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Vibrationally-assisted energy transfer in a trapped ion quantum simulator

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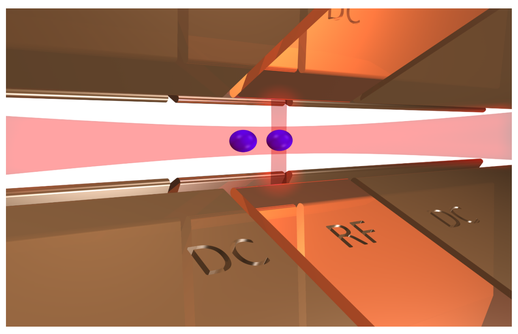
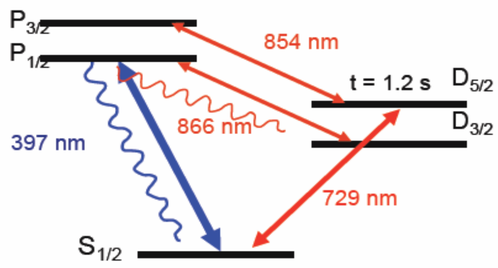
Experimental setting



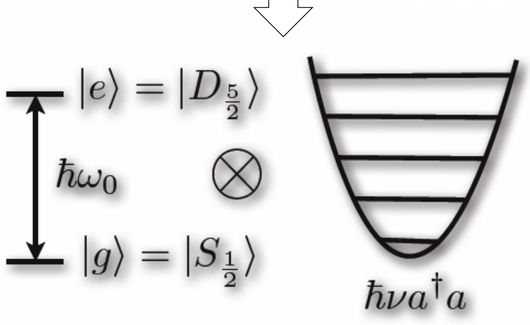
Two trapped Ca^+ ions. The laser beams generate the simulated Hamiltonian below.

Energy levels of Ca^+



- All available from diode lasers

Simplified description of a single ion



Physical motivation

Energy transfer from pigments in light-harvesting complexes is believed to critically depend on spectral properties of the bosonic environment.

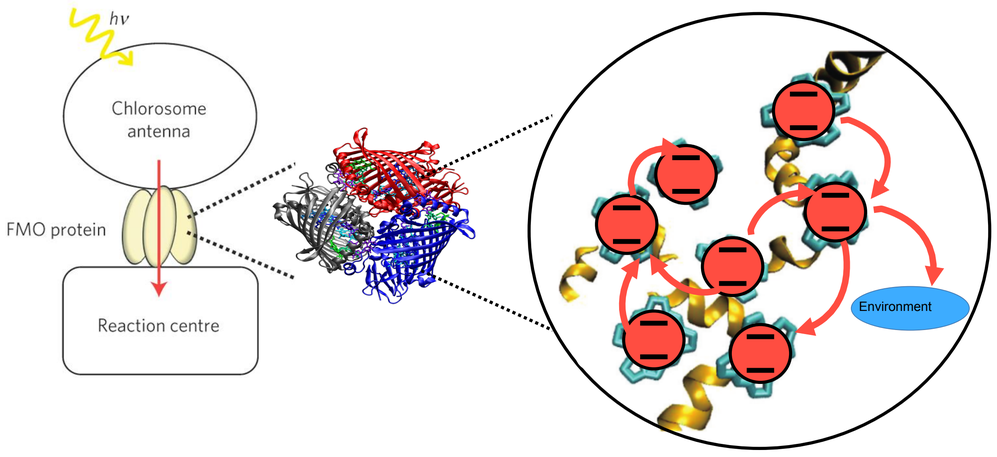


Fig. modified from Ishizaki and Fleming, PNAS 106.41 (2009)

Two-site model exhibiting vibrationally-assisted energy transfer between coupled two-level systems:

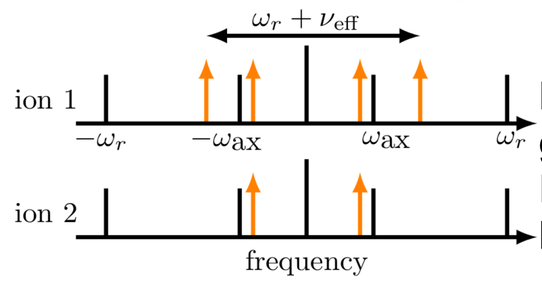
$$H = \frac{\Delta}{2}\sigma_z^{(1)} + \frac{J}{2}\sigma_x^{(1)}\sigma_x^{(2)} + \frac{\kappa}{2}\sigma_z^{(1)}(a + a^\dagger) + \nu_{\text{eff}}a^\dagger a$$

Inhibits direct coupling	Direct site-site coupling	Environment coupling – Can assist energy transfer	Environmental frequency

