The Wings of Lepidoptera: what we already know

- The wings of Lepidoptera are important both in flight and in signaling (sexual selection warning coloration, mimicry and camouflage)
- They are primarly composed of membranes covered by scales, but also contain complex networks of cellular structures, for example an extensive distribution of sensilla along the wing veins
- Much of the research on thermoregulation in adult Lepidoptera has been focused on thoracic temperature and flight

Aim of the work: investigating the thermodynamic and thermoregulatory properties of the wing itself, first by observing the distribution and persistence over the entire adult lifespan of living tissues in the wings of butterflies, and then by studying the thermodynamics of the wing and the physical and behavioral adaptations that modulate wing temperatures in ways that protect these tissues

Methods

MORPHOLOGY

- Three species: Vanessa cardui, Satyrium caryaevorus, and Parrhasius m-album
- Anesthetized with CO_2 and scales removed from both sides of the wings
- Photos and videos taken with a microscope equipped with a CCD camera.
- Methylene blue used to stain the neurons in wing veins

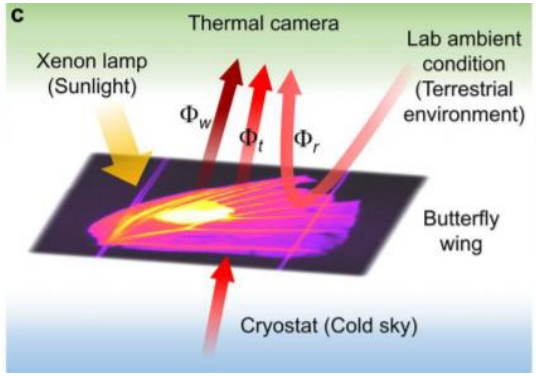
INFRARED HYPERSPECTRAL IMAGING

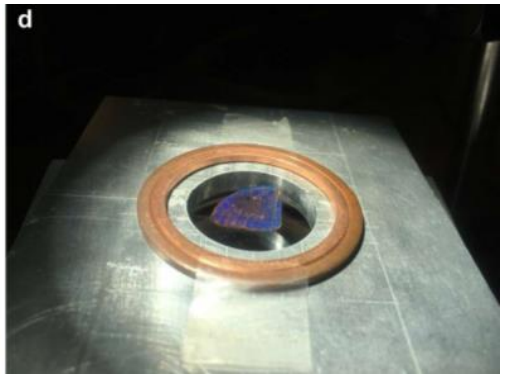
- Trasmissivity and reflectivity distribution with one transmission and reflection spectrum at each position
- Optical transmission and reflection hyperspectral data cube
- Creation of an emissivity hyperspectral data cube for visualizing butterfly wings at different infrared wavelengths
- Derivation of T distribution on the butterfly wings

