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Gábor Horváth *Editor*

Polarization Vision and Environmental Polarized Light

Third Edition

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Preface

Many terrestrial and aquatic animal species (Horváth and Varjú 2004; Sabbah et al. 2005; Horváth 2014; Foster et al. 2018; Heinloth et al. 2018; Shabayek et al. 2018; Yadav and Shein-Idelson 2021) are *polarization sensitive*. These animals can detect/sense linearly—and some of them also circularly—polarized light. Humans are also sensitive to linearly and circularly polarized light, but we do not use this sensorial ability, about which many people do not even know. In contrast, only a few species are able to discriminate between two monochromatic lights of the same intensity but differing only in their angle (direction) and/or degree of linear polarization. This ability is called *true polarization vision* (Bernard and Wehner 1977; Wehner and Labhart 2006).

The monograph of Horváth and Varjú (2004)—the first edition of the comprehensive polarization series of Springer—summarized the knowledge accumulated until 2004 about polarization sensitivity/vision and the polarization characteristics of natural and some artificial surfaces/objects. After 2004, the progress of science in this field was so rapid and significant that in 2014 a further monograph (Horváth 2014) was dedicated for the survey of linearly/circularly polarized light and polarization sensitivity/vision in the animal kingdom, including also human polarization sensitivity. This book focused predominantly on the progress in this topic between 2004 and 2014. Not surprisingly, after 2014 the accumulation of new data and information in this field of natural sciences continued unabatedly, the consequence of which is the birth of the present monograph entitled *Polarization Vision and Environmental Polarized Light* dealing mainly with the progress of this topic between 2014 and 2024.

This monograph is written, among others, by experts of polarization sensitivity/vision in different taxa, from the extinct trilobites, through crustaceans, insects, fishes, amphibians, reptiles, birds, to humans. The subject of this work is twofold: (i) It surveys the polarization sensitivity/vision in animals and humans, the underlying receptor-physiological and neural mechanisms, the biological functions of this sensorial ability, and the polarization-guided behaviour of animals. (ii) It presents numerous natural and artificial polarization patterns measured by imaging polarimetry and occurring in our optical/visual environment.

In *Part I* we summarize the most important results achieved in the last decade about linear and circular polarization sensitivity/vision in trilobites (Trilobita), vinegar flies (*Drosophila melanogaster*), bees (Apoidea), ball-rolling dung beetles (Scarabaeidae), desert locusts (*Schistocerca gregaria*), butterflies (Lepidoptera), horseflies (Tabanidae), scarab beetles (Scarabaeidae), springtails (Collembola), yellow fever mosquitoes (*Aedes aegypti*), mayflies (Ephemeroptera), dragonflies and damselflies (Odonates), crustaceans, cephalopods, fishes, amphibians, reptiles, birds, bats, seals (*Phoca vitulina*) and humans.

In *Part II* we treat environmental polarization with implications to polarization sensitivity/vision. First, the polarization signals in crustaceans and insects are surveyed, then the reflection-polarization characteristics of water surfaces are discussed, finally several case studies of polarized light pollution and ecological/evolutionary traps for polarotactic aquatic insects are considered.

The whole *Part III* of this monograph is devoted exclusively to the celestial Viking navigation. This longest part summarizes the knowledge accumulated about this subject in the last decades.

Part IV of this book summarizes the newest literature about the polarization of sun- and moonlit skies, eclipse skies, solar coronas and Kordylewski's dust clouds. This part ends with the novel knowledge gathered in astronomical polarization measured with telescopes mounted by polarization-sensitive cameras.

A novelty of this opus is that one of its chapters is dedicated to the structure, optics and functions of the eyes and vision of extinct trilobites. On the basis of the paleontological, anatomical and paleo-biooptical information accumulated about the visual system of these ancient arthropods, their possible polarization sensitivity is discussed. In the Appendix of this chapter physical optical calculations are presented to support the conclusions drawn about trilobite polarization sensitivity.

This work also surveys the polarization patterns occurring in nature and the man-made optical environment. Compared to the two preceding polarization monographs (Horváth and Varjú 2004; Horváth 2014), the novelty of this survey is that the monitoring of polarization characteristics spreads beyond the Earth's surface and atmosphere, namely, from the Kordylewski's dust clouds along the Moon's orbit, through the lunar/planetary disks and solar corona in the Solar System, up to so distant celestial bodies of the Universe as comets, stars, interstellar dust/molecular clouds, pulsars, magnetars, quasars, blazars, nebulae and accretion disks of black holes. Although these extraterrestrial polarization patterns measured by ground- or satellite-born astronomical imaging polarimetry have no relevance for polarization sensitivity/vision, they are important components of our optical environment, which is not restricted only to the biosphere.

