How can the D-Wave machine exhibit long-time quantum behaviour

2015 J. Phys.: Conf. Ser. 626 012057

(http://iopscience.iop.org/1742-6596/626/1/012057)

Journal of Physics: Conference Series **626** (2015) 012057 doi:10.1088/1742-6596/626/1/012057

How can the D-Wave machine exhibit long-time quantum behaviour

D Drakova[1] and G Doyen[2]

[1] Faculty of Chemistry, University of Sofia, Bulgaria
[2] Ludwig-Maximilians Universität, München, Germany

E-mail: nhdd@chem.uni-sofia.bg

Abstract. Extensive experiments have demonstrated quantum behaviour in the long-time operation of the D-Wave quantum computer. The decoherence time of a single flux qubit is reported to be on the order of nanoseconds [1], which is much shorter than the time required to carry out a computation on the timescale of seconds [2, 3]. Previous judgements of whether the D-Wave device should be thought of as a quantum computer have been based on correlations of the input-output behaviour of the D-Wave machine with a quantum model, called simulated quantum annealing, or classical models, called simulated annealing and classical spin dynamics [4]. Explanations for a factor of 10^8 discrepancy between the single flux qubit decoherence time and the long-time coherent quantum behaviour of many integrated flux qubits of the D-Wave device have not been offered so far. In our contribution we investigate a model of four qubits with one qubit coupled to a phonon and (optionally) to environmental particles of high density of states, called gravonons. The calculations indicate that when no gravonons are present, the current in the qubit is flipped at some time and adiabatic evolution is discontinued. The time dependent wave functional becomes a non-correctable superposition of many excited states. The results demonstrate the possibility of effectively suppressing the current flip and allowing for continued adiabatic evolution when the entanglement to gravonons is included. This adiabatic evolution is, however, a coherent evolution in high dimensional spacetime and cannot be understood as a solution of Schrödinger's time dependent equation in 4 dimensional spacetime. Compared to Schrödinger's time development in 4D, the evolution is considerably slowed down, though still adiabatic. The properties of our model reflect correctly the experimentally found behaviour of the D-Wave machine and explain the factor of 10^8 discrepancy between decoherence time and quantum computation time. The observation and our explanation are in anology to the 10^8 discrepancy factor found, when comparing experimental results on adsorbate quantum diffusion rate with predictions of Schrödinger's time dependent equation, which can also be resolved in a model with the coupling to gravonons included.

1. Introduction

The D-Wave machine is a quantum computer of the quantum annealing type [5]. It is designed to solve classical optimization problems, namely to optimize a cost function of many free parameters and problems, which can be mapped on the classical Ising model [6]. The way to achieve the solution is by the algorithm of quantum annealing: slow variation of external experimental parameters, so that, as the adiabatic theorem says, the system develops with time adiabatically in its energetically ground state. At the end of the quantum annealing time the D-wave presents the solution of the optimization problem. In this sense the D-wave machine is different from all other attempts to construct a quantum computer.

The expectation that quantum computation will be faster than classical is not confirmed, but nevertheless there is sound proof that the D-Wave machine operates as a quantum computer. Numerous evidences, ranging from spectoscopic data [7] to theoretical simulations [4, 7, 8, 9], give sound basis to accept its quantum nature. This macroscopic construction, consisting of hundred to more than 500 flux qubits on a chip, interacting with each other and subjected to transverse magnetic fields, behaves coherently according to Schrödinger's time dependent equation and performs coherently quantum operations over long time of seconds and even minutes. A single flux qubit, the building block of the D-Wave device, a macroscopic object with $10^6 - 10^9$ Cooper pairs and dimensions of the order of 10^4 Å, "loses coherence" within nanoseconds in the photon field in Ramsey interference experiments [1]. The experimental observation is: the probability for switching between the two current states decays with time, interpreted as "loss of coherence", and reaches a finite value for the excitation probability larger than zero. The suggested causes for the damping of the amplitude of the oscillations range from experimental imperfections and poor control of the electromagnetic environment of the flux qubit, to external and internal noises of different nature and the involvement of various dissipative channels (charge noise, photon noise, quasiparticle excitations above the superconducting gap, radiative and dielectric loss, etc.).

