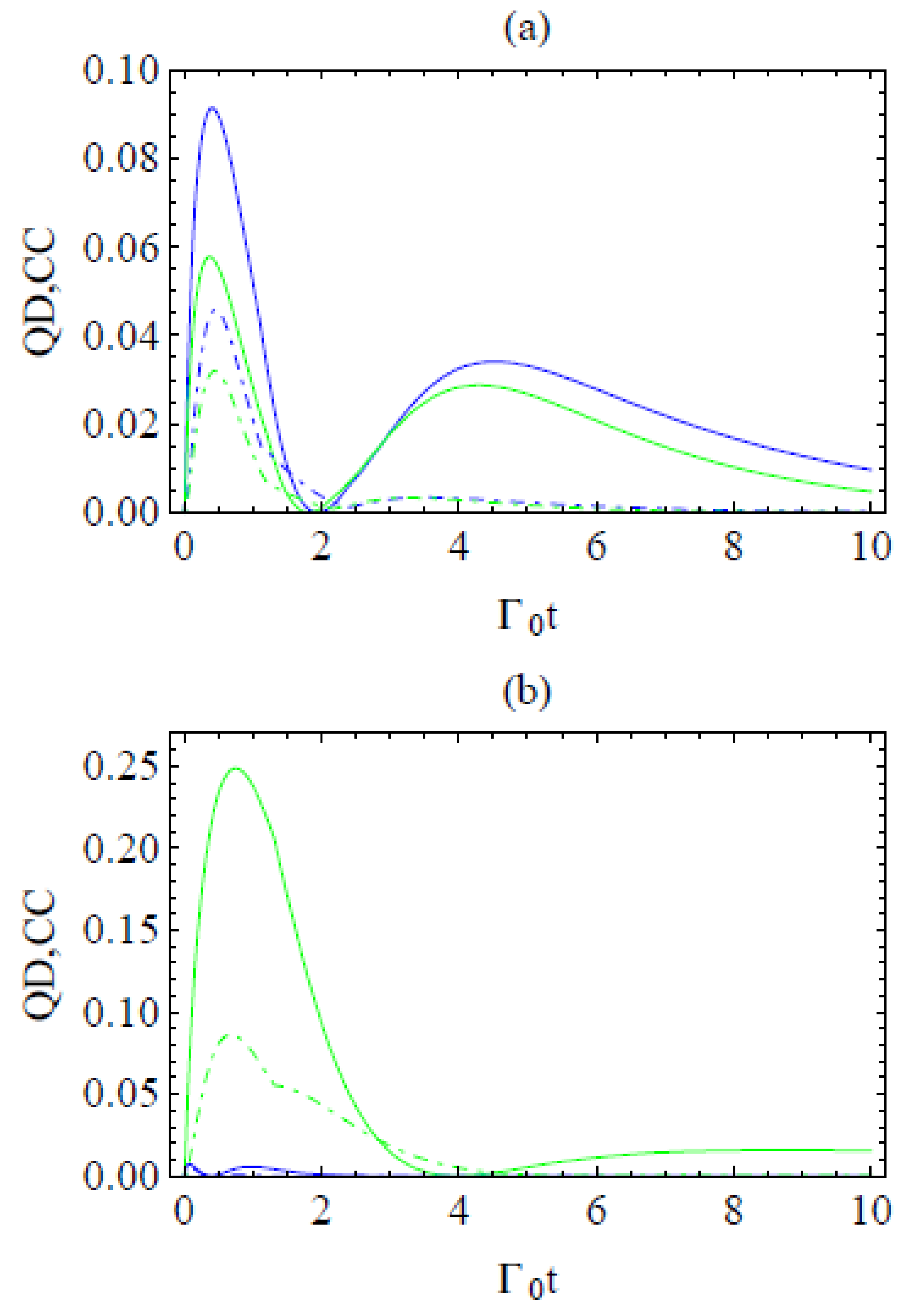
Figure 1: (Left) Schematic diagram of the plasmonic nanostructure which is mediated between the two qubits of our system. The two identical qubits are placed at equivalend position with respect to the nanostructure and with identical orientation. (a) A metal-coated dielectric nanosphere and (b) Square lattice (monolayer) of metal-coated dielectric nanospheres.





