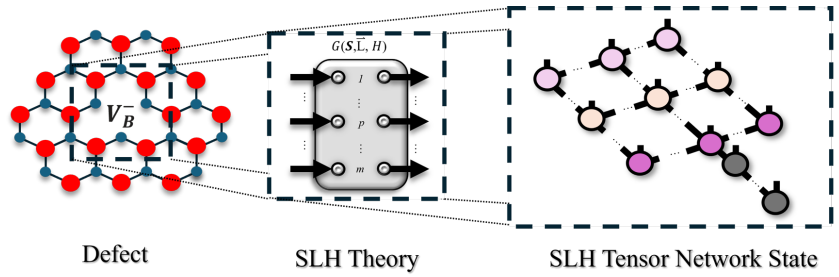
Characterization of Hexagonal Boron Nitride Quantum Defects as an SLH Tensor Network

Defect-based quantum emitters in hexagonal boron nitride (hBN) are promising for the development of spin-photon interfaces, but its quantum emission has yet to be fully understood at room temperature due to multi-environmental interactions. In this work, we combine a quantum input-output network framework with tensor network methods to describe the photon emission in the boron vacancy quantum defect, V_B^- as an SLH triple, G_{hBN}. We showcase a time-evolving block decimation algorithm between optical and spin transitions to a first-order perturbation, which the tensor network scales on a polynomial order as it reaches a steady-state solution. We investigated the effects of a range of power of a coherent laser state exciting the primarily radiative port of G_{hBN}, highlighting the output photon emission of characteristic slow radiative decay rate and fast radiative decay rate associated with an empirical lifetime of 0.7 ns. Our results and methodology demonstrate that quantum emission is emphasized by the time scale of the lifetime and the influx of photons at the input port of G_{hBN}.

Antonio Cobarrubia, *Sancia M. Tauro, Joshua R. Hendrickson, and Sanjay K. Behura*

This research is supported by the Air Force Research Laboratory's Minority Leaders Research Collaboration Program (GR131299) and the Computational Science Research Center (CSRC) at San Diego State University

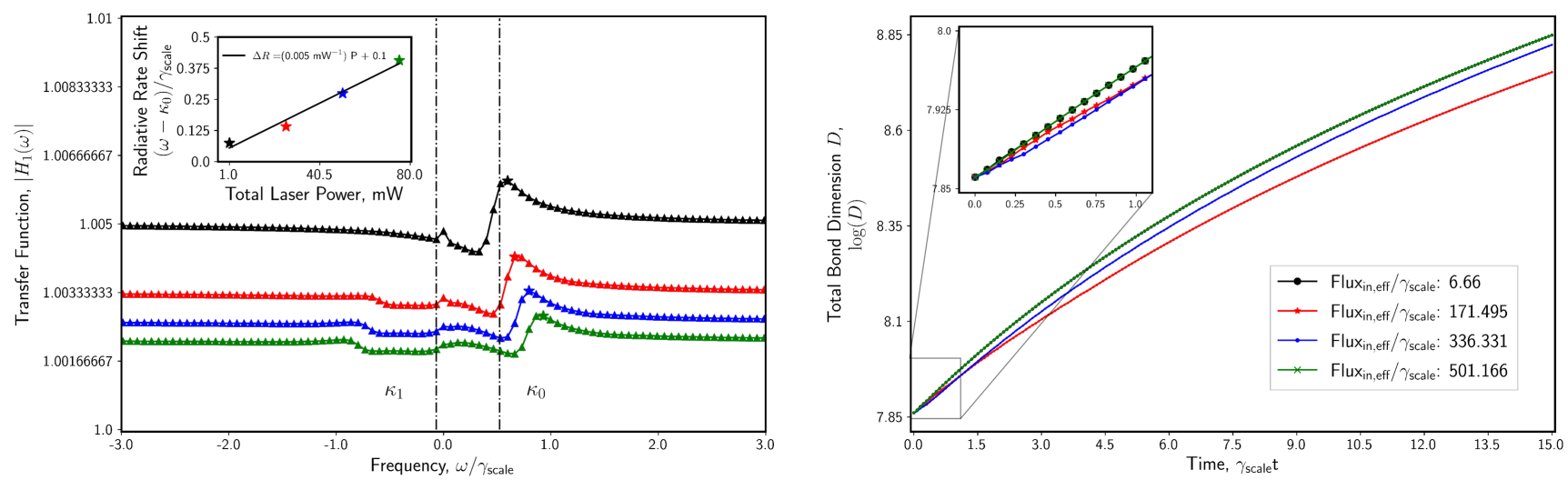


Characterization of boron vacancy (V_B^-) in hexagonal boron nitride as an SLH tensor network model.

$$|\Psi(t+dt)\rangle = \exp\{dG\}|\Psi(t)\rangle$$

$$dG = \left(-iH - \frac{\vec{L}^\dagger \vec{L}}{2}\right)dt + d\vec{B}^\dagger \vec{L} - \vec{L}^\dagger \boldsymbol{S} d\vec{B} + \mathrm{Tr}\{(\boldsymbol{S}-1)d\boldsymbol{\Lambda}\}$$

Quantum Stochastic Differential Equation of an SLH Triple where **S** is the scattering matrix, L is the Lindbladian operator, and H is the internal energy of the V_B^- defect. The infinitesimal d $\vec{B}$ and $d\boldsymbol{\Lambda}$ are associated to the bosonic field annihilation and number operator, respectively



(*Left*) Transfer function of the SLH tensor network simulated output emission of a dipole-induced radiation (κ_0) port of boron-vacancy defect, V_B^-. We examined a range of laser power that excites the ground-state to an excited-state of the V_B^- (Power ~ photon flux $\langle\Omega\rangle$). Our results highlights an approximate linear shift with an increase in power (inset), as well as the increased presence of an excited-metastable-ground state transition pathway (κ_1). (*Right*) Bond dimension growth of the SLH tensor network over the simulation time domain. An optimal expansion of growth before it reaches a steady-state (polynomial ordered) depends on the number of photons interacting with the boron vacancy defect.