Methods

SIMULATING NATURAL RADIATIVE ENVIRONMENT

- Xenon lamp shining at a distance of 0.5m to simulate sunlight



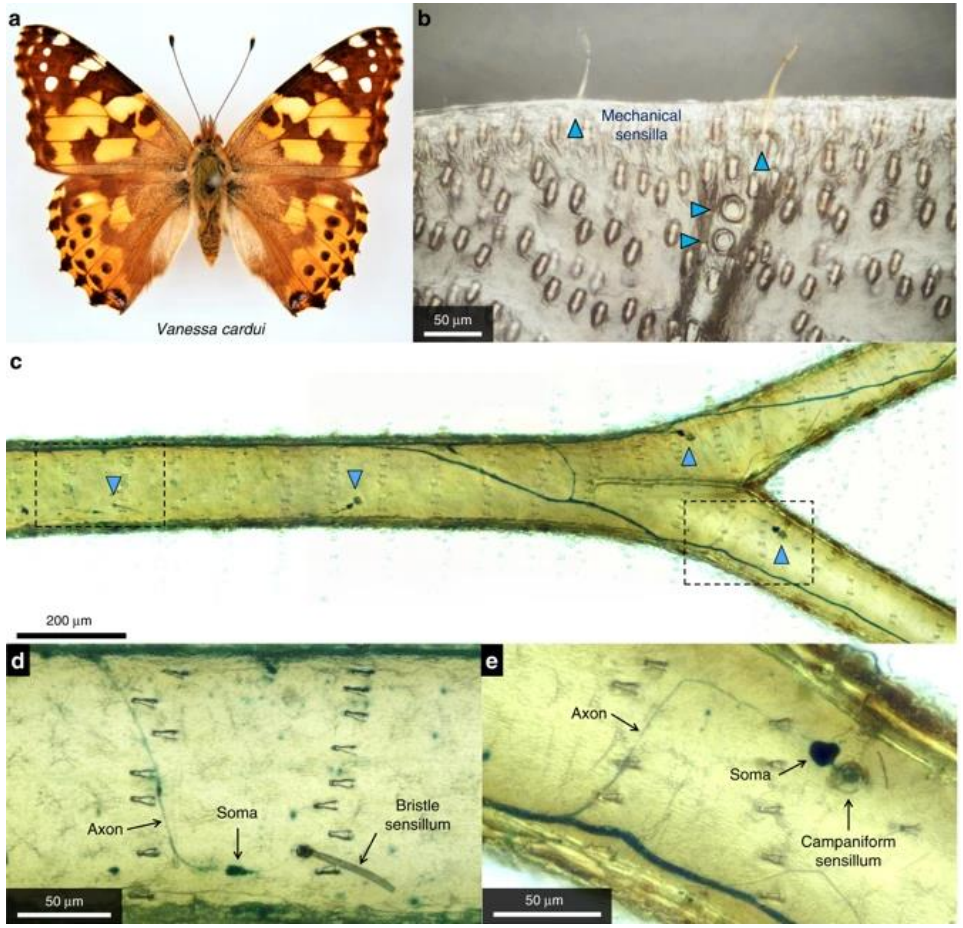


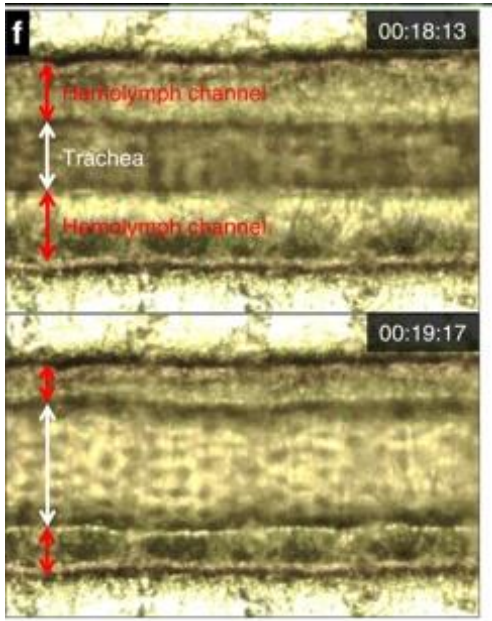
- Lab space on the top emisphere at T=25°C
- Temperature controllable cryostat used to simulate the sky in different weather conditions

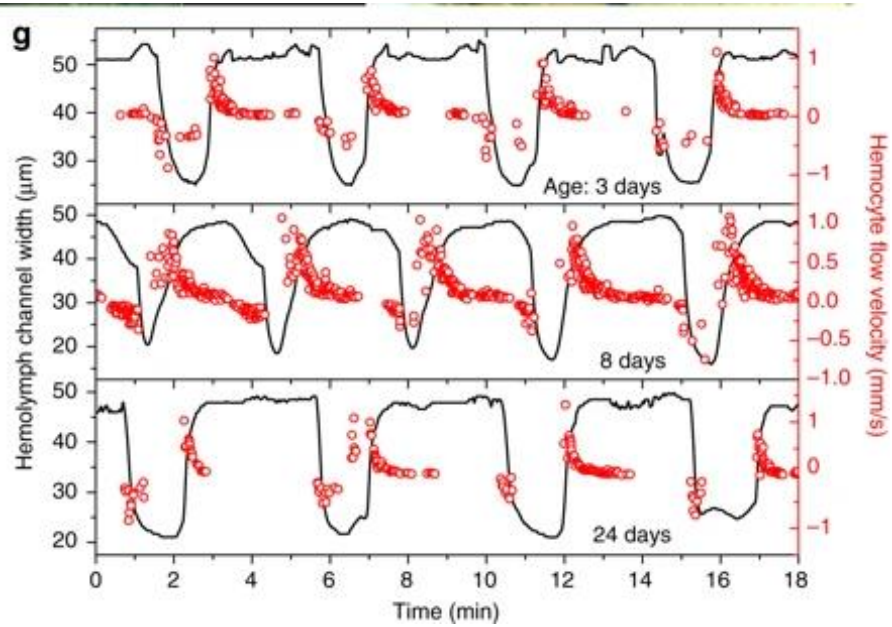
BEHAVIOR

- Study conducted over 6 different families of butterflies
- Butterfly in an arena pointed with a collimated laser beam
- Increasing of T in the region illuminated by laser and movement of the wing to avoid the beam
- Threshold $T_{trigger}$
- Increasing of T of the beam from 25 to 45 °C in 7-8s
- Butterfly in an arena with a Xenon lamp
- Lateral basking
- Use of thermal camera