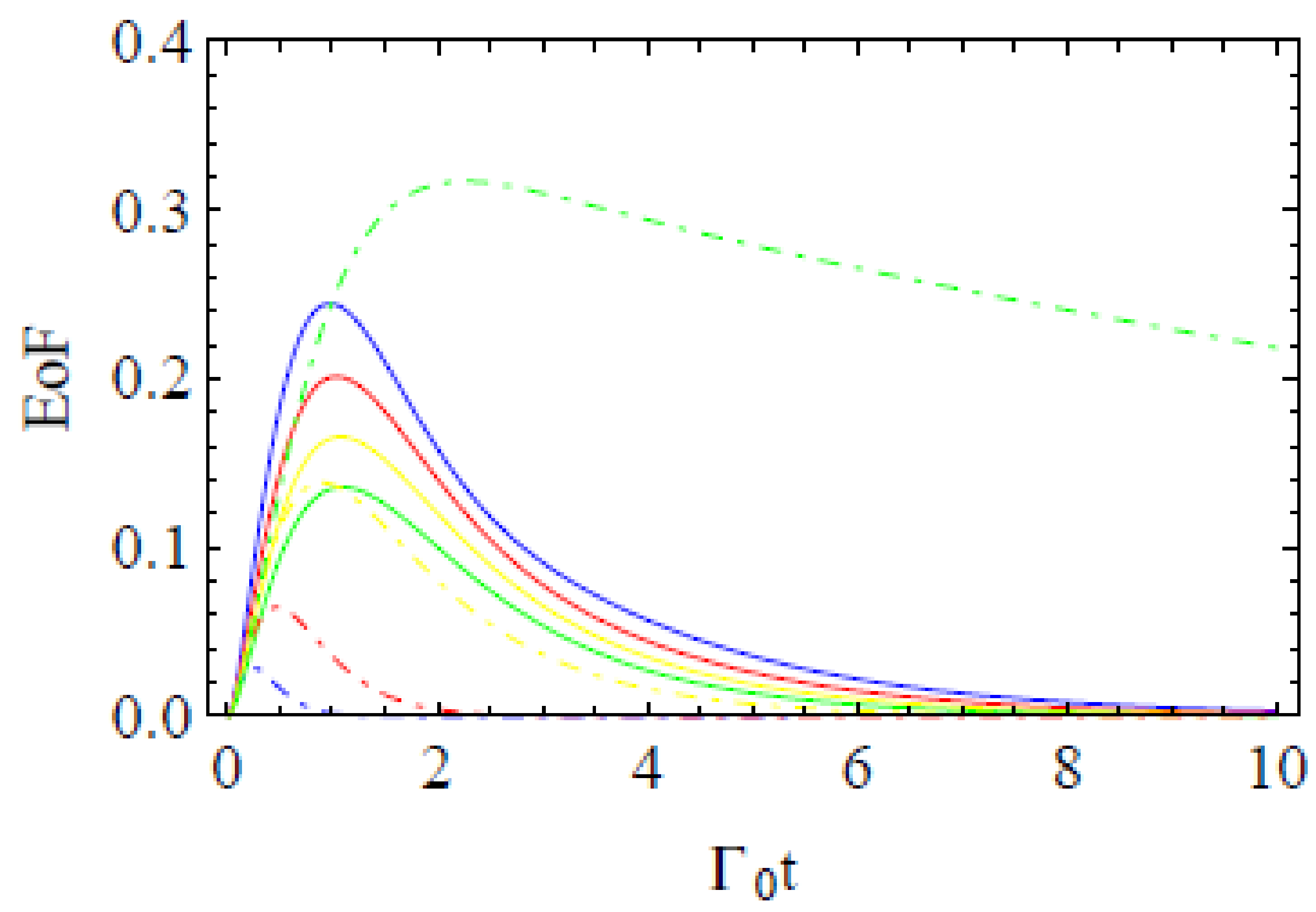


Figure 2: (Above) Plots of EoF as a function of time for a completely non-entangled initial state (one qubit is excited while the other un-excited). We use blue, red, yellow and green curves for representing results for distances d=0.4c/ω_p, d=0.5c/ω_p, d=0.6c/ω_p, and d=0.7c/ω_p, respectively, where d is the distance between the qubits and the surface of the plasmonic nanostructure (the plasmonic nanostructure is placed between the two qubits). 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.

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