

RESEARCH of PCE STAMP GROUP – related to QUANTUM INFO

1. GENERAL MODELS of QUANTUM COMPUTATION

Quantum Walks

Topological Quantum Computation

2. QUANTUM ISING & RELATED SYSTEMS

Solid-state spin systems

Spin Qubit systems

Spins in semiconductors

Q Ising Q memories and computers

Expt: LiHo, spins in
semiconductors,
Nuclear spin systems

3. DECOHERENCE MECHANISMS & their SUPPRESSION

Spin & Oscillator Bath decoherence

Dipolar Decoherence

3rd party decoherence

Light-Harvesting molecules

Expt: LiHo, other REarths
magnetic molecules,
magneto-optical expts,
Superconductors & semiconds
Adrenalin system, LHMs

4. QUANTUM MECHANICS & GRAVITY

Casimir effect, Anomalies

Entanglement & decoherence in Q Gravity

CWL theory of Q Gravity

Expt: optomechanical,
astronomical

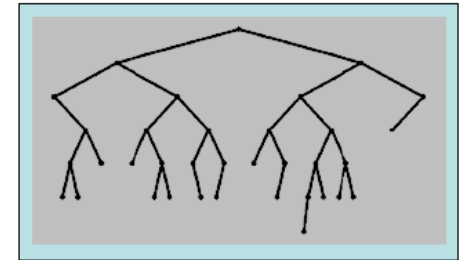
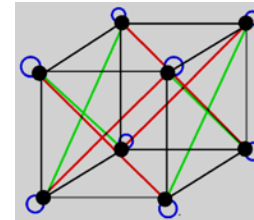
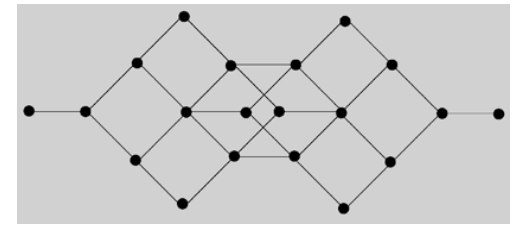
1. GENERAL MODELS of QUANTUM COMPUTATION

Simple Quantum Ising

$$H = - \sum_{i,j} V_{ij}^{zz} \tau_i^z \tau_j^z - \Delta_0 \sum_i \tau_i^x$$

Simple Quantum Walk

$$\hat{H}_s = - \sum_{ij} \Delta_{ij}(t) (\hat{c}_i^\dagger \hat{c}_j + \hat{c}_i \hat{c}_j^\dagger) + \sum_j \epsilon_j(t) \hat{c}_j^\dagger \hat{c}_j$$



Prokof'ev, N.V., Stamp, P.C.E, Phys Rev A74, 020102(R) (2006)
 Hines A., Stamp, PCE, Phys Rev A75, 0623231 (2007).

Topological Quantum Computation

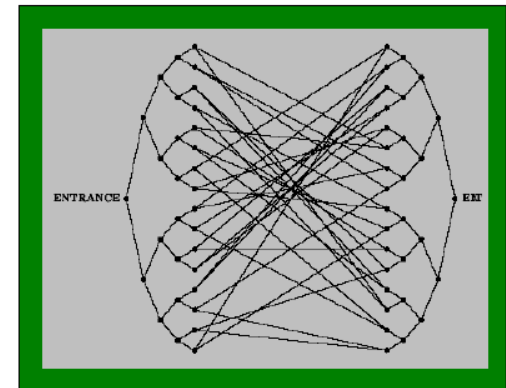
Example - the toric code system:

$$H_Q = H_{TC} - h_x \sum_b \sigma_b^x - h_z \sum_b \sigma_b^z$$

$$A_s = \prod_{j \in s} \sigma_j^x \text{ and } B_p = \prod_{j \in p} \sigma_j^z$$

Then

$$H_{TC} = -J_x \sum_s A_s - J_z \sum_p B_p$$



I.S. Tupitsyn, A. Kitaev, N.V. Prokof'ev, P.C.E. Stamp, Phys. Rev. B82, 085114 (2010)