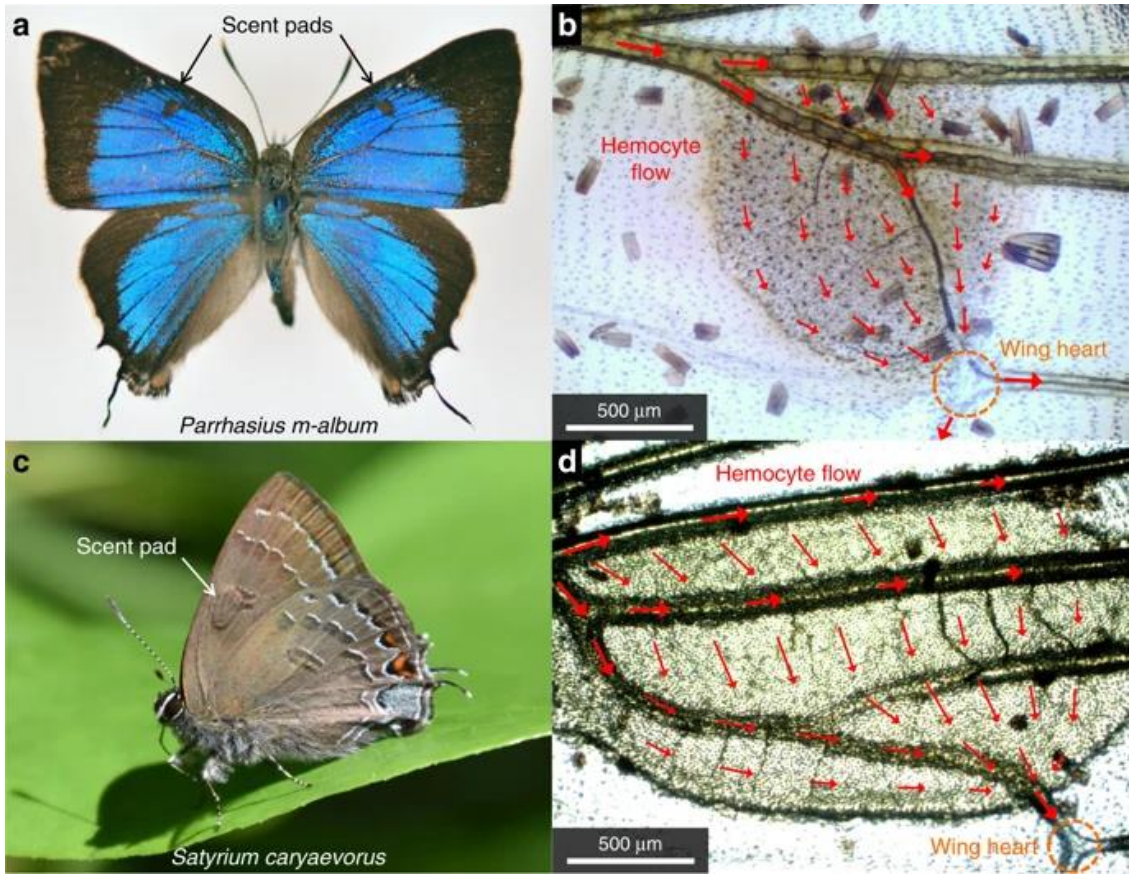
Butterfly wings as living structures

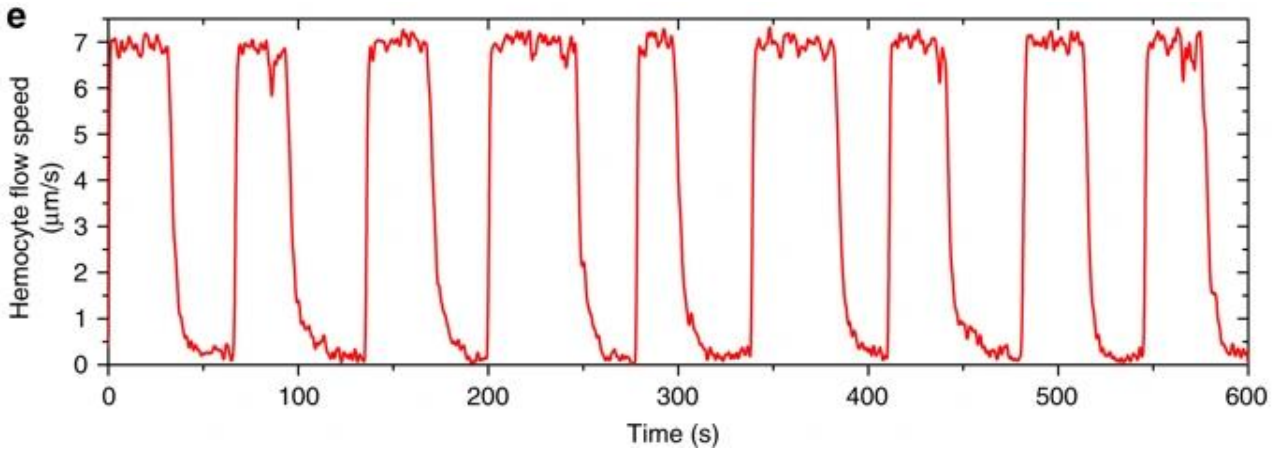




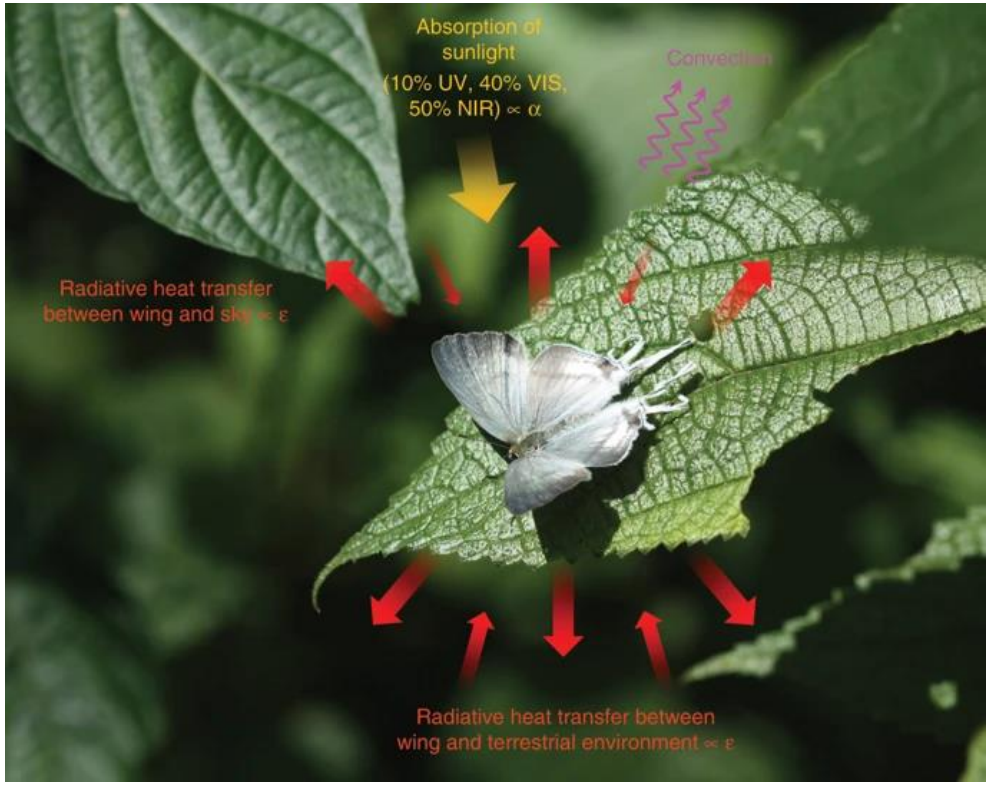


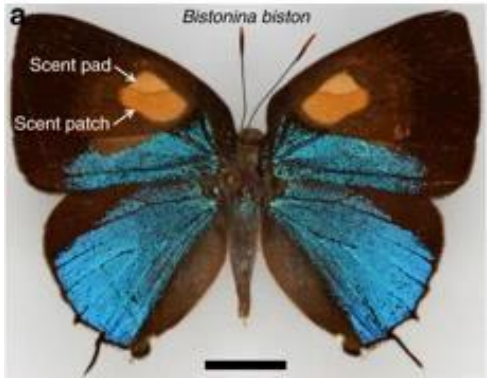
