From biomimetics to evomimetics — using biology to inspire innovation

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Part I – The Evolution of Biomimetics @ ACT

Tobias Seidl (WHS)

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Animals and plants might know better

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George de Mestral (1951)

Wondered why burren attached to his dog´s furr…

...discovered the statistical interlocking principles...

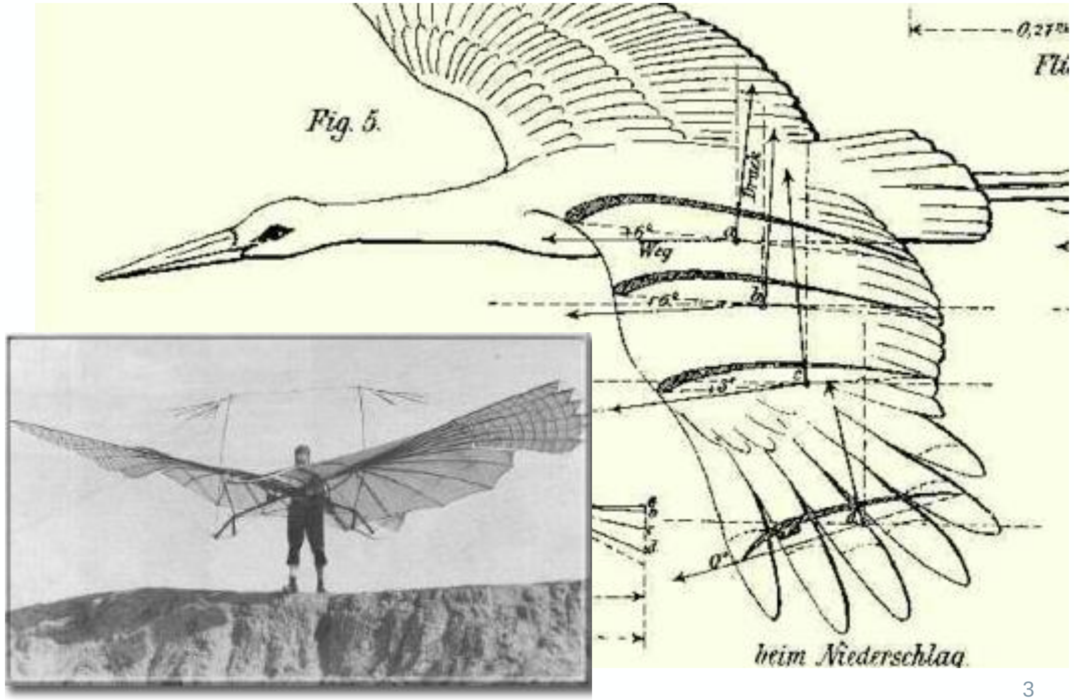
...and invented Velcro.

Otto Lilienthal (1881)

Studied bird flight...

...derived fundamental aerodynamic principles (drag, lift)...

...and successfully flew.



Numbers

Years	18
Research Fellows	9
Young Graduate Trainees	9
Interns	7
Ariadna studies	22
GSP studies	1
Books	1
Peer Review Papers	20
Conference Papers	20
Patents	1

Topics

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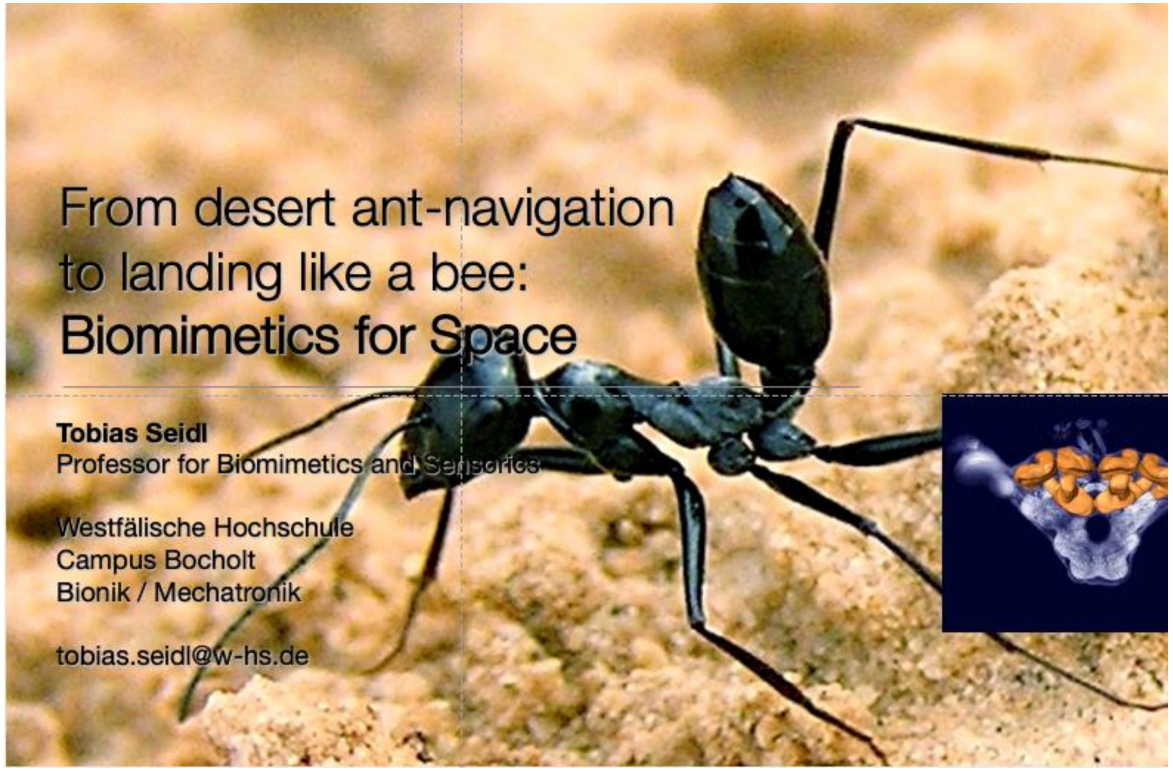
So what happened to these topics…?

10 years of ACT



Spider feet

Optic flow

Hold me tight…introducing new ways of grasping

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Paper 2002

The Journal of Experimental Biology 206, 2733-2738
© 2003 The Company of Biologists Ltd
doi:10.1242/jeb.00478

2733

Adhesion measurements on the attachment devices of the jumping spider *Evarcha arcuata*

A. B. Kesel*, A. Martin and T. Seidl
Department of Zoology, Technical Biology and Bionics, Saarland University, D-66041 Saarbrücken, Germany
*Author for correspondence (e-mail: a.kesel@rz.uni-sb.de)

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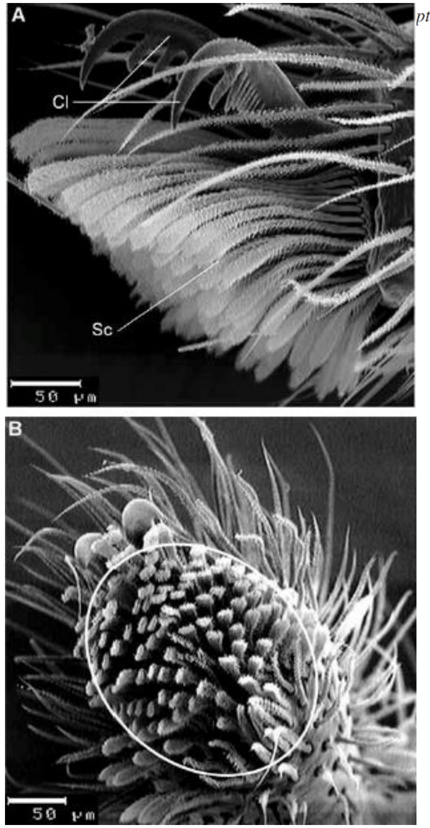
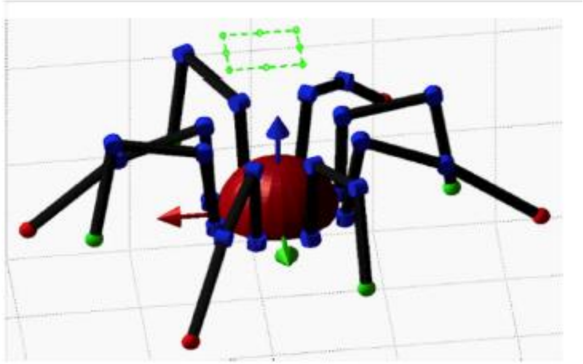
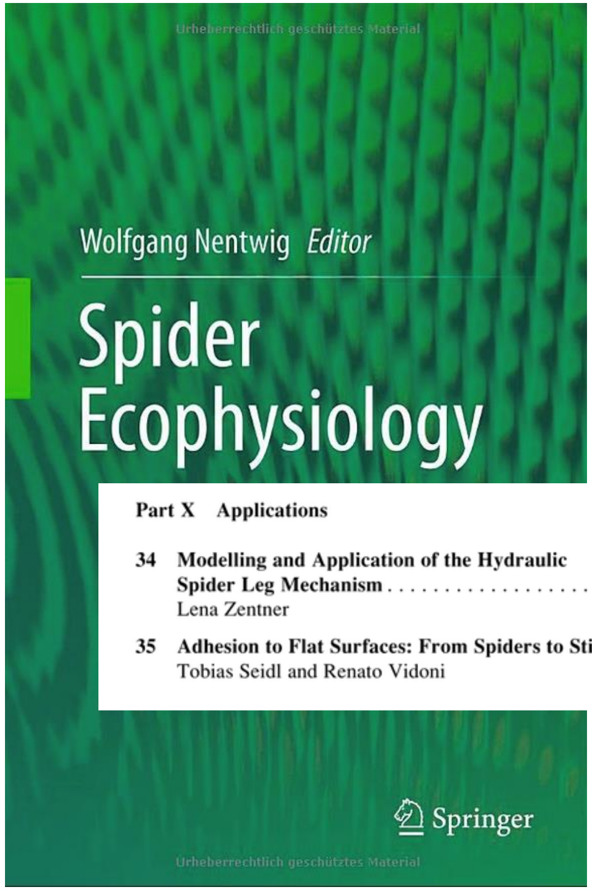




