Structure and efficiency in bacterial photosynthetic light harvesting

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Photosynthetic organisms use networks of chromophores to absorb sunlight and deliver the energy to reaction centres, where charge separation triggers a cascade of chemical steps to store the energy. Using a Lindblad master equation approach, we build a detailed model of the photosynthetic antenna complexes in purple bacteria, with a focus on explicitly modelling the interaction with natural, incoherent light and capturing the multiple effects of coupling to vibrational modes with a large range of frequencies. In particular, we include, for the first time, the effect of slow vibrational modes by introducing time-dependent disorder.

We find that the system remains almost entirely in its groundstate for all time, with only a miniscule fraction of excited state present at any given moment. This tiny fraction is, over a time average, in a state very close to the maximally mixed state within each antenna component. Exciton density moves around the antenna with the aid of the vibrational environment, which drives relaxation towards thermal equilibrium, while also continually changing the identity of the thermal state.

Additionally, we apply our model to simple artificial systems with very few structural constraints, demonstrating that efficiency depends more strongly on the proximity rather than the specific spatial arrangements of the chromophores. The high efficiency of these systems offers an explanation for the fact that different organisms achieve extraordinarily efficient energy transport with greatly differing structures. It also paves the way for a new approach to designing artificial light-harvesting devices that are highly efficient and easily synthesised.

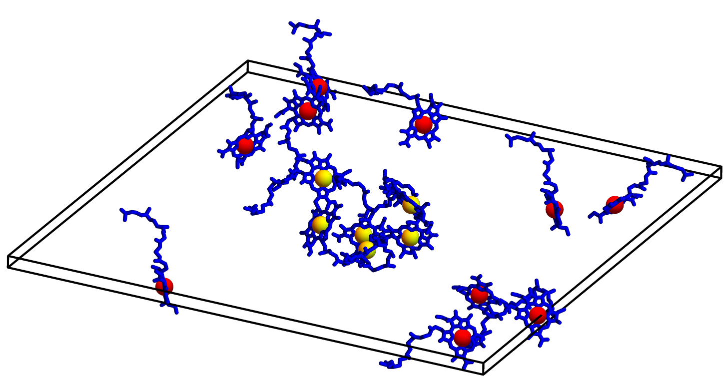

Figure 1: The efficiency of a network of chromophores does not depend strongly on their specific spatial arrangement. We demonstrate this by simulating an artificial network of chromophores placed randomly in a box around a central reaction centre (highlighted with yellow centres).