The problem we focus on is the discrepancy of 8 orders of magnitude difference in the coherence time of a single flux qubit and the coherent operation of the D-Wave machine consisting of many flux qubits. We solve the time dependent Schrödinger equation with a Hamiltonian including the entanglement of the current states to gravonons, existing in high dimensional spacetime. The quantum theory lets Copenhagen quantum mechaniscs emerge, without postulating collapse, and provides a deterministic definite outcome of a "measurement", hence the name Emerging Quantum Mechanics [10]. It has been successfully used to solve the problem of localization of quantum particles and their appearance as classical particles [11, 12], the problem of quantum diffusion of atoms on solid surfaces [13] in a telegraph-signal like dynamics [14, 15] and wave-particle duality in matter wave diffraction [16]. Within the theory of Emerging Quantum Mechanics we explain the "short coherence time" of 20 ns of a single flux qubit (section 2) and the quantum behaviour of the D-Wave machine (section 4) over a period of time 8 orders of magnitude longer than that of a single flux qubit.

2. Constructing the Hamiltonian for a single flux qubit

The environmental excitations are the gravonons, massive bosons which emerge in the limit of weak and local gravitational interaction in high dimensional spacetime (11D) [10]. The coupling to gravonons is effective only within spacetime deformations called warp resonances. The model for the non-perturbed gravonons $\{| \ grav_i\rangle\}$ is a harmonic oscillator, whereas the gravonons perturbed by matter and force fields $\{| \ \kappa_i\rangle\}$ are the solution of the $\gamma - \eta$ model described in [13].

The Hamiltonian for the single flux qubit plus photon is:

$$\begin{aligned}
\mathrm{H}_{qubit} &= \mathrm{H}_o + \mathrm{H}_{phot} + \mathrm{H}_{qubit-grav} \\
&= \sum_{j=1}^{2} \left[E_{qubit_j} a^+_{qubit_j} a_{qubit_j} + E_{w_j} a^+_{w_j} a_{w_j} + V^{qubit_j}_{loc} (a^+_{qubit_j} a_{w_j} + a^+_{w_j} a_{qubit_j}) \right] \\
&+ \omega_{phot} b^+_{phot} b_{phot} + \sum_{j=1}^{2} \left[\varepsilon_{grav_j} c^+_{grav_j} c_{grav_j} + \sum_{\kappa_j} \varepsilon_{\kappa_j} c^+_{\kappa_j} c_{\kappa_j} \right] \\
&+ V_{phot,qubit} (a^+_{qubit_1} a_{qubit_2} + a^+_{qubit_2} a_{qubit_1})(b^+_{phot} + b_{phot}) \\
&+ \sum_{j=1}^{2} \sum_{\kappa_j} \left[W_{grav_j,w_j} n_{w_j} c^+_{grav_j} c_{\kappa_j} + W_{w_j,grav_j} n_{w_j} c^+_{\kappa_j} c_{grav_j} \right] .
\end{aligned} \tag{1}$$

The meaning of the symbols is w_j: regions in the Josephson junction (warp resonances), where

Journal of Physics: Conference Series **626** (2015) 012057 doi:10.1088/1742-6596/626/1/012057

Cooper pairs couple to gravonons. $a^+_{w_j}$, a_{w_j}, n_{w_j}: creation, annihilation and number operator for persistent current in the state $\mid w_j\rangle$ in the Josephson junction; $a^+_{qubit_j}$, a_{qubit_j}: creation and annihilation operator for persistent current in the state $\mid qubit_j\rangle$ in the flux qubit; b^+_{phot}, b_{phot}: creation and annihilation operator for the photon; $c^+_{grav_j}$, c_{grav_j}: creation and annihilation operator for the lowest energy gravonon in the potential, which is not perturbed by interaction between the matter field and the photon field; $c^+_{\kappa_j}$, c_{κ_j}: creation and annihilation operator for gravonons in the deformed manifold.

The terms in the second line of the Hamiltonian eq. (1) describe the two current states in the qubit (first term), in regions of the Josephson junction where the Cooper pairs couple to the gravonons w_j (second term) and their interaction $V^{qubit_j}_{loc}$ (third term). The first term in the third line of eq. (1) describes the photon field with frequency ω_{phot}, the second term the gravonons in the initial wave packet and the third term the excited gravonons due to interactions with the supercurrents in the Josephson junction. The interaction of the supercurrent with the photon is the standard coupling between a photon and matter, i.e. the common dipole coupling term (fourth line of eq. 1). The last term in eq. (1) is the coupling between gravonons and the supercurrents of the quadrupole coupling kind.

