Filling a Critical Gap: Transfer of Nuclear Excitation via Low-Energy Couplings

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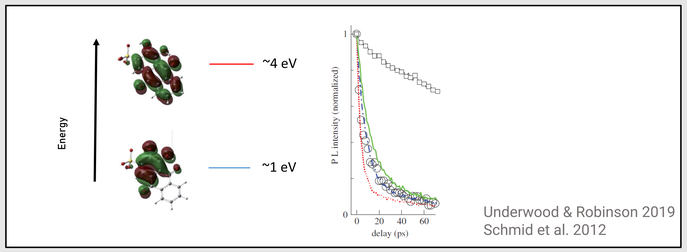
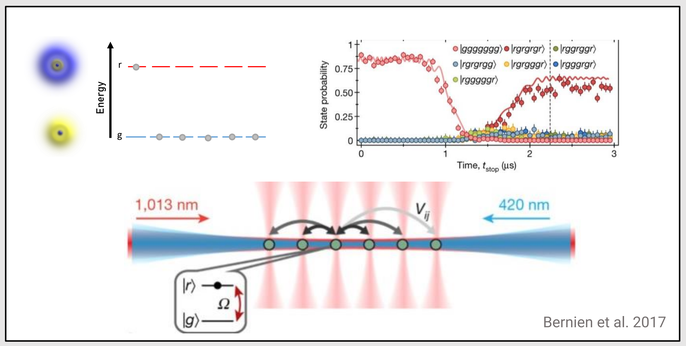
I. Controlling quantum state transitions

Most energetic quantum states decay to a lower state "at their own pace" (spontaneous emission), per the corresponding half-life.

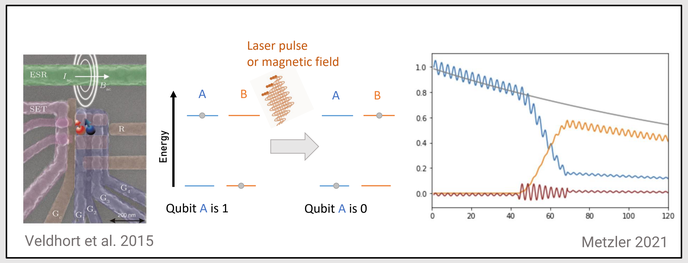
However, quantum engineering increasingly manages to control excitation and de-excitation of quantum states (at molecular, atomic, and nuclear scales):



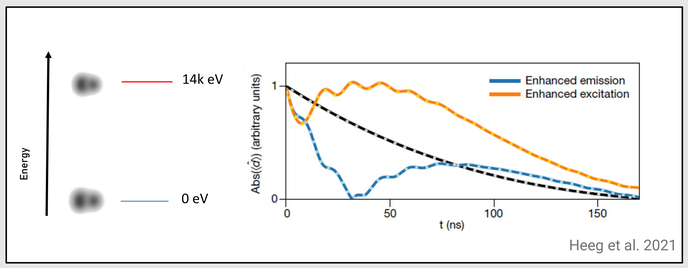
Spontaneous (squares) and accelerated (circles) de-excitation of a molecule. Acceleration is caused by energy transfer to a strongly coupled resonant neighboring molecule.



Deliberate excitation and de-excitation of atoms in a chain due to tuning couplings between those atoms.



Flipping a Quantum Dot qubit by temporarily increasing the coupling strength to a nearby resonant qubit.



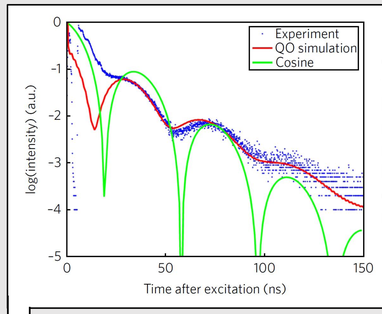
Accelerating the de-excitation of Fe-57 nuclei by coupling to nearby resonant nuclei.

II. Low-energy couplings in the literature

What has been done? What needs more work?

Two key parameter in each of these resonance energy transfer processes are:

- the state transition energy
- the energy in the coupling medium (from low to high)



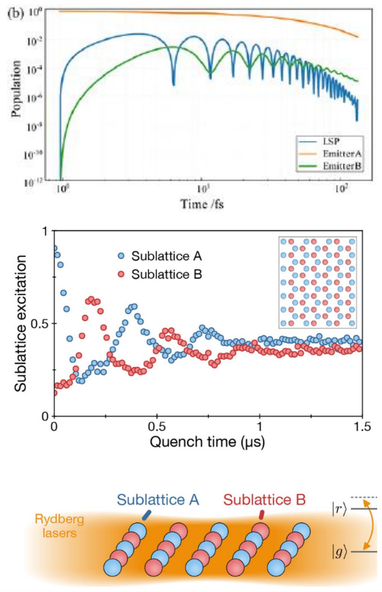
Rabi oscillations of 14.4 keV transition energy between resonant nuclei mediated by 14.4 keV photons as coupling medium.

MORE WORK NEEDED

e.g. Rabi oscillations of 14.4 keV transition energy between resonant atoms mediated by <3 eV photons as coupling medium.

