IOCU 2026 Conference

The 3rd International Online Conference on Universe

4–6 March 2026 | Online

MDPI

Quantum Biology: Quantum Phenomena in Living Systems in a Cosmic Context

Isac Maria Crina [1]

[1] Alexandru Ioan Cuza University of Iași, Faculty of Biology, Department of Biology, 20A Carol I Boulevard, 700505 Iași, Romania

crina.isac@student.uaic.ro

INTRODUCTION & AIM

Quantum biology is an emerging interdisciplinary field that investigates the role of quantum mechanical phenomena in biological systems. While classical biochemistry explains many aspects of life, increasing experimental and theoretical evidence indicates that non-trivial quantum effects such as coherence, tunneling, and entanglement contribute functionally to essential biological processes.

Quantum coherence has been observed in photosynthetic pigment protein complexes, quantum tunneling has been implicated in enzyme catalysis and olfaction, and spin-dependent reactions involving entanglement are associated with magnetoreception. These discoveries challenge the traditional assumption that quantum effects are too fragile to persist in warm, noisy biological environments.

The aim of this work is to analyze the fundamental quantum mechanisms underlying selected biological processes and to evaluate how these mechanisms might operate under extreme cosmic conditions, including low temperatures, high radiation levels, microgravity, and low-energy environments. A broader objective is to explore the implications of quantum biological processes for the emergence and sustainability of life beyond Earth.

METHOD

The study integrates insights from experimental and theoretical research across quantum physics, molecular biology, and astrobiology. Key approaches include:

- Analysis of quantum coherence in photosynthetic pigment–protein complexes, such as the Fenna–Matthews–Olson complex.
- Examination of proton and electron tunneling in enzymes like alcohol dehydrogenase, and evaluation of vibrationally assisted olfaction models proposed by Luca Turin.
- Review of spin dynamics and radical pair mechanisms in cryptochrome, relevant to magnetoreception in species such as the European robin.
- Interpretation of these mechanisms in the context of extreme cosmic environments, including temperature, radiation, gravity, and energy limitations.

This comprehensive synthesis highlights patterns and principles across diverse studies, emphasizing the functional relevance of quantum phenomena in biology and astrobiology.

RESULTS & DISCUSSION

Analysis indicates that quantum coherence can persist for biologically relevant timescales in structured protein environments, enabling highly efficient energy transfer during photosynthesis. Such efficiency may be particularly advantageous in low-light or energy-limited cosmic environments.

Quantum tunneling in enzyme catalysis reduces effective activation barriers and may allow biochemical reactions to proceed under lower temperature conditions than predicted by classical kinetics. This suggests that metabolic activity could remain viable in cold extraterrestrial habitats.

The radical pair mechanism in magnetoreception demonstrates that spin-dependent quantum processes can operate within warm biological systems despite environmental noise. Although high radiation environments may disrupt coherence through decoherence processes, low temperatures may conversely enhance tunneling probabilities and prolong coherence lifetimes.

Microgravity conditions could influence molecular diffusion and reaction kinetics, potentially modifying coherence times and interaction rates. In low-energy stellar environments, optimized quantum transport mechanisms may provide a selective advantage by maximizing energy utilization efficiency. Collectively, these findings support the hypothesis that quantum optimization strategies may contribute to biological robustness and adaptability across a wider range of environmental conditions than previously assumed.

CONCLUSION

Quantum effects such as coherence, tunneling, and spin dynamics are not merely theoretical possibilities but experimentally supported contributors to biological function. Their persistence in warm and noisy terrestrial environments suggests that they may also operate under certain extreme cosmic conditions. Understanding these mechanisms expands the theoretical limits of habitability and informs astrobiological models of life beyond Earth. Furthermore, insights derived from quantum biology offer valuable guidance for the development of quantum-inspired technologies and biomimetic systems.By bridging quantum physics, biology, and astrobiology, this work emphasizes the possibility that quantum principles constitute a universal foundation underlying complex living systems across the cosmos.

FUTURE WORK / REFERENCES

1. Engel, G. S., Calhoun, T. R., Read, E. L., Ahn, T. K., Mančal, T., Cheng, Y. C., ... & Fleming, G. R. (2007). Evidence for wavelike energy transfer through quantum coherence in photosynthetic systems. Nature, 446(7137), 782-786.
2. Lambert, N., Chen, Y. N., Cheng, Y. C., Li, C. M., Chen, G. Y., & Nori, F. (2013). Quantum biology. Nature Physics, 9(1), 10-18.
3. Ritz, T., Adem, S., & Schulten, K. (2000). A model for photoreceptor-based magnetoreception in birds. Biophysical journal, 78(2), 707-718.