Quantum Simulation

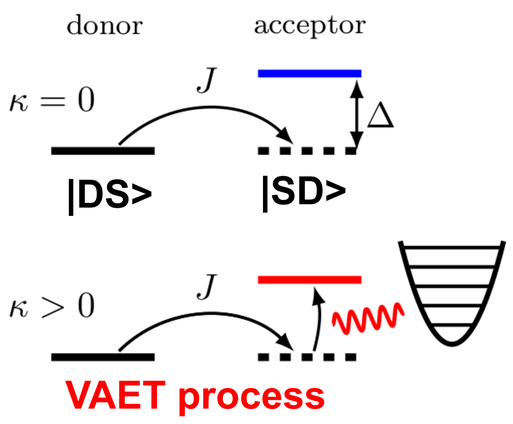
We implement a two-site VAET model. The electronic levels of the two ions serve as two-level energy sites, and the quantum motion of the ions provides and environment. The site-site and site-environment couplings are engineered via quantum gates.

Experiment: Prepare the combined electronic state |DS> and look for population transfer to |SD> while varying model parameters.

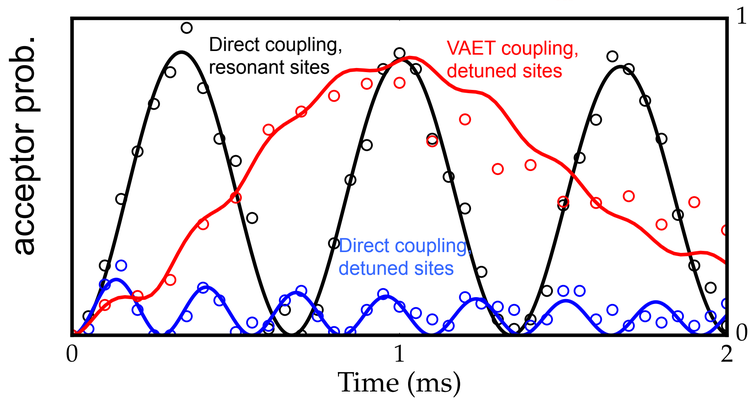


Laser tones required to generate the model Hamiltonian. The laser beams are shown at left.

$J = 2\pi \times 1.3$ kHz, $\Delta = 0$
$\Delta = 4J, \nu_{\text{eff}} >> J, \kappa = 1.5J$
$\Delta = 4J, \nu_{\text{eff}} = \Delta, \kappa = 1.5J$

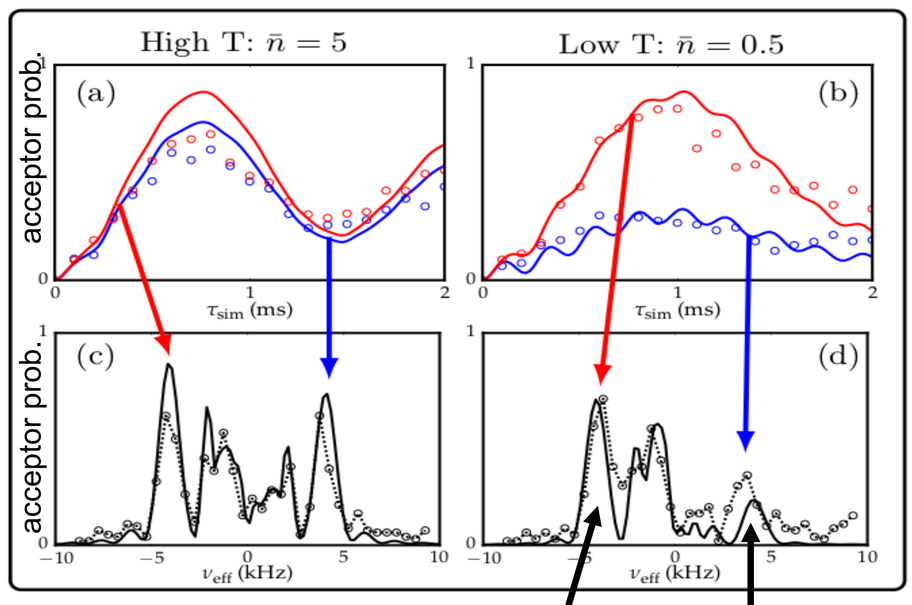


VAET process



Energy transfer vs frequency and temperature

Enhanced energy transfer between sites when the environment frequency is an integer fraction of the detuning because the environment changes by an integer number of quanta during the transfer process.



Environment **absorbs** excess energy

Environment **provides** energy

Outlook

To outperform classical computers, our model must be extended. We believe a three-site model, which can exhibit interesting phenomena such as directed energy flow, can be realized in the near future. A five-site model coupled to 15 vibrational degrees-of-freedom is sufficiently complex to outperform modern supercomputers. We expect that our platform can be scaled to this level, as extending the model requires approximately linear increases in laser power.

Acknowledgements

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