Butterfly wings as living structures

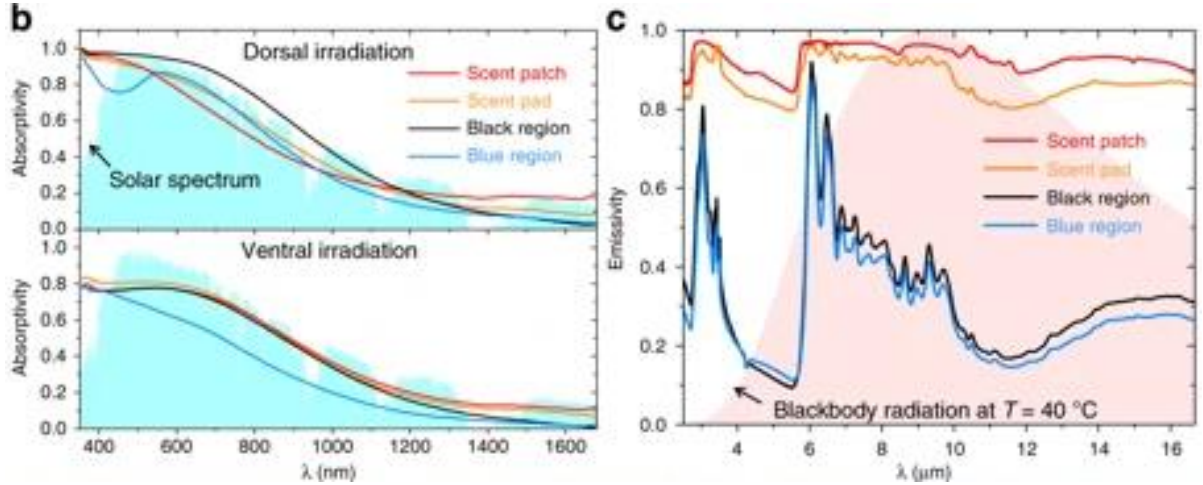




Thermodynamics of wings





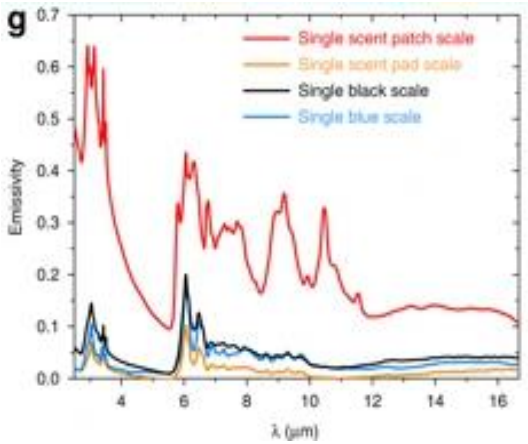


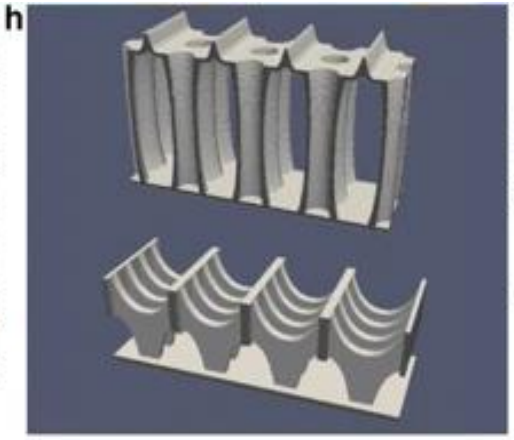
With dorsal irradiation the region covered by black scales has stronger solar absorption than lighter-colored scent patch, scent pad and structural blue region.