CURRENT WORK: PCE Stamp solo

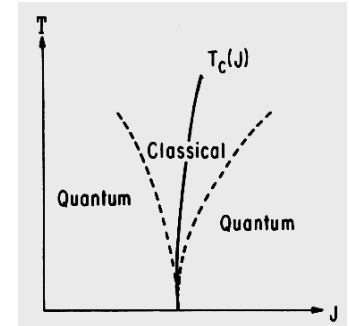
2. QUANTUM ISING & RELATED SYSTEMS

The basic simple model is
$$H = - \sum_{i,j} V_{ij}^{zz} \tau_i^z \tau_j^z - \Delta_0 \sum_i \tau_i^x$$

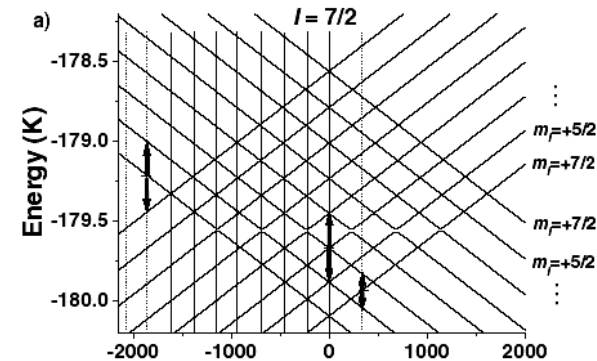
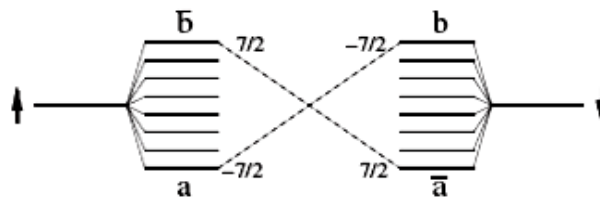
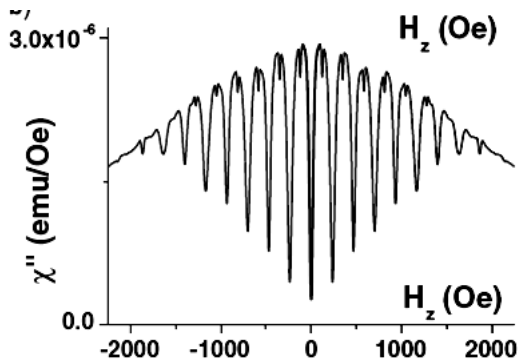
Interesting for many reasons:

- Quantum phase transitions
- Quantum Spin Glasses + dielectric glasses
- Related to Q Computation & Q memory models
- Maps to many other systems

Can also model coupled Quantum Computer + Q Memory system



Key experimental system: LiHo Nuclear spin bath crucial



Also looking at dynamical effects

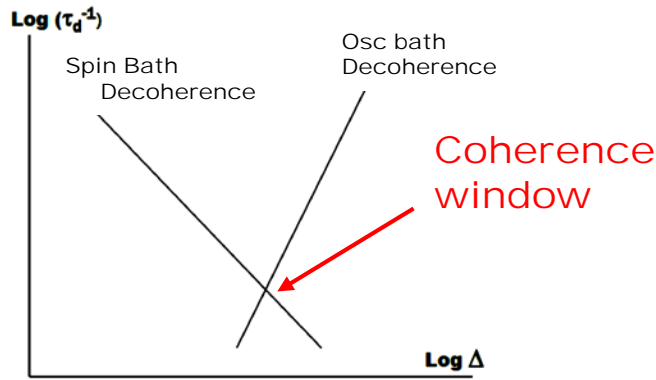
$$H(t) = - \sum_{j=1}^N [\mathbf{B}_o + \mathbf{H}(t)] \cdot \boldsymbol{\tau}_j - \sum_{i < j} V_{ij} \tau_i^z \tau_j^z + H_{\text{HF}}$$

Schechter M, Stamp PCE, Phys. Rev Lett **95**, 267208 (2005)
Gomez-Leon A, Stamp PCE, arXiv: 1512:08315