The time dependent Schrödinger equation is solved for the time development of the total wave functional: $\mathrm{i}\hbar\frac{\partial}{\partial t}\Psi(t) = \mathrm{H}_{qubit}\Psi(t)$, which is represented in the basis of field configurations. These are tensor products of the field states of the supercurrent, the photon field and the gravonon field. In our theory the interaction with the environment is included in the Hamiltonian, the environment is accounted for, when we solve Schrödinger's equation. In contrast, stochastic approaches, starting from the Liouville equation for the dynamics of the density matrix with the total Hamiltonian of the system plus environment, revert to an equation where the system alone is included in the Hamiltonian, whereas the effects of the environment are in the Lindblad term [17].

The fields in the system are the persistent current of the qubit ϕ_{qubit}, the photon field ϕ_{phot}, the gravonon field comprising $\{\mid grav\rangle\}$, $\{\mid \kappa\rangle\}$ and $\{\mid \lambda\rangle\}$. The notation for the field configurations is $\mid \phi_{qubit}, \phi_{phot}, \kappa, \lambda\rangle$, for instance $\mid 1,0,0,0\rangle$ for the initial wave packet, $\mid -1,1,0,0\rangle$ for the switched current configuration plus photon, etc. According to the assumed principle that only those warped field configurations which arise from the flat field configurations (non-warped configurations) via first order transitions are taken into account, only configurations of the kind $\mid \phi_{qubit}, \phi_{phot}, \kappa, 0\rangle$ and $\mid \phi_{qubit}, \phi_{phot}, 0, \lambda\rangle$ are involved.

The physical nature of the gravonons as massive bosons arising from gravitons, as well as the derivation of an effective Schrödinger equation in high dimensional spacetime *yielding gravonons similar to the common quantum particles as its solution*, are described in detail in ref. [10]. The gravonons are the only quanta which reside not only in 4 dimensional spacetime, but in the additional compactified hidden spacial dimensions. The decisive features of the gravonons are the high density of the gravonon quanta and weak coupling to the matter fields.

3. Explaining the coherence time of a single flux qubit in the photon field

The solution of the time dependent Schrödinger equation gives the time dependent total wave functional as a superposition of the basis configurations, varying with time. The initial wave packet in interaction with the rest configurations, but not with the gravonons, splits into two components below and above its energy, corresponding mostly to the two current configurations, clockwise and anticlockwise. With the entanglement with the gravonons they acquire finite broadening and shifts as it is shown in the left panel of fig. 1. Each group of eigenstates has entangled to the nearly degenerate part of the gravonon continuum. Oscillations between the eigenstates below and above the energy of the initial wave packet occur in the absence of entanglement with the gravonons. This is the situation for short times. Since the total wave

Journal of Physics: Conference Series **626** (2015) 012057 doi:10.1088/1742-6596/626/1/012057