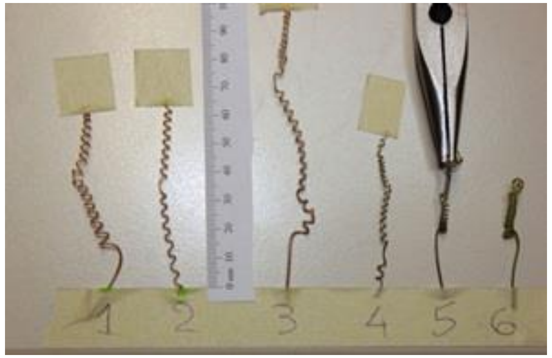
Ariadna + Papers 2009

Chapter 2013



Part X Applications

Ariadna + Papers 2015

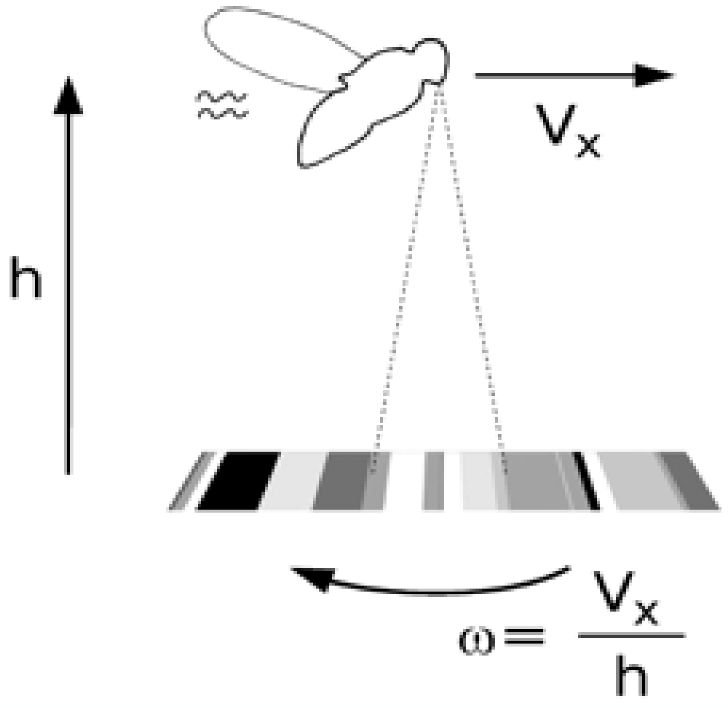


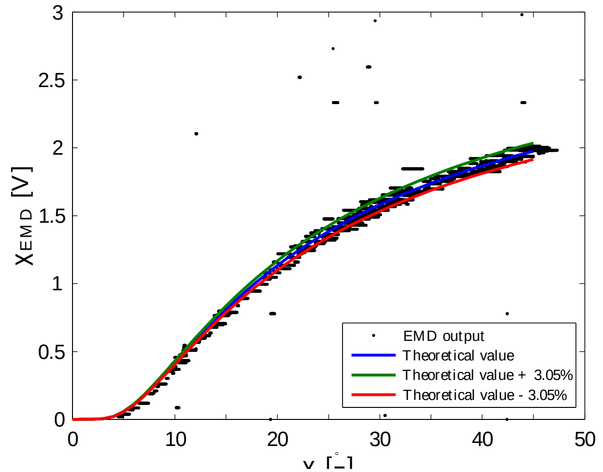
ESA ITT 201x

Get down safely…introducing new ways to land

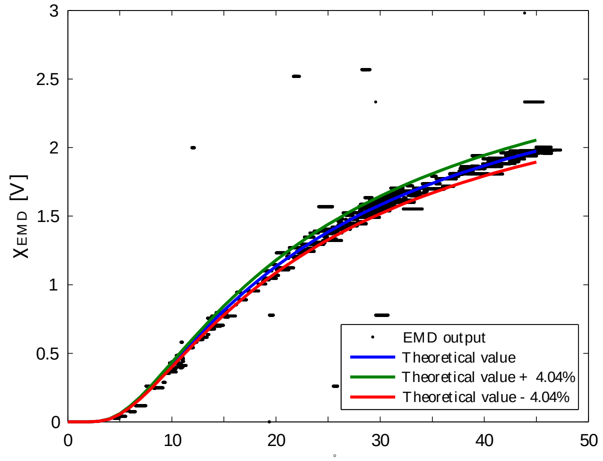
Cockroach behaviour 2008

Optic Flow-Landing 2008



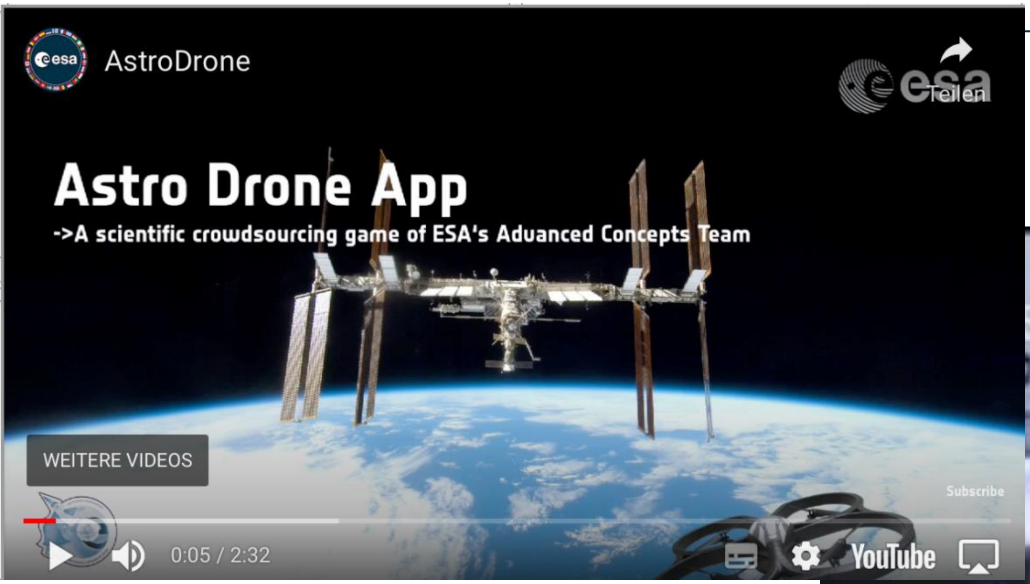


Bright side of the Moon



Dark side of the Moon

Get down safely…introducing new ways to land



Time-to-contact landing 2011

Get down safely…introducing new ways to land

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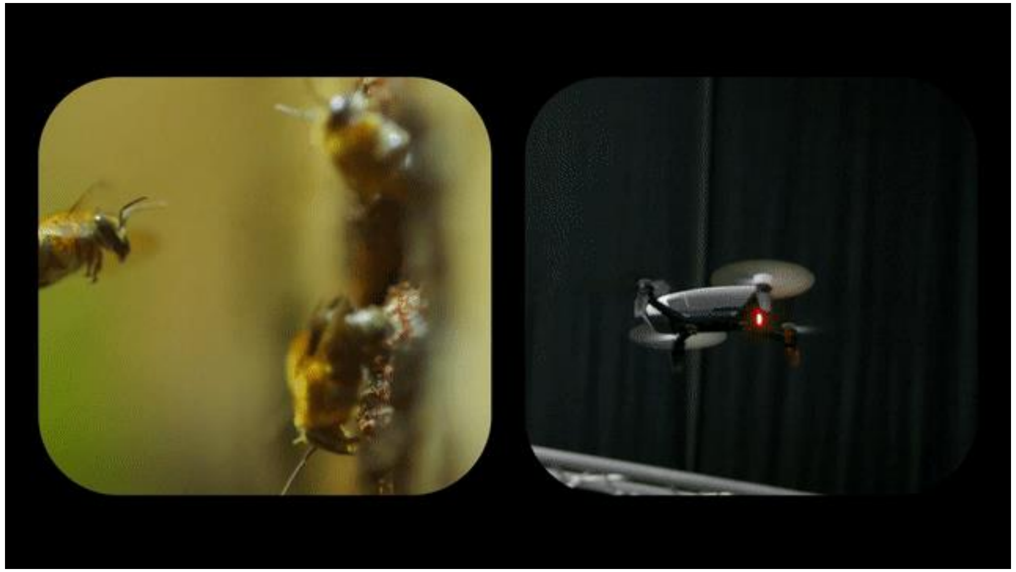
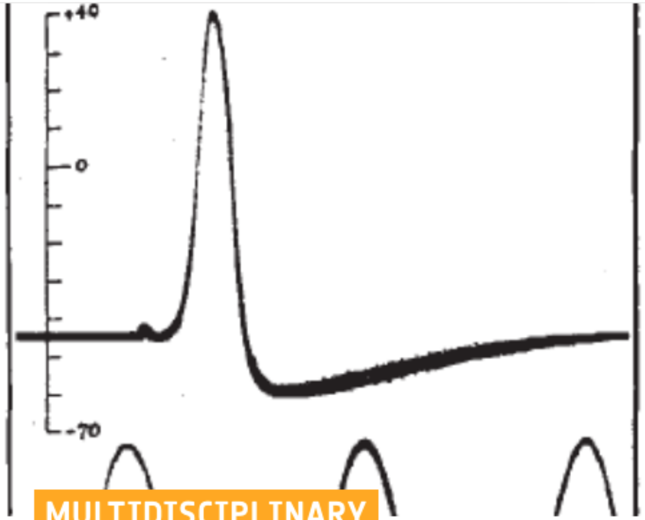
Guido, Christophe, and Tobias 2021



Get down safely…introducing new ways to land

And what it developed into @ ACT:

