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Quantum Effects in Microtubules: Energy Flow, Information Dynamics, and Relevance to Neurodegeneration

Dr Lea Gassab *(University of Waterloo, Canada)*

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Venues: Online and NITheCS Seminar Room, Stellenbosch University

ABSTRACT

Microtubules are central components of the neuronal cytoskeleton, where they support cell structure, intracellular transport, and synaptic function. Their destabilization is increasingly recognized as an early and important feature of neurodegenerative pathology. At the same time, oxidative stress is strongly implicated across major neurodegenerative disorders and can directly disrupt axonal microtubule organization and integrity.

In this context, microtubules are not only structural elements but also plausible photophysical and information-processing substrates. Recent experiments report unexpectedly efficient ultraviolet photoexcitation migration in microtubules, with diffusion lengths on the order of a tubulin dimer and sensitivity to anesthetics. Newer studies on large tryptophan networks in tubulin-based architectures show collective ultraviolet responses consistent with superradiant behavior and geometry-dependent fluorescence yield changes.

In our recent work, we used a quantum open-systems framework to study ultraviolet excitation dynamics in microtubule tryptophan networks. Using a Lindblad description built from a radiative non-Hermitian model, we examined how excitation conditions and network structure influence energy and information flow, and we used quantum information measures to characterize coherence and correlations in these systems. This lets us study not only where the tryptophans are arranged in the microtubule, but also how excitations and correlations evolve over time across that network.

In conclusion, we will highlight the limitations of current models and available experimental evidence, and discuss what is needed for future progress, including stronger experimental validation and more realistic biological modelling.

BIOGRAPHY

Lea Gassab earned her bachelor's and master's degrees at ENS Lyon (France) and completed a PhD in Physics at Koç University (Türkiye). Her research spans quantum biology, quantum optics, and quantum metrology. She is currently a postdoctoral scholar in the Quantum Neurobiology Lab led by Professor Travis Craddock at the University of Waterloo. In September 2025, she was awarded a Provost Interdisciplinary Postdoctoral Fellowship to investigate oxygen radical–induced energy transfer mechanisms in microtubule networks, with the goal of advancing quantum biological approaches to neurodegenerative disease intervention.

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