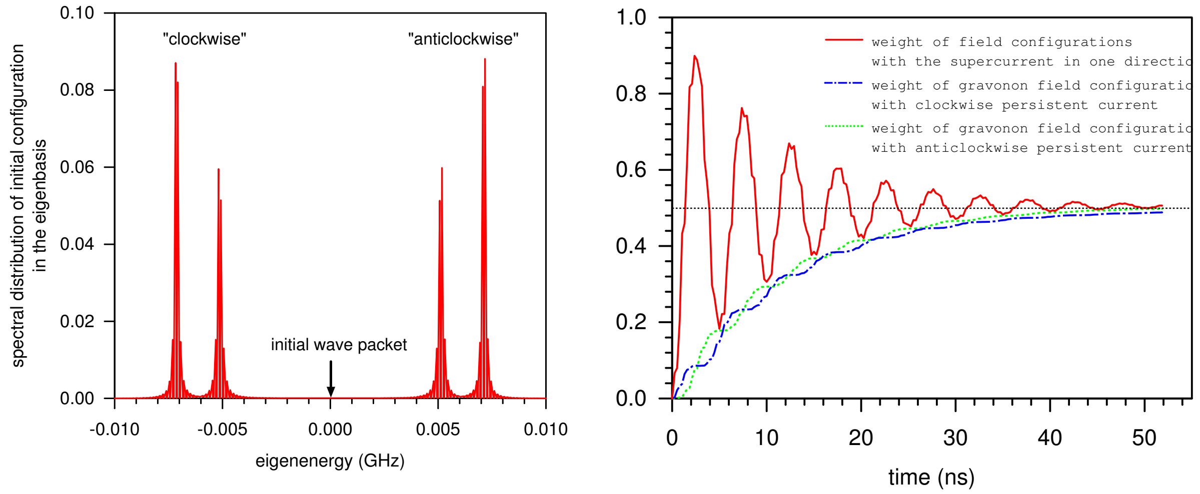

Figure 1. Left panel: spectral weight of the initial wave packet $\mid 1,0,0,0\rangle$ in the gravonon band resulting from the interactions in the local 4 dimensional subspace and the broadening due to entanglement of all local configurations with the gravonons. The configurations at energy lower than that of the initial wave packet are mostly with clockwise persistent current $\mid 1,0,0,0\rangle$ and $\{\mid 2,0,\kappa,0\rangle\}$. Those with higher energy are dominated by configurations with anticlockwise persistent current plus photon $\mid -1,1,0,0\rangle$ in the flux qubit and $\{\mid -2,1,0,\lambda\rangle\}$ in the warp resonance.
Right panel: The development with time of the weight of all field configurations with the supercurrent in one direction in a single flux qubit (full red curve) shows oscillations at short time which are exponentially damped, leading to a finite final value at long time. The reason for the damping of the oscillations is the development of the entanglement of the current states with gravonons which hinders and finally precludes the current switching. The weight of field configurations with gravonon components for the two current states are plotted as functions of time with green (short dashed) and blue (long dashed) curves.

functional has not yet acquired the components with the excited gravonons, it can be written as:

$$\Psi_1(t) = a(t) \mid 1,0,0,0\rangle + b(t) \mid 2,0,0,0\rangle + c(t) \mid -1,1,0,0\rangle + d(t) \mid -2,1,0,0\rangle \qquad (2)$$

However, the entanglement with the gravonons develops with time. The weights of warped field configurations with the persistent current clockwise, as well as those with the persistent current in the anticlockwise direction, increase with time:

$$\Psi(t) = A(t)\Psi_1(t) + \sum_{\kappa} k_\kappa(t) \mid 2,0,\kappa,0\rangle + \sum_{\lambda} l_\lambda(t) \mid -2,1,0,\lambda\rangle \qquad (3)$$

At $t = 50$ ns, when the entanglement to the gravonons has fully developed, only the warped field configurations in the total wave functional eq. (3) contribute, i.e. $A(t)$ tends to zero. They saturate at some final and finite values, i.e. the coefficients in the expansion of $\Psi(t)$ in the basis field configurations do not change with time any more. The single flux qubit is in a superposition of the two persistent current configurations, which does not change with time. In the time before the freezing of the current distribution in the flux qubit occurs, of course, the oscillations between the two current configurations are still discernible, as it shown by the full red curve on the right panel in fig. 1, though with damped amplitude. At time $t = 50$ ns a single

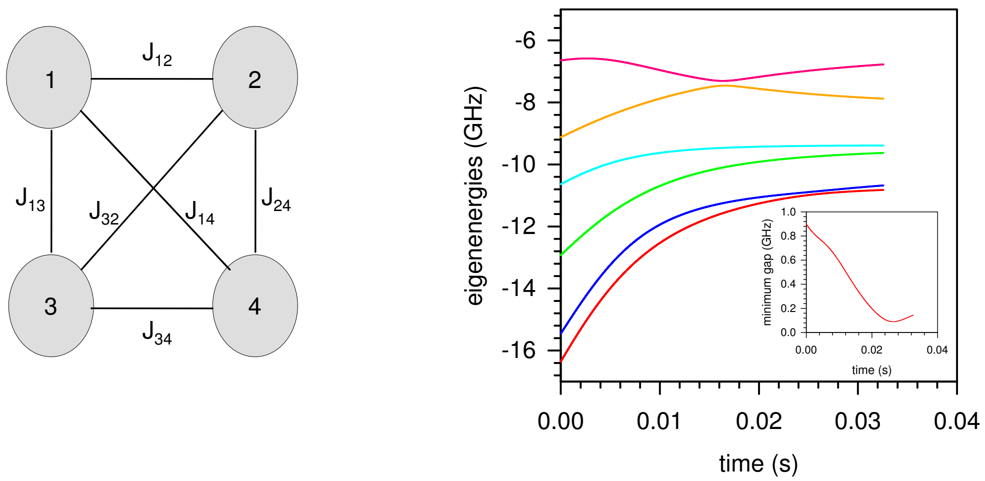

Figure 2. Left panel: a model of a four flux qubit processor implementing the time dependent Hamiltonian eqs. (4-6). The theoretical model of the D-Wave machine consists of 4 flux qubits interacting with each other with interaction strengths $J_{\alpha\beta}$ and subjected to external transverse magnetic fields with strength $ht_\alpha(t)$ varying with time.
Right panel: variation with time of the lowest eigenenergies of the 4 flux qubit system. The gap between the global energy minimum and the first excited field configuration is plotted in the inset, achieving a minimum value of less than 0.1 GHz at the time of avoided crossing.