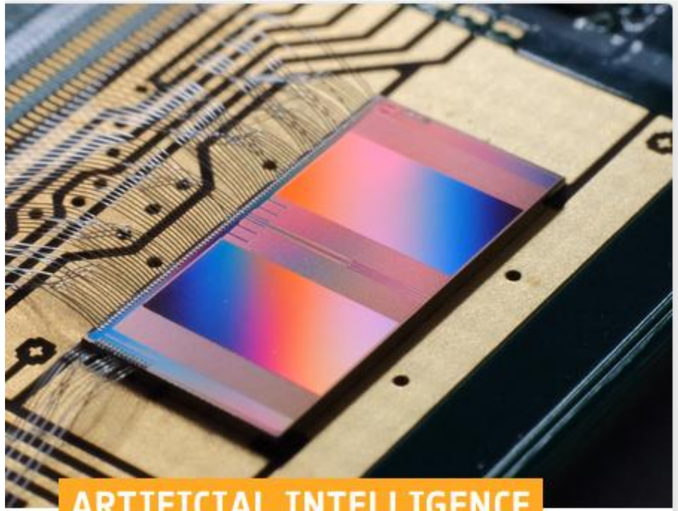
2021



MULTIDISCIPLINARY

Temporal information processing with spiking neural networks

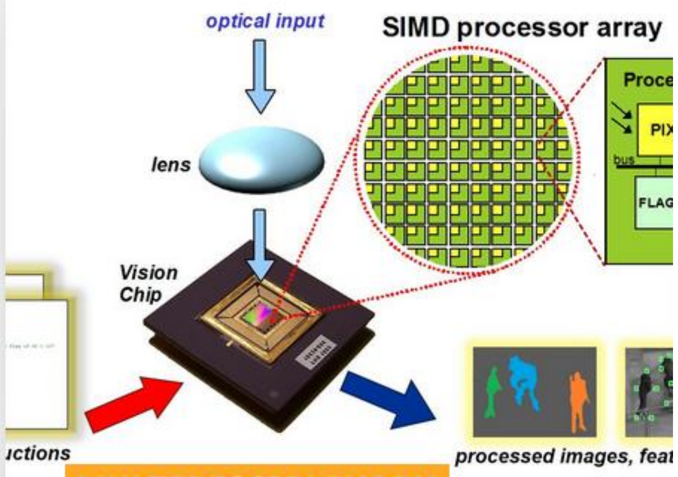
2021



ARTIFICIAL INTELLIGENCE

Analogue neuromorphic computing for onboard artificial intelligence

2022



MULTIDISCIPLINARY

Retinomorphic Vision Model for On-chip Feature Extraction

Part II – Above & Beyond Biomimetics

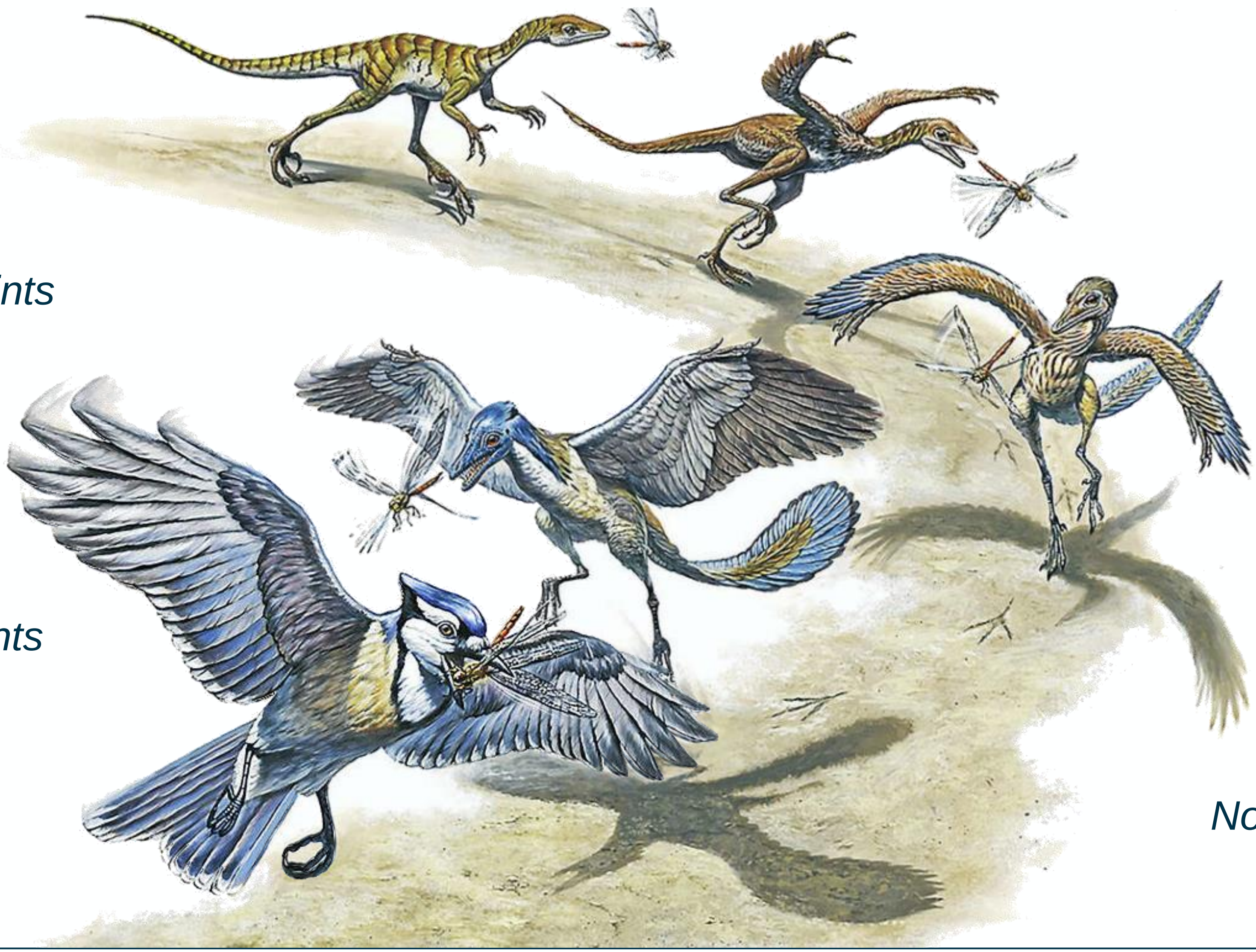
Chris Broeckhoven (ACT)

Challenges to biomimetics: towards a biodiversity-based approach

Phylogenetic history

Developmental constraints

Environmental constraints



Functional trade-offs

Exaptations

Non-adaptive evolution

Challenges to biomimetics: towards a biodiversity-based approach

Bioinspiration & Biomimetics

PERSPECTIVE

Biodiversifying bioinspiration

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Keywords: bioinspiration, biodiversity, natural history specimens, computational analysis, data science

Abstract

Bioinspiration—using insights into the function of biological systems for the development of new engineering concepts—is already a successful and rapidly growing field. However, only a small portion of the world's biodiversity has thus far been considered as a potential source for engineering inspiration. This means that vast numbers of biological systems of potentially high value to engineering have likely gone unnoticed. Even more important, insights into form and function that reside in the evolutionary relationships across the tree of life have not yet received attention by engineers. These insights could soon become accessible through recent developments in disparate areas of research; in particular, advancements in digitization of museum specimens, methods to describe and analyze complex biological shapes, quantitative prediction of biological function from form, and analysis of large digital data sets. Taken together, these emerging capabilities should make it possible to mine the world's known biodiversity as a natural resource for knowledge relevant to

PERSPECTIVE

ADVANCED FUNCTIONAL MATERIALS
www.afm-journal.de

Escaping the Labyrinth of Bioinspiration: Biodiversity as Key to Successful Product Innovation

Chris Broeckhoven and Anton du Plessis**

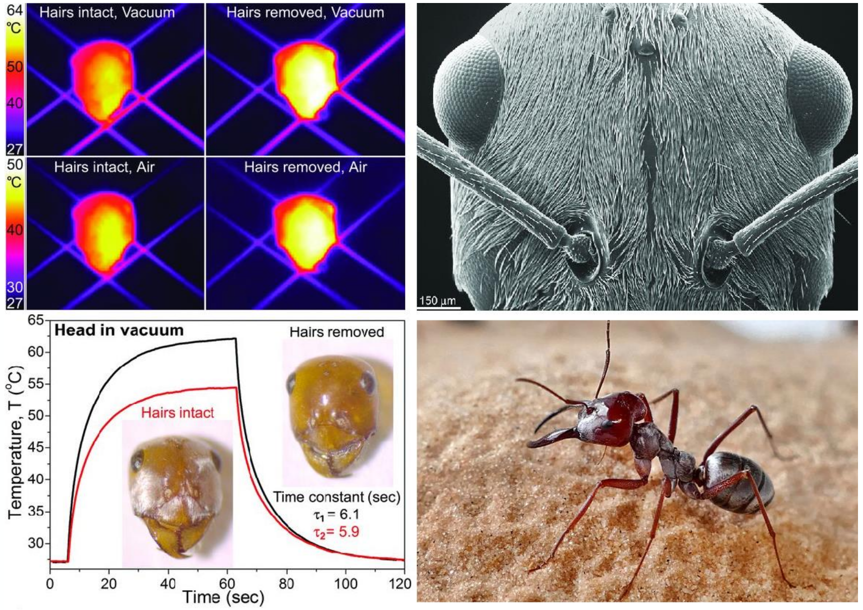
Nature provides an infinite source of inspiration for innovative designs that may be required to tackle the social, economic, and environmental challenges the world faces. Despite the surging popularity and prevalence, the discipline of bioinspiration is limited in unleashing its full potential by the inadequate understanding of biological and evolutionary concepts, often leading to suboptimal solutions and a lack of further development toward successful products. Here, the constraints and limitations that pose potential pitfalls for bioinspiration, but are generally overlooked by most practitioners of bioinspiration, are discussed. It is highlighted that an awareness of biodiversity is key to address this issue, and ultimately to the successful application of bioinspiration in general. Furthermore, a practical approach to the analysis of biodiversity information is provided and attention is drawn to opportunities for improving the translation of biological knowledge into innovative solutions. Primary emphasis is placed on direct bioinspired product innovations, though many of the concepts central to the ideas are applicable to the wider domain of bioinspired materials science, chemical, and systems engineering, among others. With this perspective, the guiding thread that will enable to escape the labyrinth of bioinspiration and follow the right track to successful innovation is brought back.

1. Bioinspiration—What's in a Name?

Innovation is key not only to sustain competitiveness in an increasingly saturated global market, but also to confront specialized scientific disciplines which we collectively refer to as "bioinspiration[1]" (Table 1). The idea of emulating biological strategies for product innovation took the spotlight during the last decade of the 20th century, and has since been a hot topic due to the fascinating capabilities of natural materials and the structures made from them.[2–4] The growing popularity of bioinspiration is expressed in the exponential increase in publications[5,6] and upsurge of spin-off companies and patented products. Striking examples hereof include gecko-inspired adhesives that can generate substantial adhesive forces and be applied to large areas and over a wide range of surfaces,[7,8] bioinspired spinning and silk materials[9,10] that create sustainable solutions in the textile industry, shark-skin-inspired coatings that reduce the drag and improve the fuel efficiency of airplanes,[11,12] as well as synthetic liquid-repellent surfaces inspired by carnivorous pitcher plants.[13] Economists have predicted that by 2030, bioinspired innovation in general (i.e., products, investments, start-up companies, etc.) is projected to account for approximately 1.6 trillion US$ of total output globally[14] and bioinspiration might be critical to lower the costs of environmental, health, and safety protection.