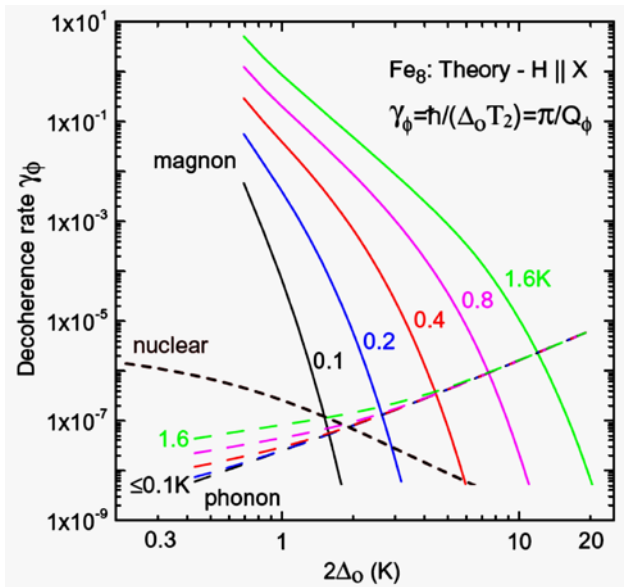
CURRENT WORK: with A Gomez-Leon, R McKenzie, T Cox

3. DECOHERENCE MECHANISMS

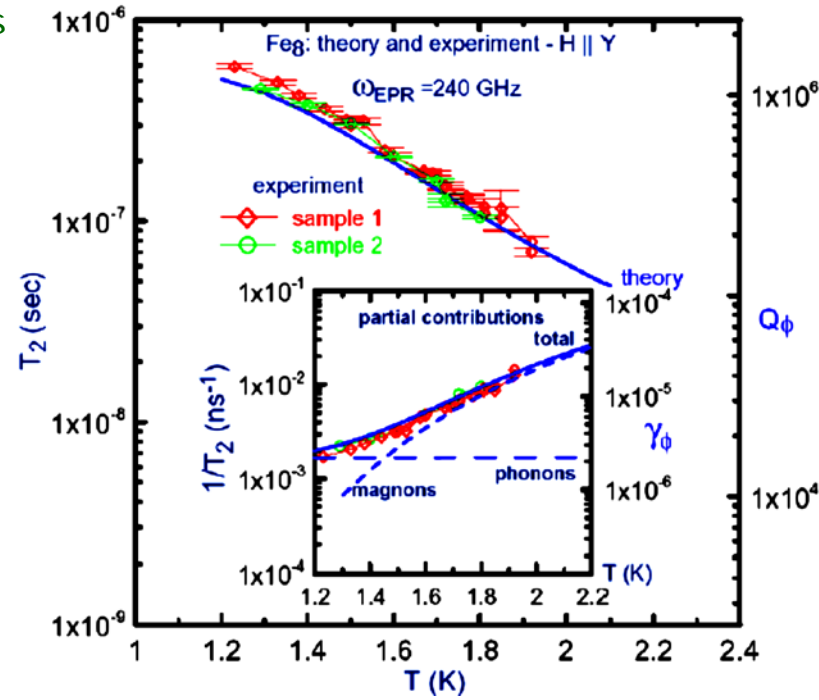
Fighting decoherence is like fighting the hydra



Conventional mechanisms have generic behaviours shown above. We're now getting a handle on these - experimentally & theoretically



LEFT: Theory
RIGHT: Expt

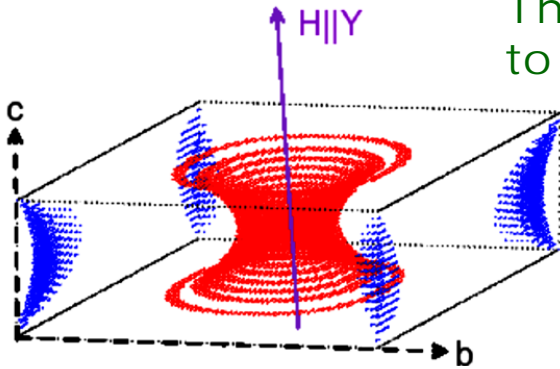


Morello, A, Stamp, P.C.E., Tupitsyn, I.S., Phys. Rev. Lett **97**, 207206 (2006);
S. Takahashi, ...PCE Stamp, Nature **476**, 76 (2011).