flux qubit is frozen in a configuration in which the relative contributions of current clockwise and current anticlockwise in the superposition does not change. At that time, according to our theory, the flux qubit is maximally entangled with the gravonon environment in a coherent state. The reason not to change with time is that, due to entanglement with the gravonons, the components and their contributions to the total superimposed quantum configuration cannot change while the gravonons are in the hidden spacial dimensions. Recurrence of the gravonons back in three dimensional space, disentanglement from the degenerate gravonon band the local current configuration is originally entangled with, and entanglement with the gravonon band, degenerate with the current configuration of opposite direction, are needed to change the current configuration in the flux qubit. As these local field configurations are not energetically degenerate, the change of current requires energy.

The theoretical result in the right panel of fig. 1 is in satisfactory agreement with the experimental Ramsey fringes in ref. [1] (fig. 4A).

4. Explaining the coherence time of the D-Wave machine: four flux qubits in transverse magnetic fields

The theoretical model of the D-Wave machine consists of four qubits, as it is shown in the left panel of fig. 2, interacting with one another and subjected to external transverse magnetic fields which vary with time. The Hamiltonian for quantum annealing H_{QA} is now time dependent since the transverse external magnetic fields on the flux qubits vary with time:

$$\mathrm{H}_{QA}(t) = \sum_{\alpha=1}^{4} \mathrm{H}_{o,\alpha} + \mathrm{H}_P + V(t) + \mathrm{H}_{qubit-grav,3}. \quad (4)$$

Four terms describing the non-interacting flux qubits are taken from the Hamiltonian in eq. (1), however, exempting the interaction with the photon field in the fourth line of this equation.

Journal of Physics: Conference Series **626** (2015) 012057 doi:10.1088/1742-6596/626/1/012057

Gravonon coupling is introduced only within one qubit. H_{QA} includes terms describing the interaction between the flux qubits:

$$\mathrm{H}_P = \sum_{\alpha \neq \beta = 1}^{4} J_{\alpha\beta} \sigma_\alpha^z \sigma_\beta^z \tag{5}$$

and the interaction with the external magnetic fields:

$$V(t) = \sum_{\alpha=1}^{4} ht_\alpha(t) \sigma_\alpha^x \tag{6}$$

σ_α^z and σ_α^x are the Pauli matrices. The manipulation with time of the magnetic fields represents the quantum annealing procedure. Reducing the external transverse magnetic fields $\{ht_\alpha\}$ slowly ensures the adiabatic time development of the system towards the ground state of the Ising Hamiltonian, which is the solution of the optimization problem.

The time dependent Schrödinger equation is solved with a time dependent Hamiltonian:

$$\Psi(t) = \exp\left[-\frac{\mathrm{i} \int_0^t \mathrm{d}\tau \mathrm{H}_{QA}(\tau)\tau}{\hbar} \right] \Psi(0). \tag{7}$$

The computational basis consists of 16 flat field configurations denoted by 4 labels, which indicate the state of each flux qubit by 1 for current in the clockwise direction and -1 for current in the anticlockwise direction:

$$\begin{aligned} &\mid 1111\rangle \quad \mid 111-1\rangle \quad \mid 11-11\rangle \quad \mid 1-111\rangle \quad \mid -1111\rangle \quad \mid 11-1-1\rangle \quad \mid 1-11-1\rangle \quad \mid -111-1\rangle \\ &\mid 1-1-11\rangle \quad \mid -11-11\rangle \quad \mid -1-111\rangle \quad \mid -1-1-11\rangle \quad \mid -1-11-1\rangle \quad \mid -11-1-1\rangle \\ &\mid 1-1-1-1\rangle \quad \mid -1-1-1-1\rangle. \end{aligned} \tag{8}$$

They represent eigenstates of the Ising Hamiltonian. The notation for the gravonons is omitted, being in all cases the ground configurations $\mid 00\rangle$ with gravonons in one qubit only. Thus without gravonons we have a 16×16 matrix of configurations to diagonalize to get the eigenenergies of the 4 flux qubit system. The lowest eigenenergies and their variation with time can be seen in the right panel of fig. 2.