Namib Desert beetles: biodiverse inspiration for planetary exploration

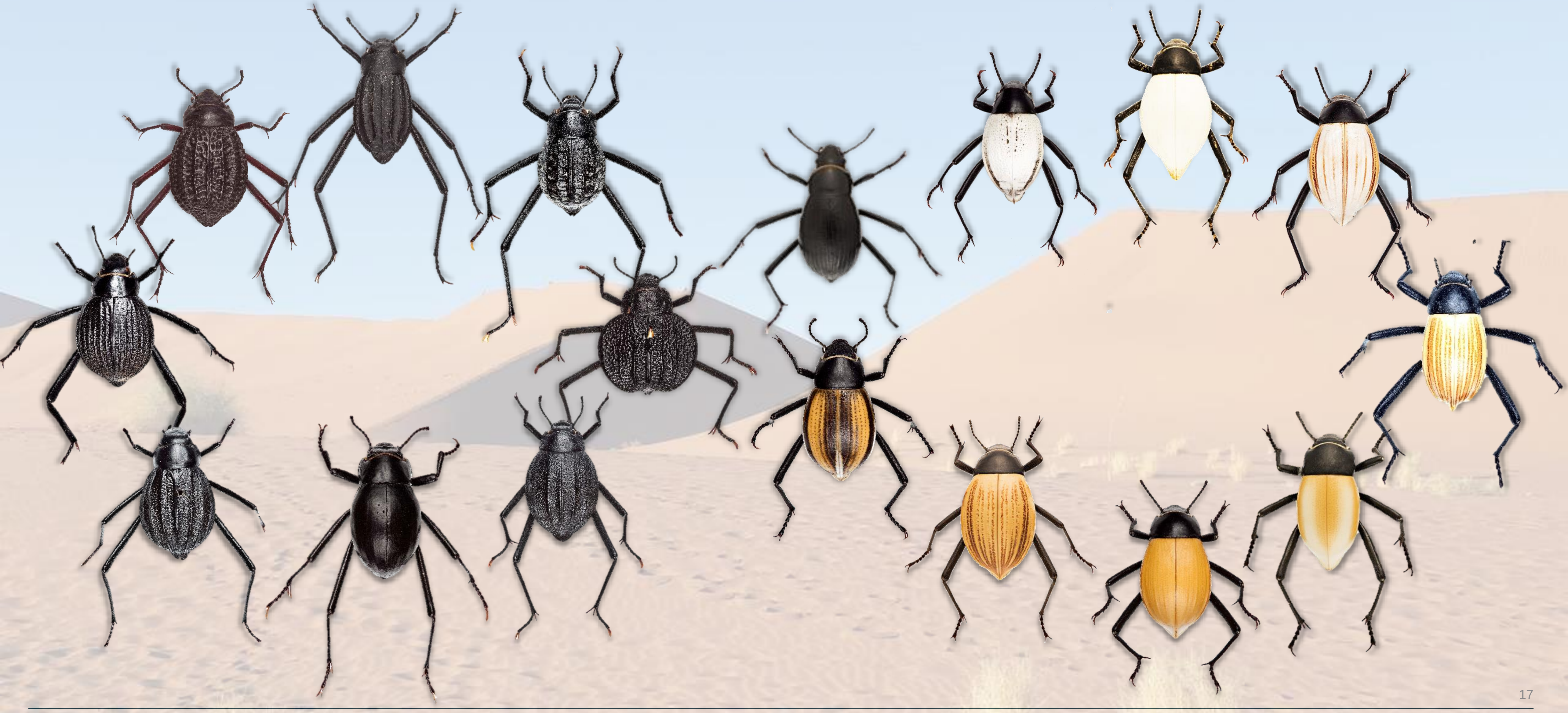
Deserts as planetary analogues



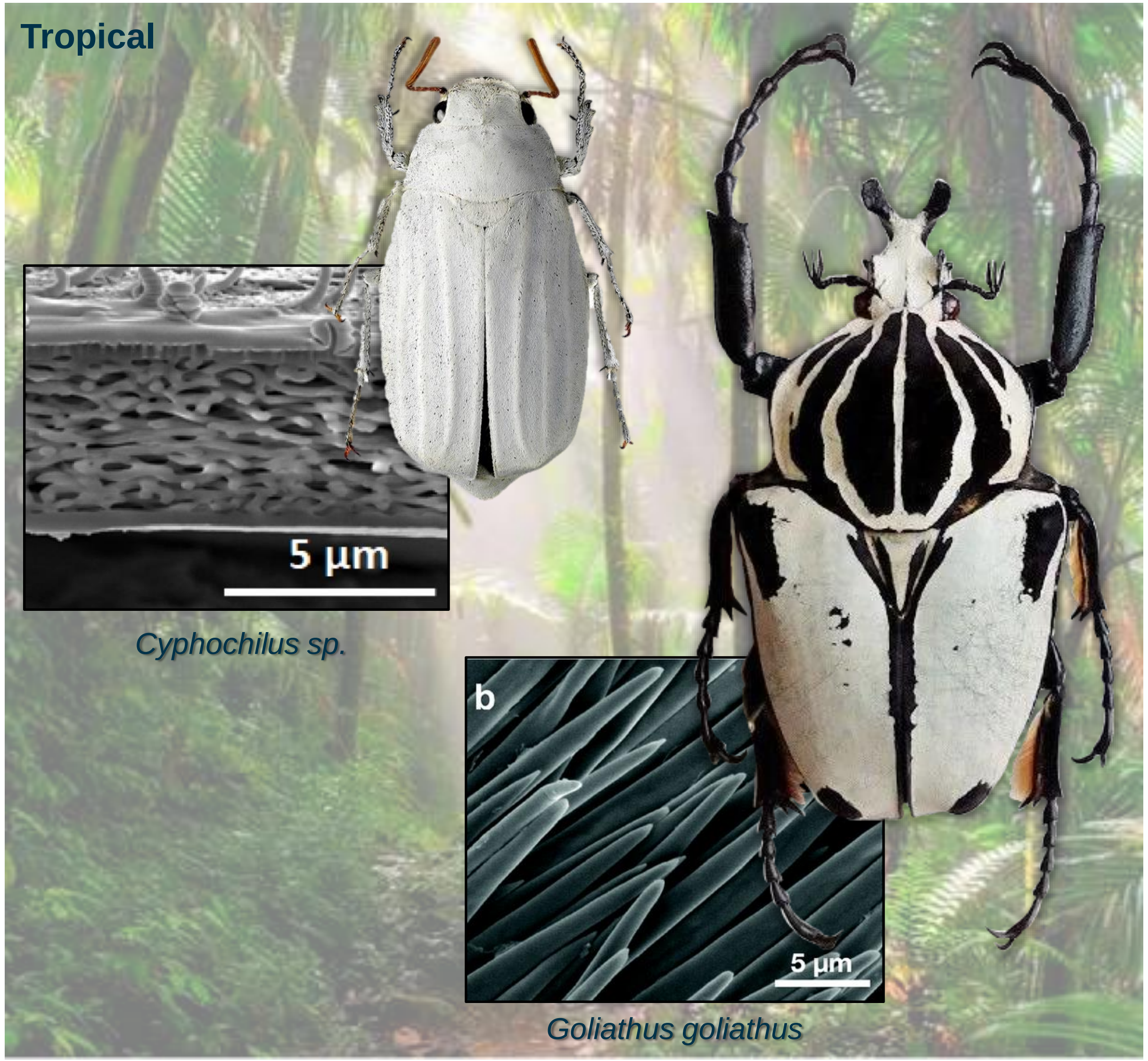
- Tolerate extreme temperatures
- Extraordinary adaptations
- Thermal significance of colouration