CURRENT WORK:
with A Gomez

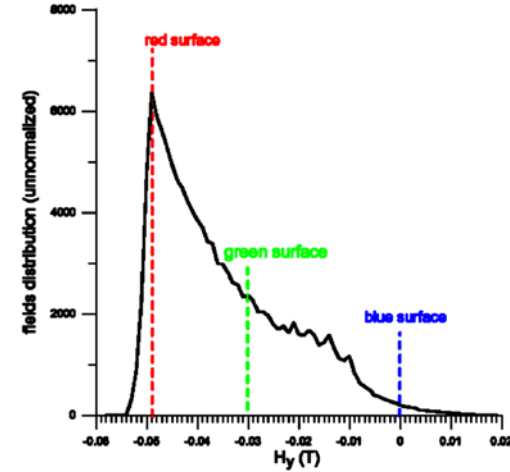
Dipolar Decoherence: This is an example of long-range decoherence between the qubits, coming from long-range unscreened inter-qubit interactions

There are certain generic features to all such long-range couplings:



Shape of sample determines results

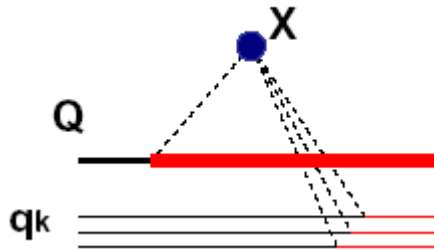
Qubit collective modes develop "resonant surfaces" develop.



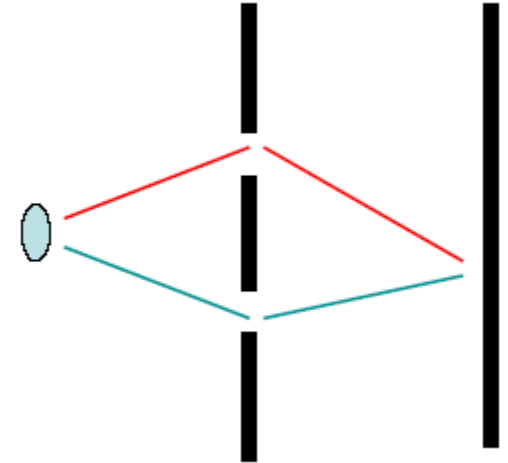
Typically these long-range couplings are the worst for decoherence. Not clear that error correction codes can deal with them.

CURRENT WORK: with A Gomez-Leon, T Cox

3rd Party Decoherence: this is almost unexplored. It is surely important for experiments. It arises because a system can entangle with a bath without ever coupling to it.



Example:
buckyball



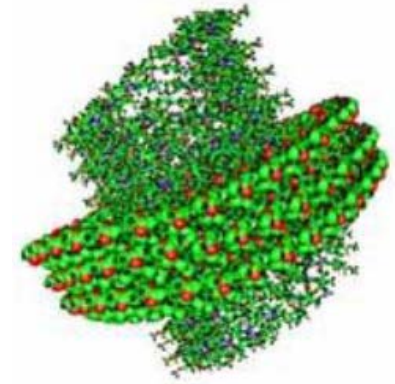
Stamp, P.C.E., Studies Hist. Phil. Mod. Phys. 37, 467-497 (2006)

CURRENT WORK: with C deLisle

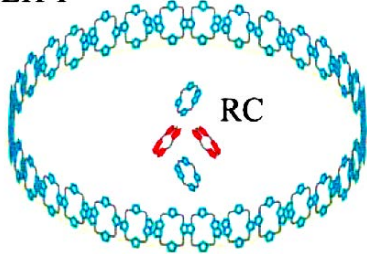
Decoherence and quantum relaxation in Biomolecules

Typically we deal with charge & spin transport in biomolecules. Experiments show long-range coherence (in LHM: Light-Harvesting Molecules) & EPR-style entanglement (in FAD complexes, or, eg., smaller pyrene molecules, used in avian navigation).

chlorosome (green sulfur bacteria)



LH-I



Without spin we have a bare Hamiltonian

$$H_o = \sum_{ij} \left[t_{ij} c_i^\dagger c_j e^{iA_{ij}^o} + H.c. \right] + \sum_j \varepsilon_j c_j^\dagger c_j$$

often in ring configurations.