At $t = 0$ the effect of $ht_\alpha(t = 0) \neq 0,\ \alpha = 1, ..., 4$ is to mix in all computational basis configurations, leading to the ground state configuration of the 4 flux qubit system in the presence of the transverse magnetic fields. At the annealing time $t = t_f$ the external local transverse magnetic fields are switched off, i.e. $ht_\alpha(t_f) = 0,\ \alpha = 1, ..., 4$ and the 4 flux qubit system provides the solution of the Ising Hamiltonian eq. (4) with $V(t_f) = 0$. As the coupling to the gravonons is very weak and local, the broadening into resonances of the eigenenergies of the 4 flux qubit system is orders of magnitude smaller than the energy differences between the eigenstates even at the time of avoided crossing (cf. the inset in the right panel of fig. 2). Hence, the energy broadening, due to entanglement to gravonons, cannot lead to superpositions of the eigenstates of the 4 flux qubit system, which would destroy the adiabaticity.

In analogy with the single flux qubit case, while entangled with the gravonons each flux qubit is frozen after 50 ns in a configuration, in which the relative contributions of the two current states in this qubit does not change with time any more. Each flux qubit is stabilized in this superposition, which is typical for the global ground state configuration. Hence, the global ground state of the D-Wave machine cannot change either. Once in the ground configuration, the system of many flux qubits will stay in the ground configuration for ever. Entanglement to gravonons stabilizes the global ground state configuration and helps the coherent adiabatic time development of the D-Wave machine towards the final solution.

4.1. Destroyed adiabaticity of the D-Wave machine: four flux qubits in a phonon field

Thermal excitations cannot be avoided even at the millikelvin temperatures at which the D-Wave machine operates. It was experimentally demonstrated in ref. [3] for a 16 qubit D-Wave machine that the success probability at temperature in the range 20-100 mK is higher than at lower temperature in contrast to other attempts for quantum computing.

Let a phonon be excited in just one of the flux qubits, e.g. the third qubit in fig. 2. Terms are added to the quantum annealing Hamiltonian H_{QA} eq. (4) for the phonon and its interaction with the supercurrent of the kind:

$$\mathrm{H}_{phon} = V_{qubit,phon}\sigma_3^x(d_{phon}^+ + d_{phon}) + \frac{1}{2}\omega_{phon}d_{phon}^+ d_{phon}. \tag{9}$$

The term H_{phon} is analogous to the Jaynes-Cummings Hamiltonian of a two-level atomic system, coupling to the phonon field with coupling strength $V_{qubit,phon}$. d_{phon}^+ and d_{phon} are creation and annihilation operators for the phonon mode and ω_{phon} is the phonon frequency. With the definition of H_{phon} in eq. (9) the effect of the phonons is to account just for switching the supercurrent in the third qubit.

The result of a sudden perturbation of the 4 flux qubit system by a single phonon mode is destroyed adiabaticity. Figure 3 (left panel) shows that a fast entanglement to the phonon field around $t = 0.01$ s perturbs the distribution of the supercurrents in the third flux qubit, which is typical for the global ground state configuration of the 4 flux qubit system. Dramatic and nonrepairable arbitrary switches between the currents in the flux qubit occur which means that the global ground configuration of the 4 flux qubit system is changed, hence its adiabatic time development is destroyed and cannot be recovered. The coupling to the phonon leads to destroyed adiabatic time development in the global ground configuration of the 4 flux qubit system, as it can be seen in the plot on the left panel in fig. 3. The quantity on the vertical axis is the number of the eigenstate of the non-perturbed 4 qubit system and not its energy. The areas of the points in the plot scale with the weight of the eigenstates of the 4 flux qubit system, which get involved in $\Psi(t)$. When the perturbation by the phonon is switched on excited field configurations of the 4 flux qubit system gain weight and a significant redistribution from the global ground configuration over several excited configurations occurs. Thus, coupling to a phonon mode destroys the adiabatic time development of the system in an irrepairable way.

4.2. Gravonons suppress the effect of the phonon: four flux qubits in phonon and gravonon fields

In the Josephson junction the tunnelling currents entangle with gravonons in high spacial dimensions. The result is suppression of the effect of the phonons, and retained coherence of the system in the adiabatic ground state configuration, as it can be seen in fig. 4. The length of the symbols in the plot scales with the weight of the initial wave packet in the gravonon band, i.e. it is the spectral distribution of the initial wave packet in the gravonon continuum. The entanglement with the gravonons quenches the transitions between the low lying eigenstates of the 4 flux qubit system due to the perturbation by the phonon. The spectral distribution of the initial wave packet in the gravonon continuum is not affected by the excitation of the phonon in one of the flux qubits. As a consequence the many-qubit ground state configuration is not modified by the interaction with the phonons. The 4 flux qubit system develops adiabatically in the global ground configuration for long time significantly exceding the life time of the phonon. The gravonons suppress the effect of the phonon. While being entangled with the gravonons in the hidden dimensions, the current cannot switch direction. Entanglement to gravonons stabilizes the adiabatic ground state configuration of the D-Wave machine.