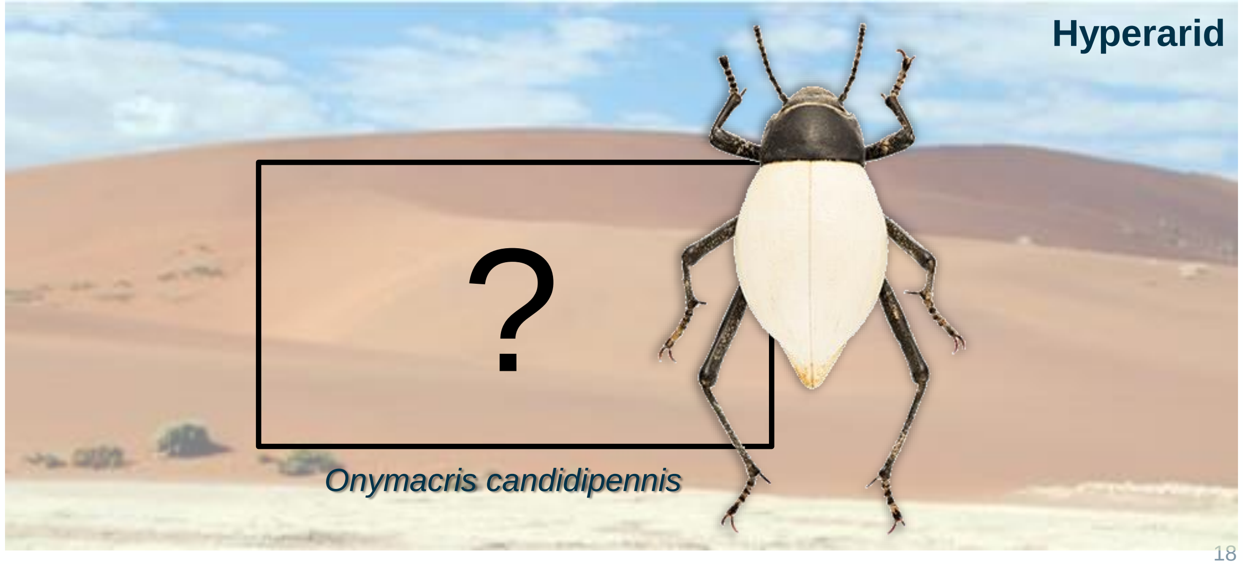
Namib Desert beetles

Namib Desert beetles: biodiverse inspiration for planetary exploration



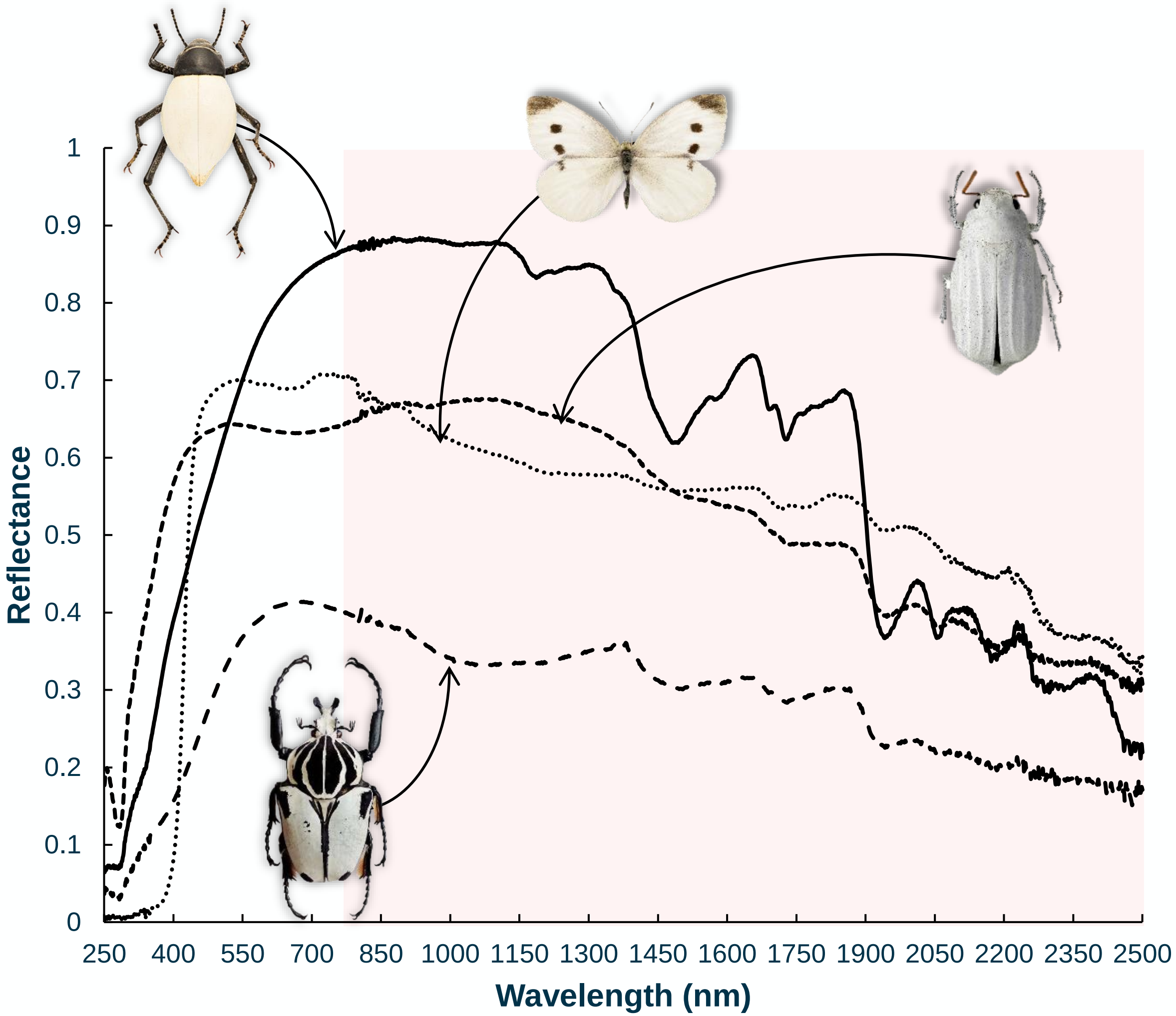
Namib Desert beetles: biodiverse inspiration for planetary exploration

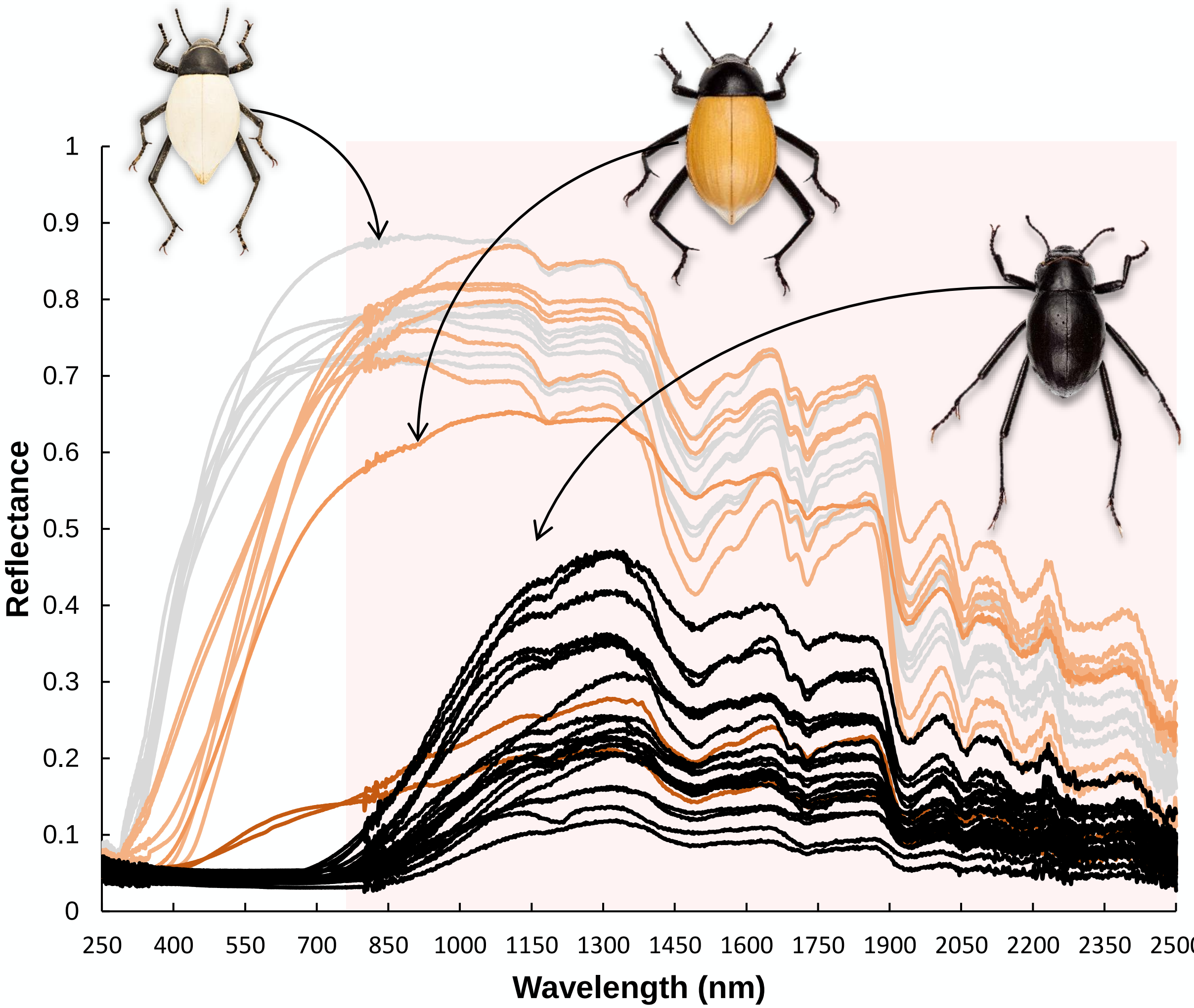




Namib Desert beetles: biodiverse inspiration for planetary exploration

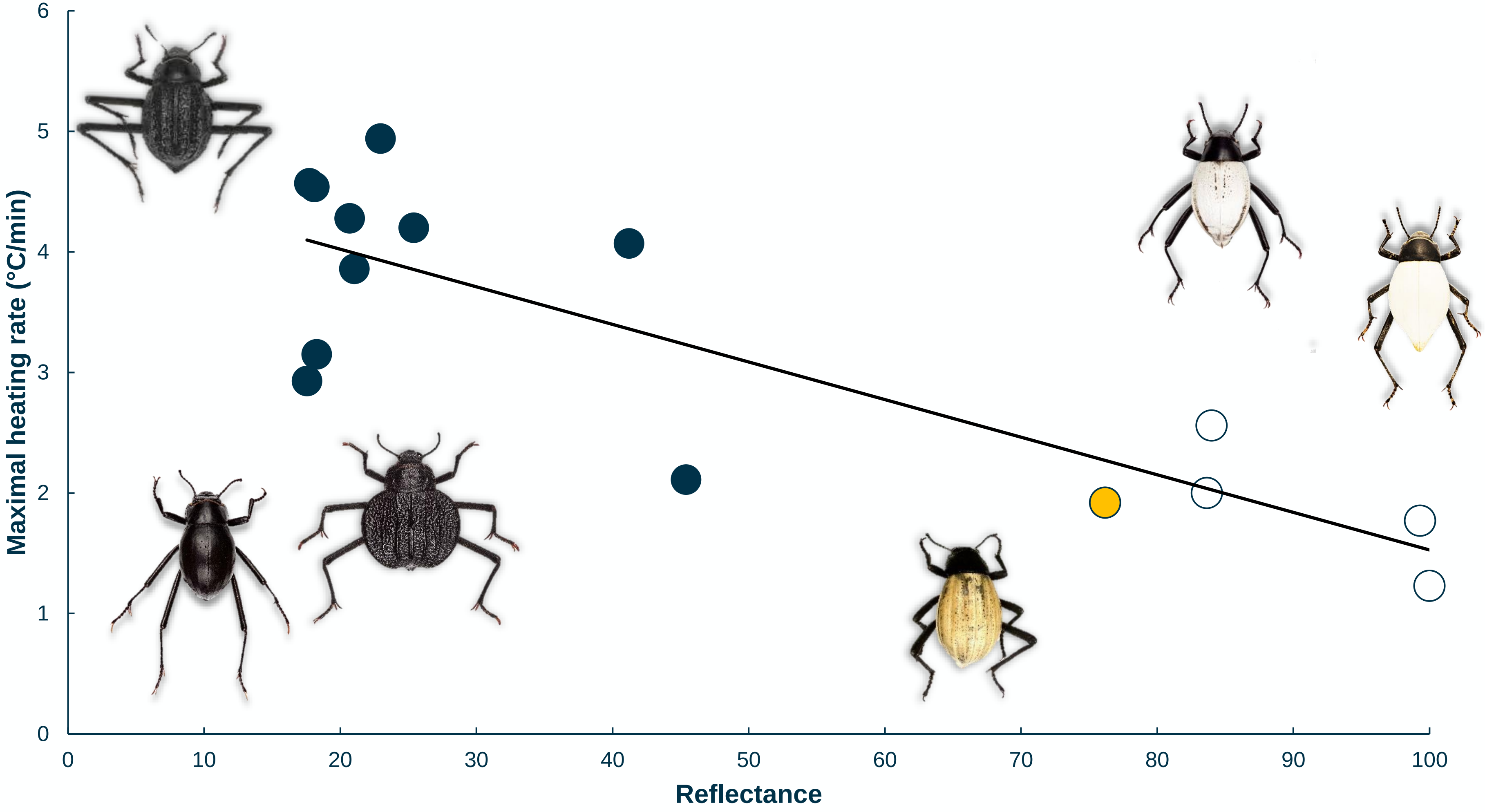
High reflectance in the near-infrared spectrum