A further specialty of the present treatise is that it contains a "booklet in book" dealing with the solar and sky-polarimetric navigation methods of Viking seafarers reconstructed on the basis of (1) a famous archaeological fragment of a Viking sun-compass, (2) numerous celestial polarization patterns measured by full-sky imaging polarimetry, (3) error functions of the four steps of sky-polarimetric Viking navigation measured in laboratory/planetarium psychophysical experiments, and (4) computer modelling of thousands of Viking voyages simulated by computer softwares using skypolarization and psychophyscial data as input. This chapter reveals the enigma of Viking navigation by means of “experimental archaeological methods”.

Every chapter has its own bibliography listing many important references at the very end. The authors were given a free hand in the structure of their chapter. Some chapters begin with an abstract and end with a summary and outlook, while others finish with conclusions and future directions. A few chapter contains also acknowledgements. On the other hand, several chapters draw conclusions at the end of each section. The chapter dealing with trilobites has also an *Appendix* for the polarization-optical calculations. The chapter of Viking navigation possesses several figures for the *Electronic Supplement*, while the chapter of astronomical polarimetry has *Electronic Supplementary References with Full Author Lists* due to the many (frequently more than 50!) authors of several references.

This book is suggested for scientists interested in animal and human vision, environmental optics, polarized light and polarization sensitivity/vision, including biologists, physiologists, ecologists, physicists, atmospheric scientists, engineers and astronomers.

Dedication

I dedicate this book to Professor Rüdiger Wehner (https://de.wikipedia.org/wiki/Rüdiger_Wehner) on the occasion of his 84th birthday. He was one of my mentors and co-authors. He wrote Chap. 1. *Polarization vision: a discovery story* (Wehner 2014) in the book entitled *Polarized Light and Polarization Vision in Animal Sciences*, being the earlier edition of the present monograph.

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About the Editor

Gábor Horváth was born in 1963 in Kiskunhalas, Hungary. In 1987 he received his diploma in physics from the Eötvös Loránd University in Budapest. Then he was a research assistant at the Department of Low Temperature Physics of the same university, where he investigated electrical percolation processes in granular superconductors. In 1989 he received a doctoral fellowship in the Biophysics Group of the Central Research Institute for Physics of the Hungarian Academy of Sciences (Budapest), where he developed a mathematical description and computer modelling of retinal cometlike afterimages. He obtained his Ph.D. at the Eötvös University in 1991. His thesis in physiological optics was a computational study of the visual system and optical environment of certain animals. In 1991–1992 he was a postdoctoral fellow in the Institute for Zoology of the University of Regensburg (Germany), where together with Professor Rudolf Schwind he studied the polarization patterns of skylight reflected from water surfaces and the polarotaxis of aquatic insects. Then he was a postdoctoral fellow at the Department for Biological Cybernetics of the University of Tübingen (Germany), where he measured natural polarization patterns and investigated the polarization-sensitive optomotor reaction in water insects together with Professor Dezső Varjú. In 1993 he finished his postdoctoral dissertation in computational visual optics to obtain the degree Candidate for Biophysical Science awarded by the Hungarian Academy of Sciences. For this treatise he won the first International Dennis Gabor Award. Between 1996 and 2018 he was an associate professor, and from 2018 he is a professor of biophysics and leader of the Environmental Optics Labortory at the Department of Biological Physics of the Eötvös University. From 2022 he is the leader of the Astropolarimetric Research Group of the HUN-REN-ELTE Hungarian Research Network in cooperation with the Eötvös University. His main research interests are the optics of animal eyes and the visual environment, animal polarization sensitivity, polarization characteristics of the optical environment as well as various biomechanical problems. He designed imaging polarimeters with which he records and visualizes the polarization patterns in nature. He participated on several expeditions and polarimetric measuring campaigns in Hungary as well as in the Tunisian and Namibian deserts, Finnish Lapland, North Pole, and on the Atlantic Ocean. He was three times a Humboldt research fellow in the Universities of Tübingen and Regensburg. He wrote his first Springer monograph (2004) about polarization vision in Tübingen with Dezső Varjú. He edited and finished the second Springer monograph (2014) dealing with polarization in Regensburg. He won several Hungarian and international prizes and awards for his scientific achievements in biological optics.

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