The Impact of Spaceflight Conditions on Circadian Rhythms: The Role of Light, Magnetic Fields, and Health Implications

Alan Żmuda[1] | Graduate of the Faculty of Biology at the Jagiellonian University in Krakow, Graduate of the Leon Kozminski Academy at the Space Research Center, Polish Astrobiological Society

Introduction

Long-duration space missions expose astronauts to unique stressors: microgravity, radiation, altered light-dark cycles, and a hypomagnetic field (HMF). The near-absence of Earth's geomagnetic field (GMF), together with artificial 90-minute light cycles aboard the ISS, severely disrupts circadian rhythms and sleep. (Hossain, M. S., Saha, T., Islam, M. A., Haque, K. F., Islam, M. M., Hoque, M. M., & Mou, S. S. (2025))

This desynchronization leads to cognitive impairments (attention, memory, decision-making) and physiological problems including sleep disorders, metabolic imbalance, immune suppression, and cardiovascular decline. These changes strongly resemble accelerated aging on Earth. At the molecular level, cryptochromes - core clock proteins and photoreceptors - may also function as magnetoreceptors, linking GMF absence directly to circadian disruption.

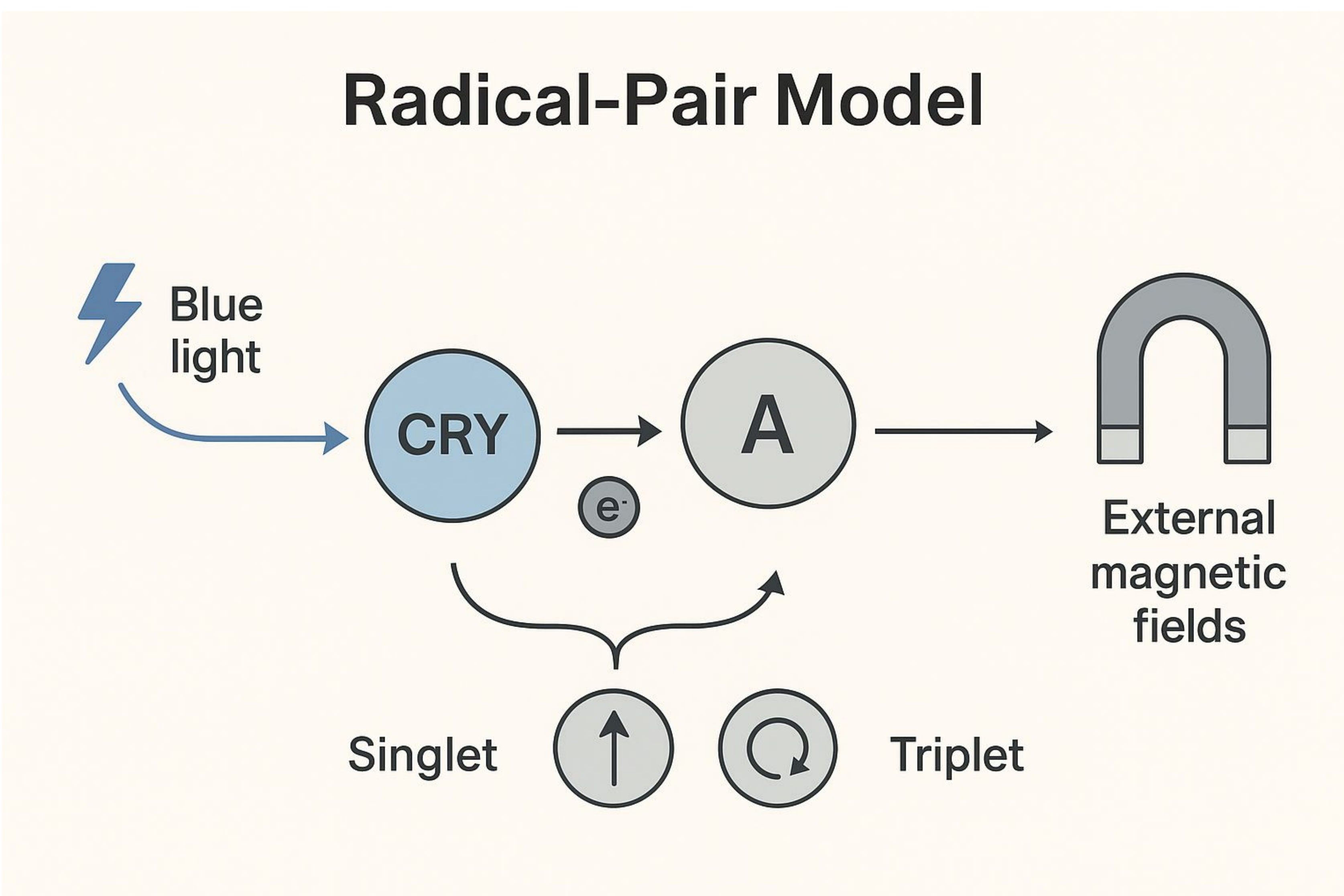

Fig.1 This diagram depicts the Radical-Pair Model, a proposed mechanism for magnetoreception mediated by cryptochrome (CRY) proteins. Upon activation by blue light, a CRY molecule transfers an electron to an acceptor (A), creating a radical pair. The spin state of this pair (singlet or triplet) is sensitive to external magnetic fields. This quantum process can influence the signaling output of the protein, providing a chemical basis for how organisms, including potentially humans, can sense magnetic fields, thereby linking the geomagnetic environment directly to the circadian timing system.(Xue, X., Ali, Y. F., Luo, W., Liu, C., Zhou, G., & Liu, N. A. (2021))

Tab.1: A comparison of biological changes occurring during the aging process on Earth (left) and during long-duration space missions (right). Circadian rhythm disruption is a common factor linking both processes. The space environment induces many phenomena analogous to aging, such as mitochondrial dysfunction, oxidative stress, and genomic instability, suggesting that spaceflight may serve as a model for accelerated aging. (Malhan, D., et al. (2023). Aging Cell.)

Aging on Earth	Aging in Space
Loss of proteostasis	Mitochondrial dysfunction
Epigenetic alterations	Oxidative stress
Telomere attrition	Loss of proteostasis
Genomic instability	Epigenetic alterations
Dysbiosis	DNA damage
Chronic inflammation	Dysbiosis
Altered intercellular communication	Systemic inflammation
Stem cell exhaustion	Cellular senescence
Cellular senescence	
Mitochondrial dysfunction	
Deregulated nutrint-sensing	
Disabled macroautophagy	

Conclusion

Spaceflight conditions, particularly altered light cycles and microgravity, lead to significant disruptions to astronauts' circadian rhythms. This results in chronic sleep deprivation and cognitive decline, which threatens mission safety and negatively impacts health, inducing changes analogous to accelerated aging. Therefore, ensuring astronaut health on future long-duration missions to the Moon and Mars necessitates a paradigm shift towards integrated and personalized countermeasures. The most promising path forward involves combining optimized light protocols and exercise regimens with novel approaches, such as gut microbiome modulation through psychobiotics, to enhance systemic resilience. The development of adaptive, real-time monitoring systems is crucial to tailor these interventions to individual astronaut chronotypes and mission demands.

Bibliography

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AKADEMIA LEONA KOŹMIŃSKIEGO

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