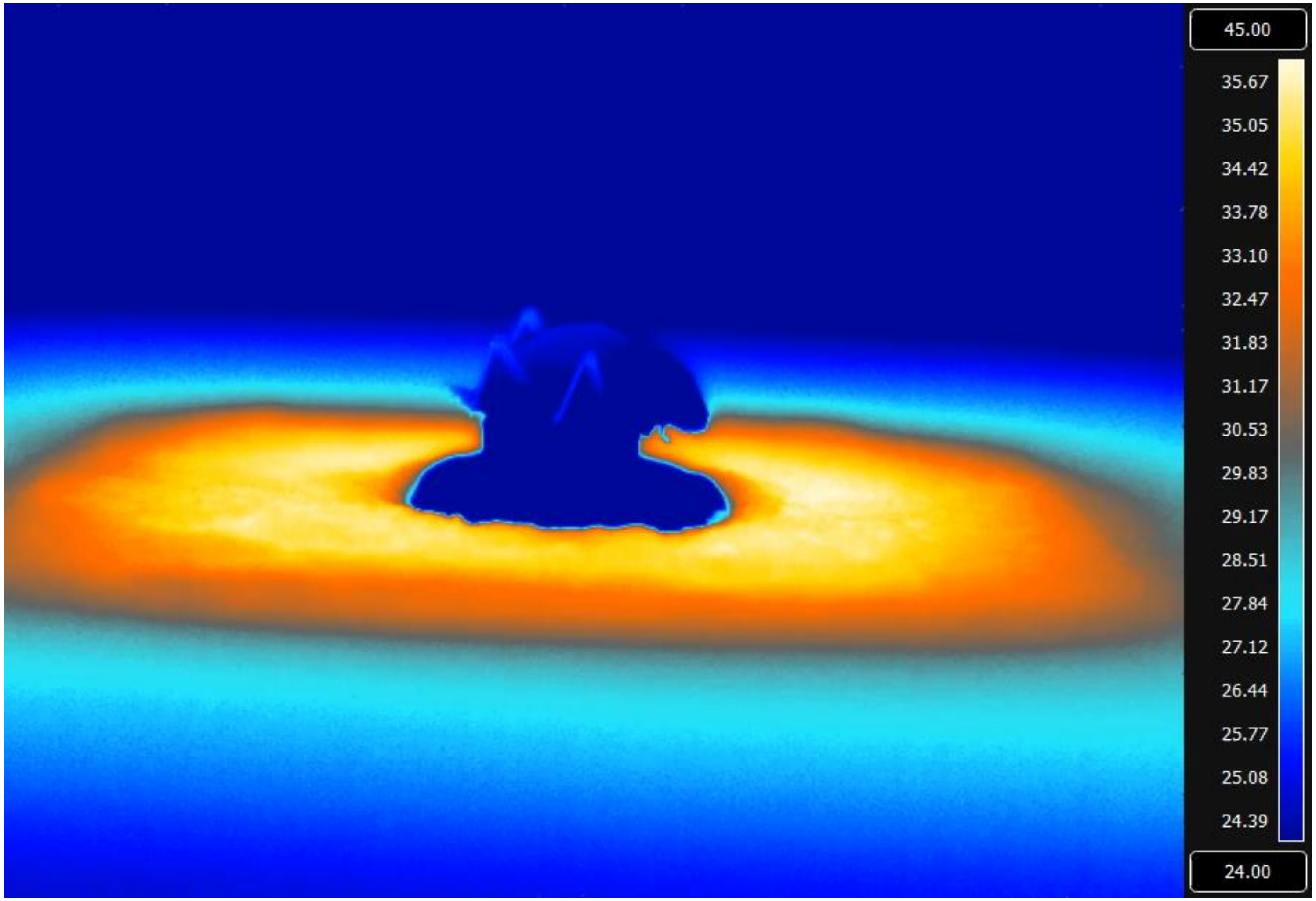
Namib Desert beetles: biodiverse inspiration for planetary exploration

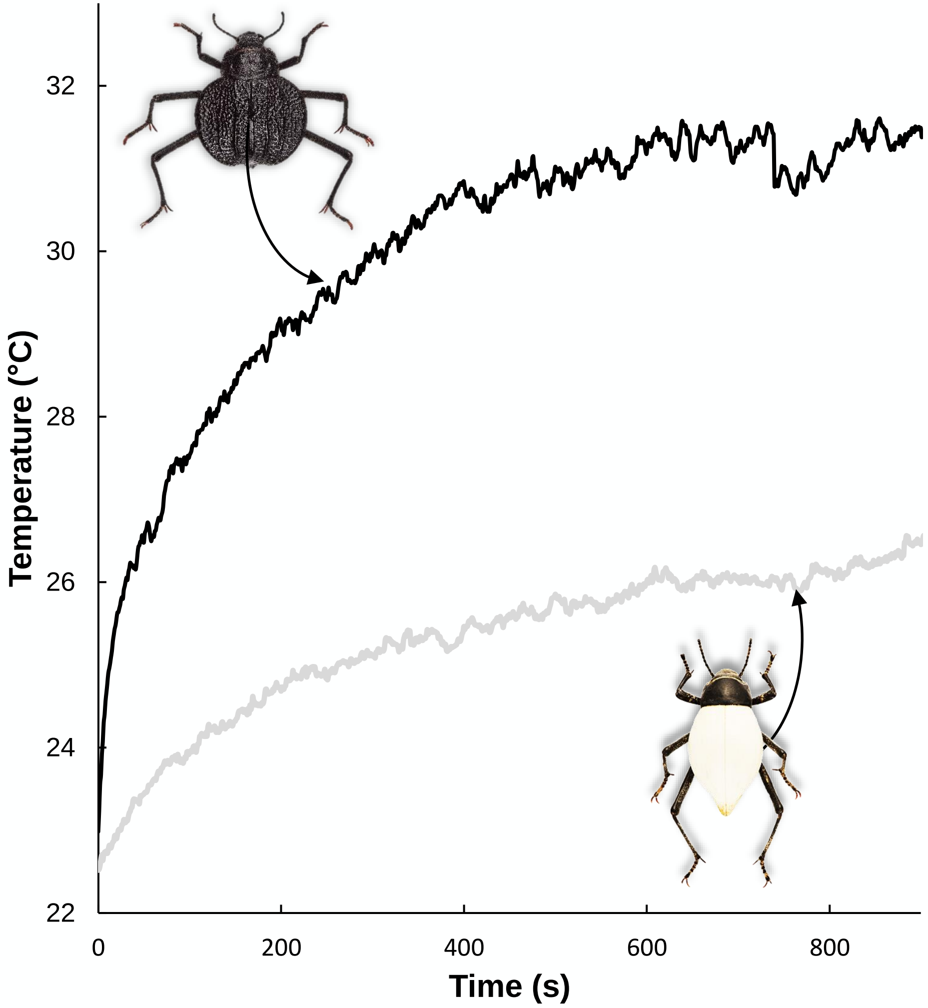
Thermal effect of near-infrared reflectance