Nuclear levels	e.g. Haber et al. 2017 **Nuclear transition energy transferred via large coupling energy**	**Nuclear transition energy transferred via much smaller coupling energy**
Molecular/atomic levels	**Atomic transition energy transferred via large coupling energy** e.g. Raimond et al. 2001 **Coupling energy similar to transition energy**	**Atomic transition energy transferred via much smaller coupling energy** e.g. Gettapola et al. 2019; Bluvstein et al. 2021 **Coupling energy much smaller than transition energy**

Rabi oscillations of 1.5 eV transition energy between resonant atoms mediated by <50 meV photons as coupling medium.

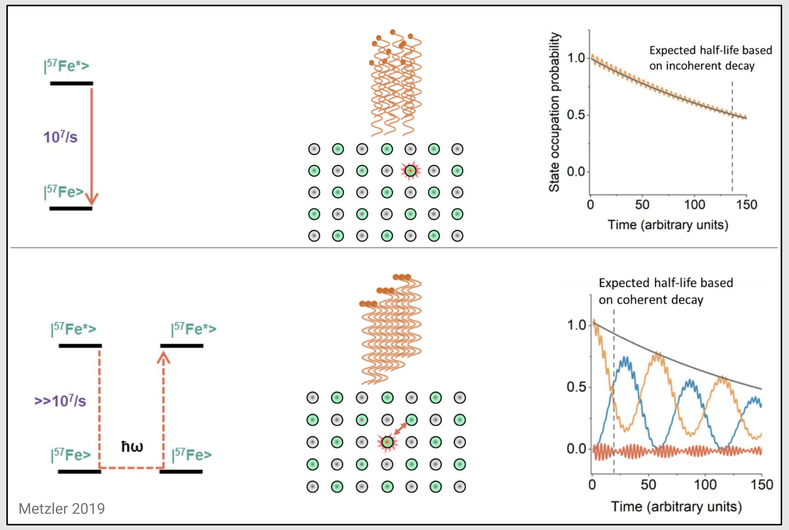


III. Exploring the impact of low-energy couplings in resonant systems at the nuclear scale

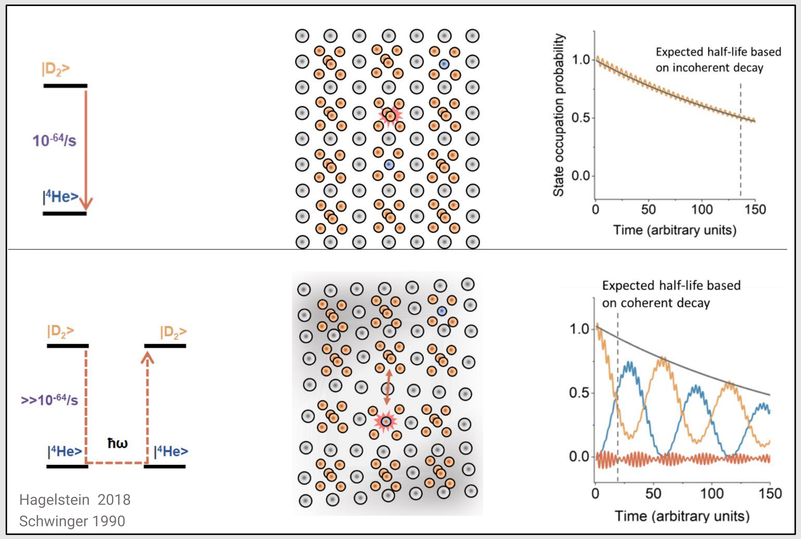
Bridge-building experiments, connecting existing literature with reported nuclear anomalies:

Transferring nuclear transition energy via much smaller coupling energy (e.g. optical photons/phonons).

- requires high population in coupling modes and/or further intensification through superradiance
- represents a fundamental tool for manipulating nuclear states elegantly



Connection to nuclear quantum dynamics literature:
acceleration of Fe-57* to Fe-57* nuclear transition; from spontaneous emission rate 10^7/s to $>>10^7$/s.



Connection to nuclear anomalies literature:
acceleration of D_2 to He-4 nuclear transition; from spontaneous emission rate 10^{-64}/s to $>>10^{-64}$/s.

Heeg, et al. (2021). Coherent X-ray–optical control of nuclear excitons. Nature, 590(7846), 401–404.

Schmid et al. (2012). Energy transfer processes along a supramolecular chain of π-conjugated molecules. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 370(1972), 3787–3801.

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Bluvstein et al. (2021). Controlling quantum many-body dynamics in driven Rydberg atom arrays. Science.

Gettapola et al. (2019). Control of quantum emitter-plasmon strong coupling and energy transport with external electrostatic fields. Journal of Physics: Condensed Matter, 32(12), 125301.

Bernien et al. (2017). Probing many-body dynamics on a 51-atom quantum simulator. Nature, 551(7682), 579–584.

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Metzler, F. (2019). Experiments to Investigate Phonon-Nuclear Interactions [Thesis]. MIT.

Hagelstein, P. L. (2018). Phonon-mediated Nuclear Excitation Transfer. J. Cond. Mat. Nucl. Sci, 27, 97–142.

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