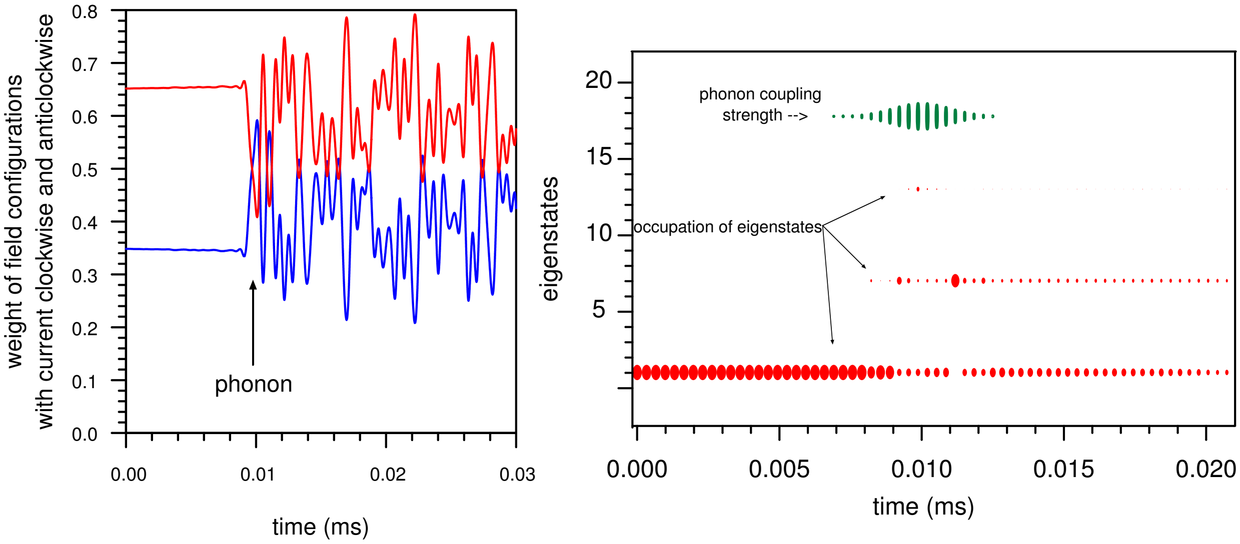

Figure 3. Destroyed current distribution and chaotic current flips in the third flux qubit as a result of the fast entanglement to the phonon field at $t \approx 0.01$ ms (left panel). On the right panel the destroyed adiabaticity in the global ground state configuration of the 4 flux qubit system as a result of the fast entanglement to the phonon field is illustrated with the variation of the weight of the low energy eigenstates at the time when the coupling in the third flux qubit to the phonon is effective. The weight of the non-perturbed eigenstates which are involved in $\Psi(t)$ is displayed with varying size of the points. When the perturbation by the phonon is switched on the variation of the weight of the low energy eigenstates of the 4 flux qubit system shows a significant redistribution from the global ground state configuration over several excited configurations. The quantity on the vertical axis is the number of the eigenstate of the non-perturbed 4 flux qubit system.

5. Conclusion

The present study of a quantum computer consisting of numerous flux qubits uses Emerging Quantum Mechanics, a method based on Schrödinger's time dependent quantum mechanics which accounts for the entanglement of fields in 4 dimensional spacetime with gravonons living in high dimensional spacetime [10]. The astonishing result is that a single flux qubit and the D-Wave computer, both macroscopic objects, retain coherence and behave as quantum objects according to the laws of quantum mechanics with long coherence time of the order of minutes. The clue to this result is the entanglement of the persistent currents in the flux qubits with the gravonons, the massive quanta of the gravitational field, which live in high spacial dimensions. The necessary condition for this result is weak coupling of the local quantum fields to an environmental continuum of high density of states, which is satisfied only by the gravonons in high spacial dimensions.