Namib Desert beetles: biodiverse inspiration for planetary exploration

Thermal effect of near-infrared reflectance

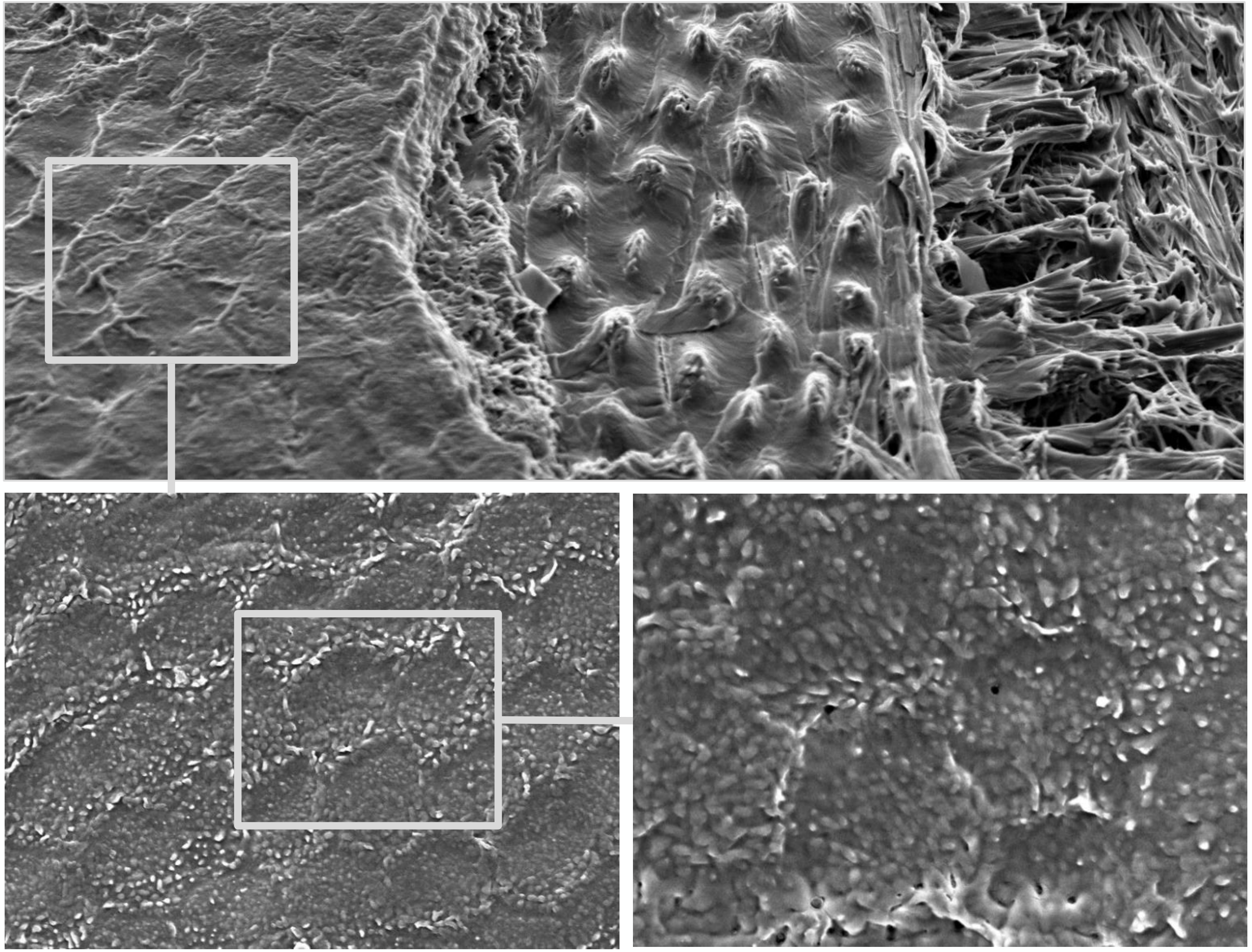




Namib Desert beetles: biodiverse inspiration for planetary exploration

Nano-, Micro- and Macrostructure

Micro-CT, visualization of elytron canals



Evomimetics: an evolution-based approach to innovation

Invited Paper

Evomimetics: the biomimetic design thinking 2.0

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ABSTRACT

The consensus is that nature is a tremendous source of ideas for innovative designs that can meet various specific functional needs, relevant to society. Designs rely on structural, constructional, process-based and behavioral traits that all result from a natural trial-and-error cycle: evolution. Being one of the pillars of biomimicry, through billion years of evolution, nature has experimented and found what works and lasts, and what does not. Evidently, this has attracted scientists, especially engineers, trying to understand working natural designs, and translate them into applicable, working synthetic designs. The 'Biomimetic Design Method' forms the underlying conceptual framework to analytically decode biologically functions and designs. However, even though the evolutionary process is considered key to all this, it is generally overlooked in this conceptual thinking. The general assumption is that particular functions in organisms result from a natural selection process that optimized the underlying design for a particular function, thereby overlooking that an organism actually represents the possibly best compromise between all its functions needed to survive, to reproduce and to produce fit offspring. Many evolutionary processes thus yield suboptimal design components that, when put together, provide an optimized organismal design that manages to perform as good as needed, within a given environment. Such evolutionary limitations thus create possible pitfalls for bio-inspired design thinking. But, when considering them as a structural part of the design thinking process ('evomimetics'), they actually create opportunities for an improved translation of biology into optimally functioning designs. Using specific examples from evolutionary biology, these processes are explained, and recommendations are formulated.

Keywords: Biomimicry, biomimetics, design, evolution, conceptual, constraints, optimization, adaptation

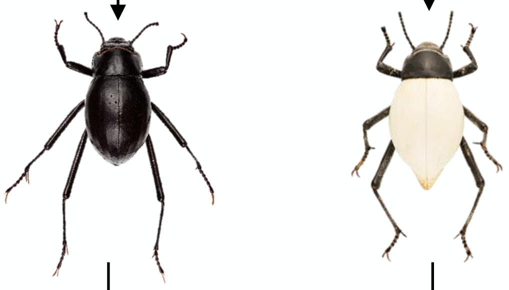
Evomimetics: an evolution-based approach to innovation

Biomimetics

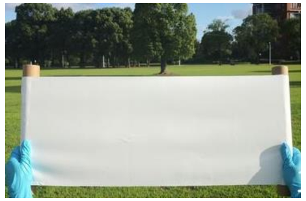
Technical question = how can we design materials with enhanced:

absorbance reflectance

Biological Model



Biomimetic Design Process



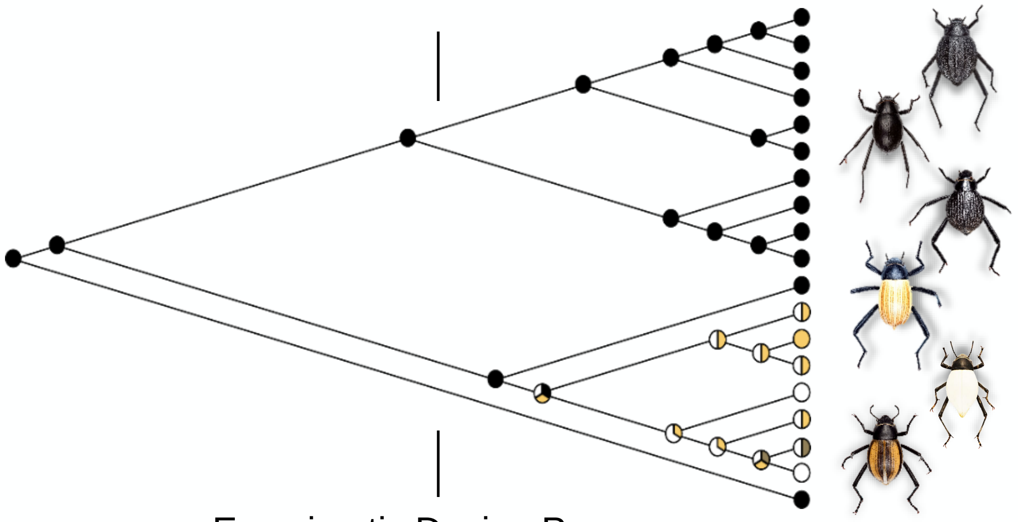
Technical Application

Evomimetics

Technical question = how can we create versatile designs that can:

absorb → reflect → absorb

Evolutionary Process



Evomimetic Design Process

1. Use biodiversity to generate 'ancestral states'
2. Find evolutionary changes in traits/functionalities
3. Use evolutionary changes in traits as a template for designs

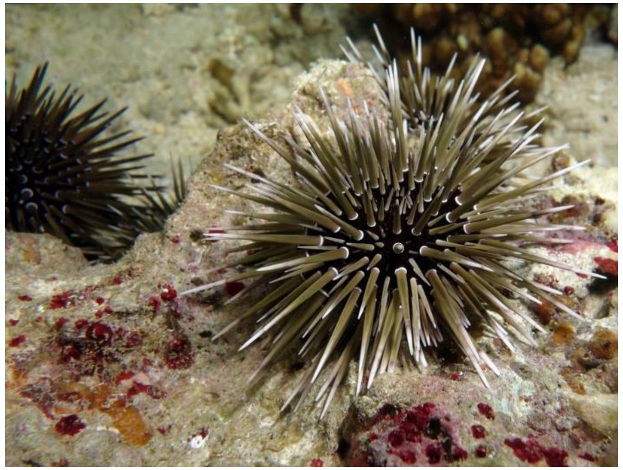
Technical Application

Evomimetics: an evolution-based approach to innovation

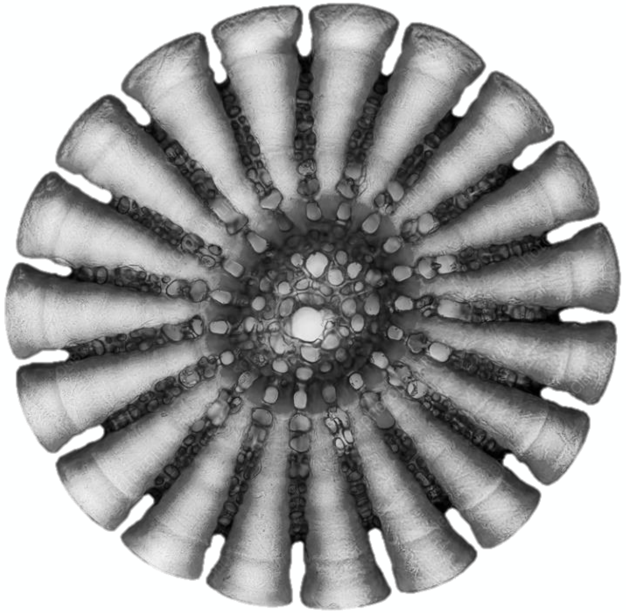
Evomimetics: an evolution-based approach to innovation

