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Butterfly Wing Scales as Inspiration for Multifunctional Building Surfaces

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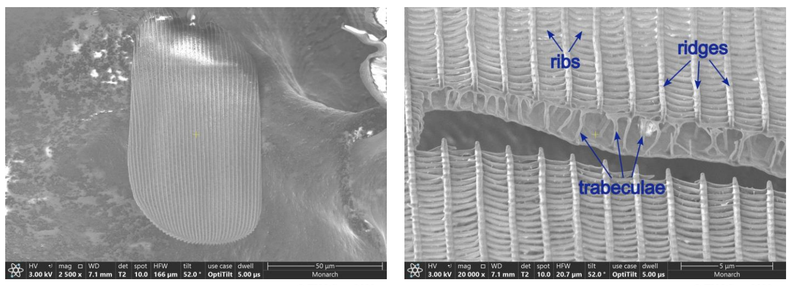
Biomimetics of Butterflies - What can we learn from them?

Butterflies have **scales** on the top and bottom of their wings, with multifunctional micro- and nanostructures. Some of the features and properties enabled or assisted by the scales are:

- **Colour**, camouflage(1)
- Increased attraction for mating
- **Thermoregulation**
- Aerodynamics
- Self-cleaning
- **Hydrophobicity**
- Light-weight structures and **structural integrity**
- Evading spider webs(2)



Single scale of a Monarch butterfly and its cross-section under the electron microscope

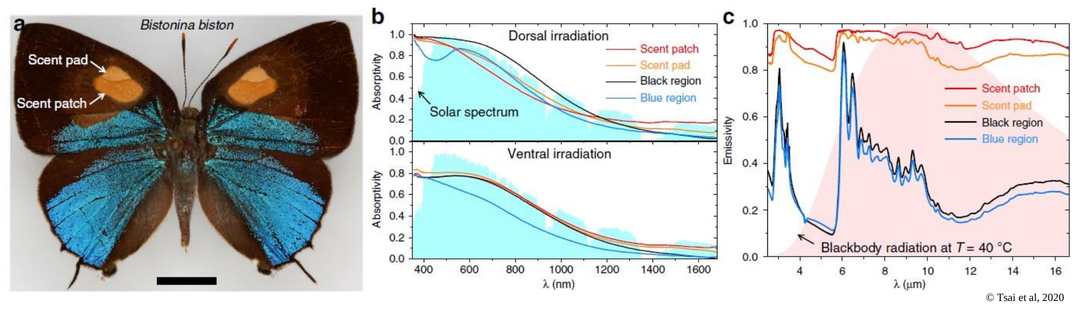
Some butterfly species use nanostructures on their wing scales that emit heat via **passive daytime radiative cooling**. Some species use structural colouring that yield bright colours.

The unique butterfly wing scale structures can inspire architecture, art, engineering, sustainable technology, environmental and life sciences and many more, fostering eco-friendly and resource-efficient practices.

Passive Daytime Radiative Cooling

The **infrared atmospheric window** is a spectral range from 7.5 µm to 13 µm, where atmospheric gases are completely or almost completely transparent for infrared radiation. This allows surfaces on Earth to emit radiation within that range into the depth of outer space, cooling off against the 2.7 K cold of the cosmic void.

Any body with a temperature above absolute zero (0 K or -273.15 °C) gives off electromagnetic radiation, called **black body radiation**, as described by Planck's law.

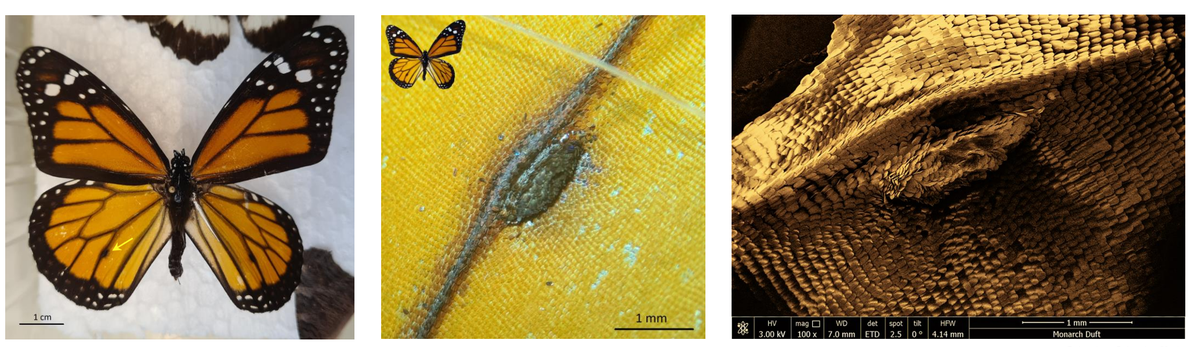


If a surface has large solar reflectivity as well as large heat emissivity (especially in the range of the atmospheric window), the ambient temperature of that surface will subsequently be lowered, without external energy input. This process is called **passive daytime radiative cooling**.(3)

Structural Differences on the Microscale

Scent scales on male butterflies are responsible for the distribution of pheromones and attraction of females. They are often arranged in distinct spots or stripes on the wings.

The scent scales of some butterfly species show a different spatial arrangement than the rest of the wing scales.