For charge transport it turns out that non-diagonal phonon couplings are crucial:

$$\begin{aligned} V &= -\tilde{\alpha} t_o \sum_i (\hat{X}_i - \hat{X}_{i+1})(c_i^\dagger c_{i+1} + h.c.) \\ &= N^{-1/2} \sum_{k,q} M(k,q) c_{k+q}^\dagger c_k (b_q^\dagger + b_q) \end{aligned}$$

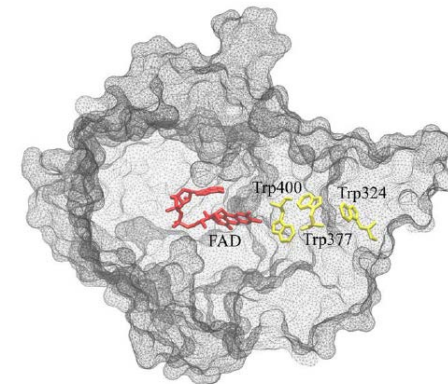
Key in the dynamics of polarons and excitons in LHM's

For spin transport, everything depends on entanglement with nuclear spins:

$$H = \sum_{\mathbf{k}=1,2} H_{\mathbf{k}} = -\gamma_e \vec{B} \cdot \sum_{\mathbf{k}} \vec{S}_{\mathbf{k}} + \sum_{\mathbf{k},j} \vec{S}_{\mathbf{k}} \cdot \hat{\lambda}_{\mathbf{k},j} \cdot \vec{I}_{\mathbf{k},j}$$

Key for avian navigation

Arabidopsis Thaliana cryptochrome-1



Z. Zhu, A. Aharony, O. Entin-Wohlman, P.C.E. Stamp, Phys Rev **A81**, 062127 (2010)
D. Marchand, ..., P.C.E. Stamp, Phys Rev Lett. **105**, 266605 (2010)

CURRENT WORK: with M Berciu, L Ruocco, Z Zhu

4. QUANTUM MECHANICS & GRAVITY

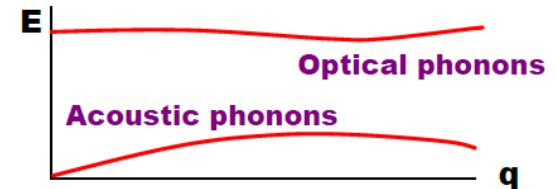
There is a large effort to test Q gravity (as opposed to classical gravity), and to look for Q gravitational effects. Involves fundamental issues and questions about:

QM on the macroscopic scale

Clash between QM/QFT and General Relativity

Possible breakdown of QM coming from gravitational effects.

Experiments: Optomechanical superpositions
Casimir effects
"2-slit" type experiments



Example Theory: CWL theory

$$G_o(2,1) = \int_1^2 \mathcal{D}q(\tau) e^{\frac{i}{\hbar} S(2,1)} \longrightarrow \sum_{n=1}^{\infty} \prod_{k=1}^n \int_1^2 \mathcal{D}q_k(\tau) \kappa_n[\{q_k\}] e^{\frac{i}{\hbar} S[q_k;2,1]}$$

Other examples: Kibble, Penrose, etc.
(and Grav decoherence theories)

P.C.E. Stamp, Phil. Trans. Roy. Soc. **A370**, 4429 (2012)

P.C.E. Stamp, New J. Phys **17**, 06517 (2015)

CURRENT WORK: with A Barvinsky, D Carney,
M DesRochers, C deLisle, J Wilson-Gerow