The major results of the present study of the D-Wave quantum computer can be summarized:

- The "coherence" time observed experimentally of a single flux qubit is explained, obtaining acceptable agreement with experiment. The explanation is based on entanglement with the gravonon continuum.
- The entanglement to gravonons also explains the coherence time of the D-Wave quantum computer.
- The entanglement to gravonons also explains why phonons do not perturb the quantum

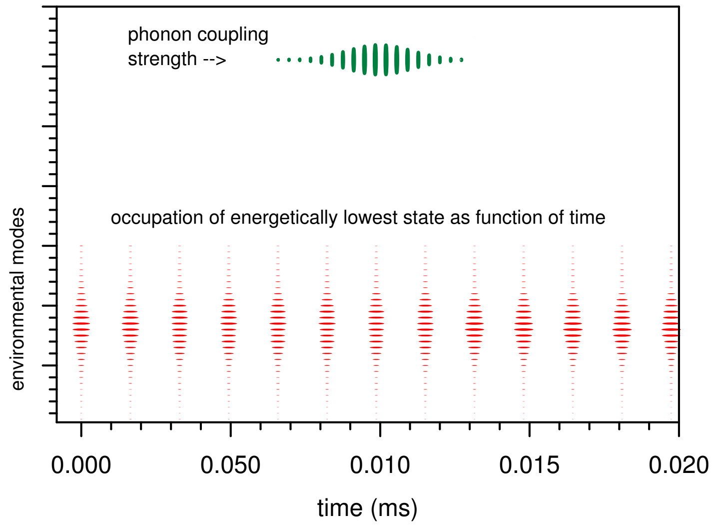

Figure 4. Entanglement of the currents with gravonons within the Josephson junction suppresses the effect of the phonon and recovers the adiabaticity of the global ground state configuration of the 4 flux qubit system. The quantity on the vertical axis is the number of gravonon state in the gravonon continuum. The length of the symbols in the plot scales with the weight of the initial wave packet in the gravonon band.

annealing process of the D-Wave machine.

These results as well as the experimental observations on the D-Wave quantum computer cannot be reproduced and explained either by stochastic quantum approaches or within conventional decoherence theory in four dimensions. This has, however, not been explicitely demonstrated in the paper so far.

Emerging Quantum Mechanics reproduces experimental observations of very different nature, where orders of magnitude discrepancies have been found by computations based on conventional quantum mechanics in three dimensional space. They include quantum diffusion of adsorbates on solid surfaces [13], and double slit diffraction experiments with massive molecules [16]. In these cases localization of quantum particles in three dimensional space is the result of the entanglement with the gravonons which live in high spacetime dimensions.

References

[1] Chiorescu I, Nakamura Y, Harmans C J P M and Mooij J E 2003 *Science* **299** 1869
[2] Johnson M W et al. 2011 *Nature* **473** 194
[3] Dickson N G et al. 2013 Nature Communications 4:1903, DOI: 10.1038/ncomms2920
[4] Boixo S, Rønnow T F, Isakov V, Wang Z, Wecker D, Lidar D A, Martinis J M and Troyer M 2014 *Nature Physics* **10** 218; *do.* 2013 *Preprint* arXiv:1304.4595v2
[5] cf. www.dwavesys.com
[6] Ising I 1924 *Contribution to the Theory of Ferromagnetism* PhD Thesis (Univ. Hamburg)
[7] Lanting T et al. 2014 *Phys. Rev.* X **4** 021041; *do.* 2014 *Preprint* arXiv:1401.3500
[8] Wang L, Rønnow T F, Boixo S, Isakov S V, Wang Z, Wecker D, Lidar D A, Martinis J M and Troyer M 2013 *Preprint* arXiv:1305.5837v1
[9] Albash T, Vinci W, Mishra A, Warburton P A, Lidar D A 2014 *Preprint* arXiv:1403.4228v3
[10] Doyen G and Drakova D 2014 *Preprint* arXiv:1408.2716
[11] Doyen G and Drakova D 2011 *J. Physics: Conf. Series* **306** 012033
[12] Drakova D and Doyen G 2011 *J. Physics: Conf. Series* **306** 012068
[13] Drakova D and Doyen G 2013 *J. Physics: Conf. Series* **442** 012049
[14] Drakova D and Doyen G 2012 *Preprint* arXiv:1204.5606 7

[15] Doyen G and Drakova D 2013 *J. Physics: Conf. Series* **442** 012032
[16] Doyen G and Drakova D *present volume*
[17] Lindblad G 1976 *Commun. Math. Phys.* **48** 119