Inject venom

Inflict mechanical damage



Diversity in Microarchitecture

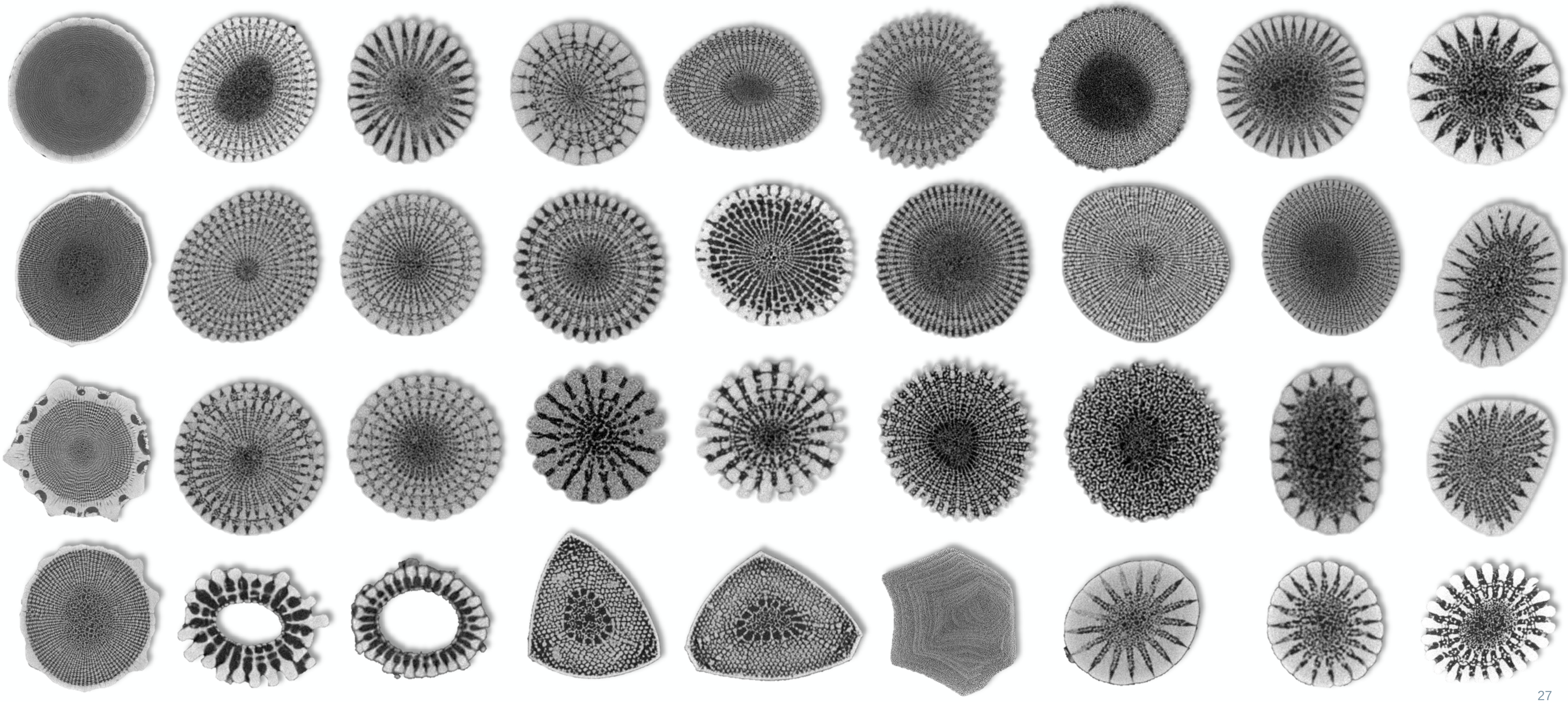


urchin spine, light micrograph

Minimize damage to the body

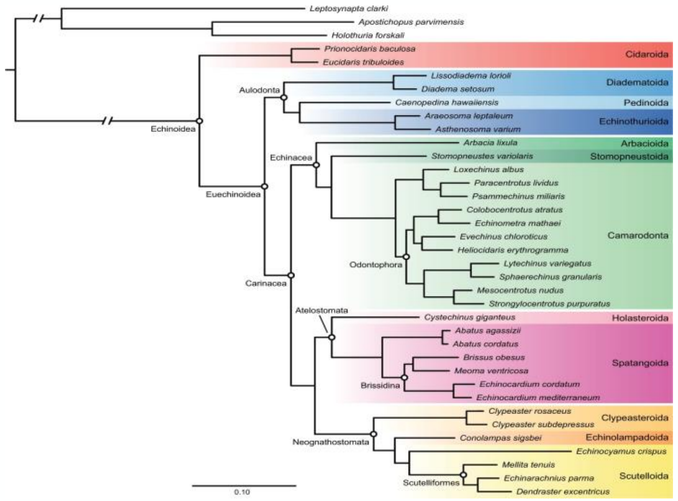
Withstand breaking waves

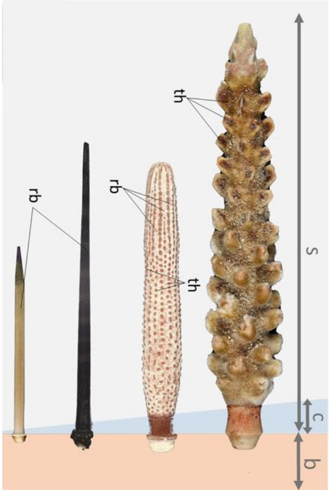
Evomimetics: an evolution-based approach to innovation



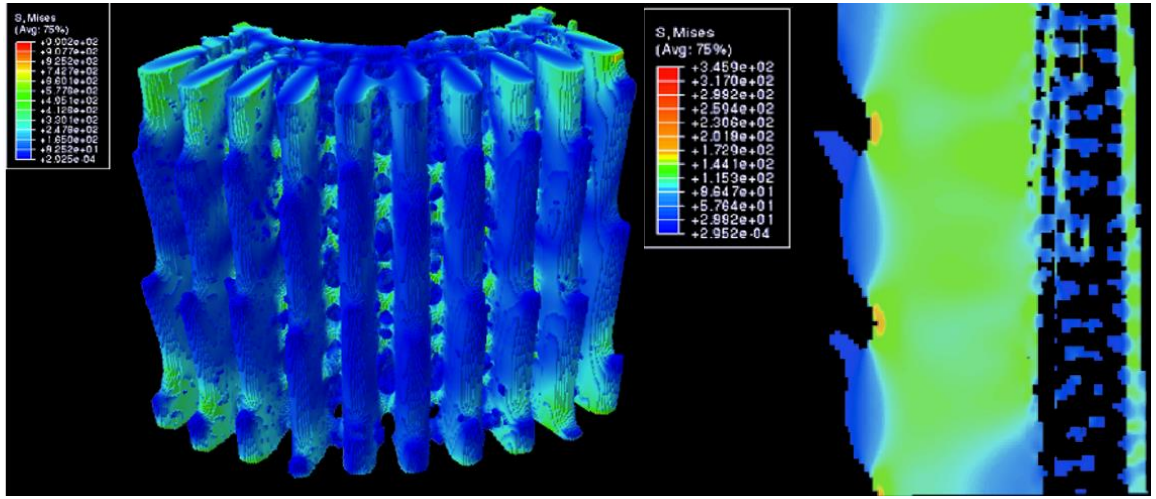
Evomimetics: an evolution-based approach to innovation

Diversity

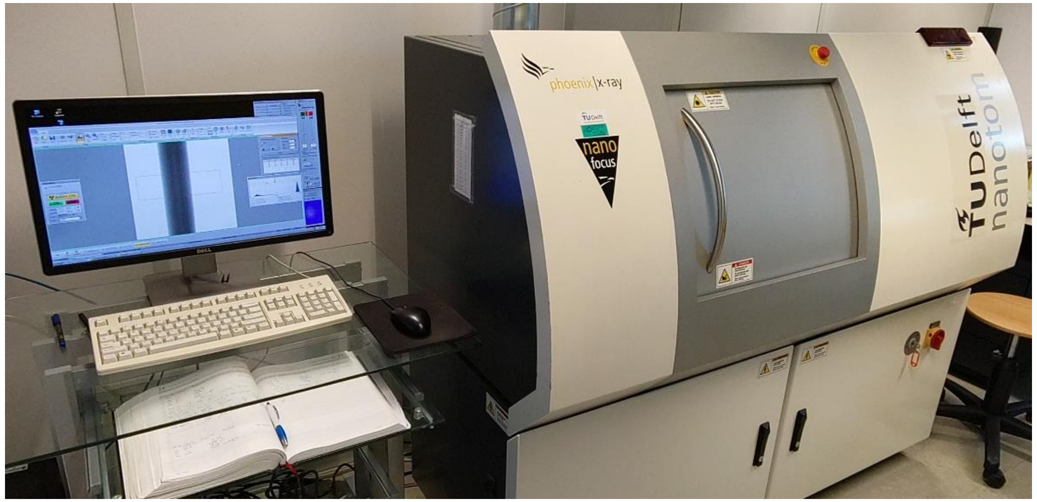




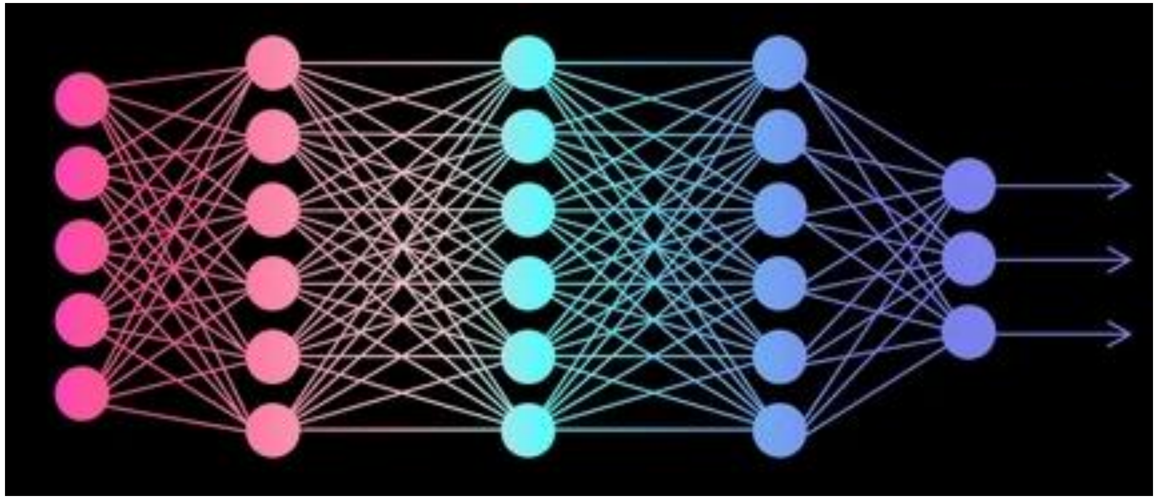
Mechanical Behaviour



Micro- and Macrostructure



Evolutionary Adaptive Changes



Evomimetics: an evolution-based approach to innovation

Foundations of evomimetics:

1. *Make the evolutionary dimension form an integral part of the biomimetic design thinking process.*
2. *Shift our focus from understanding biological organisms to the evolutionary changes that occurred in these organisms.*
3. *Use the evolutionary changes in traits – not the traits themselves – as a template for biomimetic design.*

Evomimetics can be of **significant importance to space applications**:

1. *Designs with the ability to reconfigure performance to complete any task;*
2. *These versatile designs could respond, or even adapt to, environmental changes in unfamiliar habitats*