Colouring: Sebastian Karl
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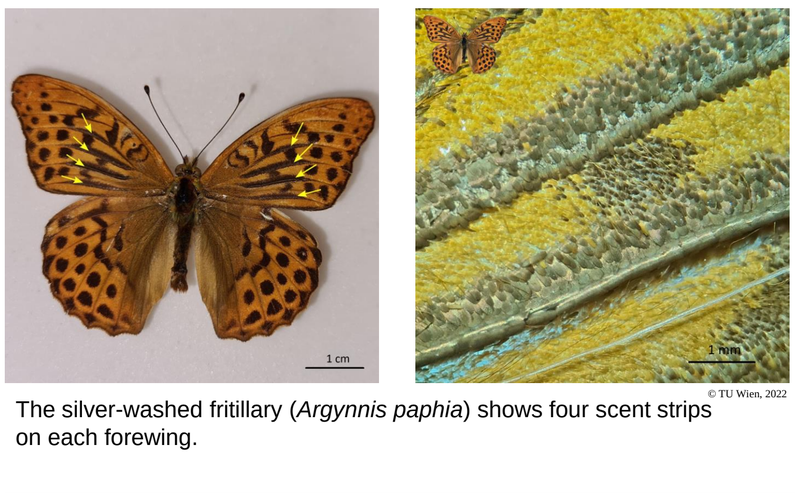
The Monarch butterfly (*Danaus plexippus*) has a distinct scent patch on each of its hindwings.

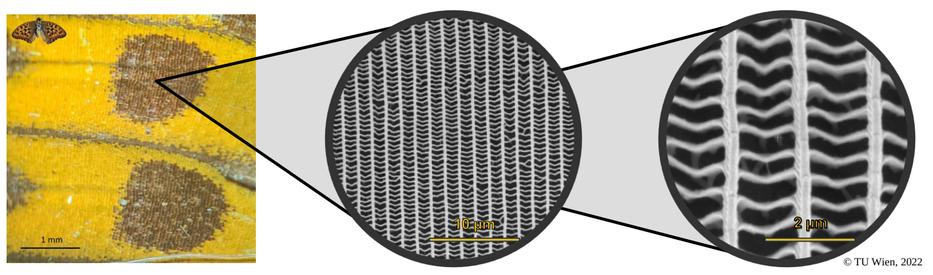


The silver-washed fritillary (*Argynnis paphia*) shows four scent strips on each forewing.

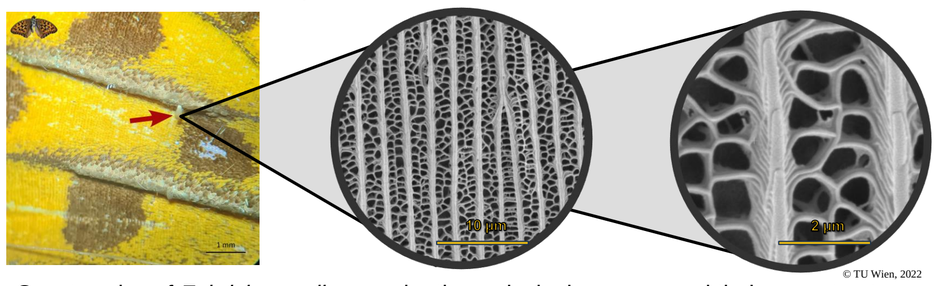
Distinct **scent patches** on butterfly wings have shown **altering emissivity**, hinting at revolutionary changes in cooling systems and modern architectural functionalities.

Structural Differences on the Nanoscale

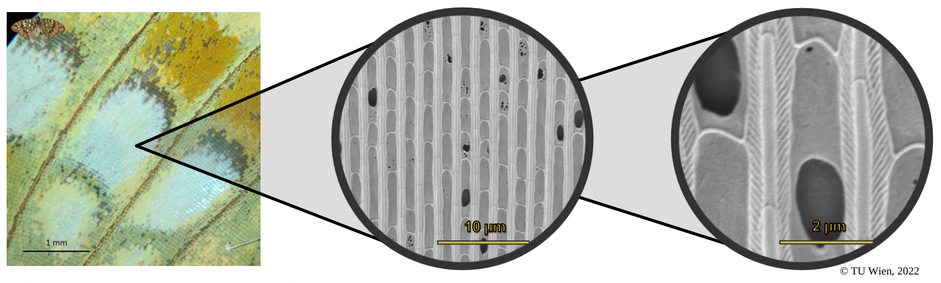
Also the **High Brown Fritillary** (*Fabriciana adippe*) shows different kinds of scales. The specimen investigated is over 60 years old, the nanostructures still are perfectly preserved, demonstrating the remarkable durability of the seemingly delicate structures.(4)



Brown scales of *Fabriciana adippe* under the optical microscope and their nanostructures under the electron microscope



Scent scales of *Fabriciana adippe* under the optical microscope and their nanostructures under the electron microscope



Silver, reflective scales of *Fabriciana adippe* under the optical microscope and their nano-structures under the electron microscope

Distinct features indicate different functionalities corresponding to the respective challenges of each type of scale. Focus of our research is structure based functionality transfer to relevant areas of application, such as building surfaces.

Integration instead of additive construction is a common feature of multifunctional structures in living Nature. This is the reason for the beauty, but also the major challenge in biomimetics. Different butterfly species seem to pursue **different strategies**, which further complicates investigations but also keeps them exciting.

(1) Kinoshita S. (2008) **Structural colors in the realm of nature**. World Scientific, 52-56
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(3) Tsai, C.-C. et al (2020) **Physical and behavioral adaptations to prevent overheating of the living wings of butterflies**. Nature Communications 11. 551.
(4) Gebeshuber I.C. and Zischka F. (2023) **Lernen vom Schmetterling für passiv selbstkühlende Fassaden**. Bulletin - Alumni-Magazin der TU Wien Nr. 54, März 2023, Cover Page & p. 22-23

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