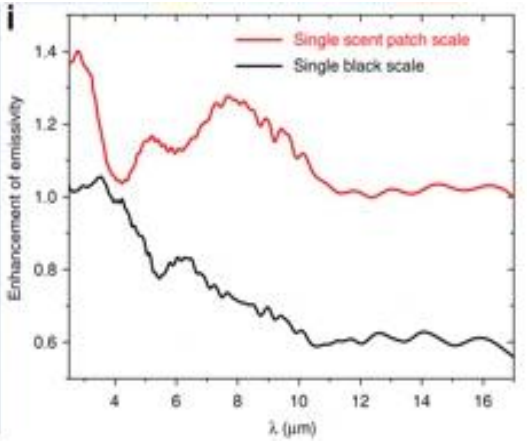
The lighter-colored ventral wing surface has reduced solar absorption.

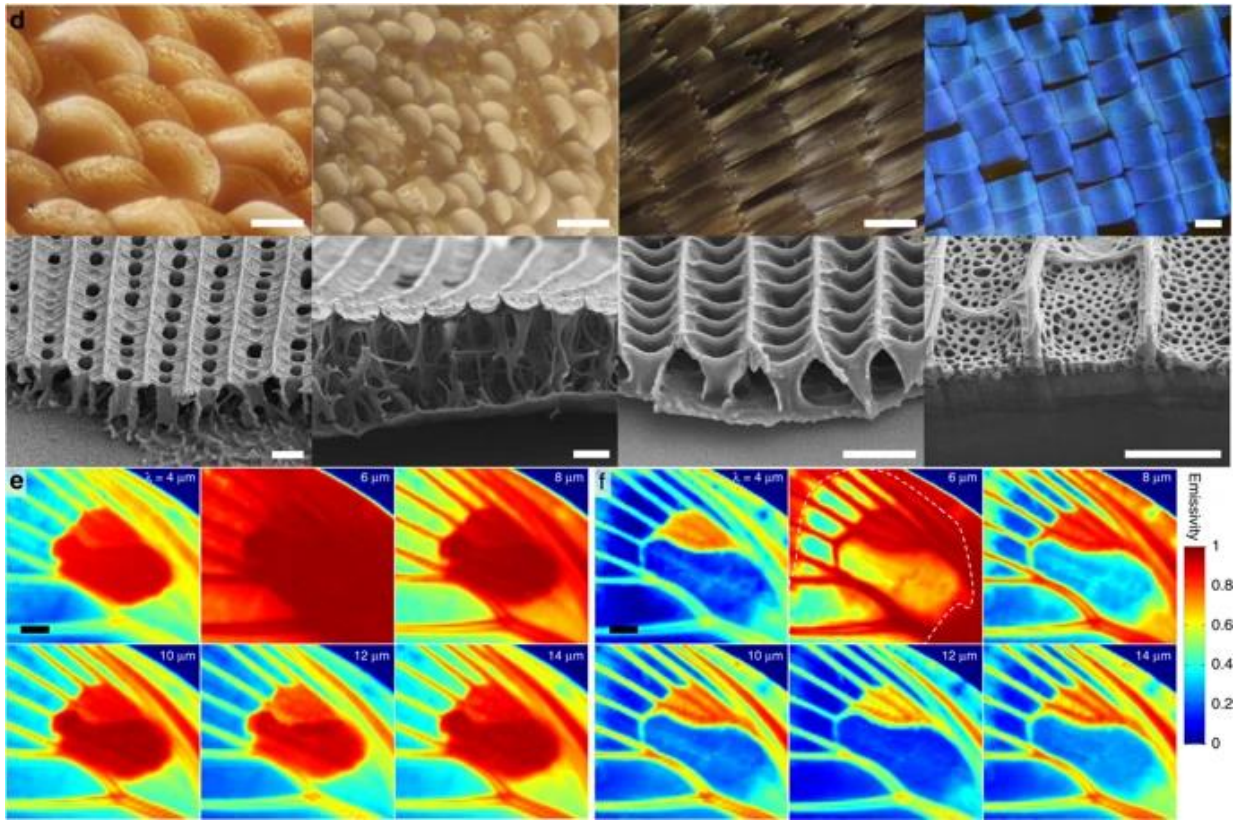
All wings regions have lower solar absorptivity in the near-infrared than in the visible. Different parts of the wings have different thermal emissivities, in particular the scent patch, scent pad and wing veins have emissivities approaching unity.

Thermodynamics of wings







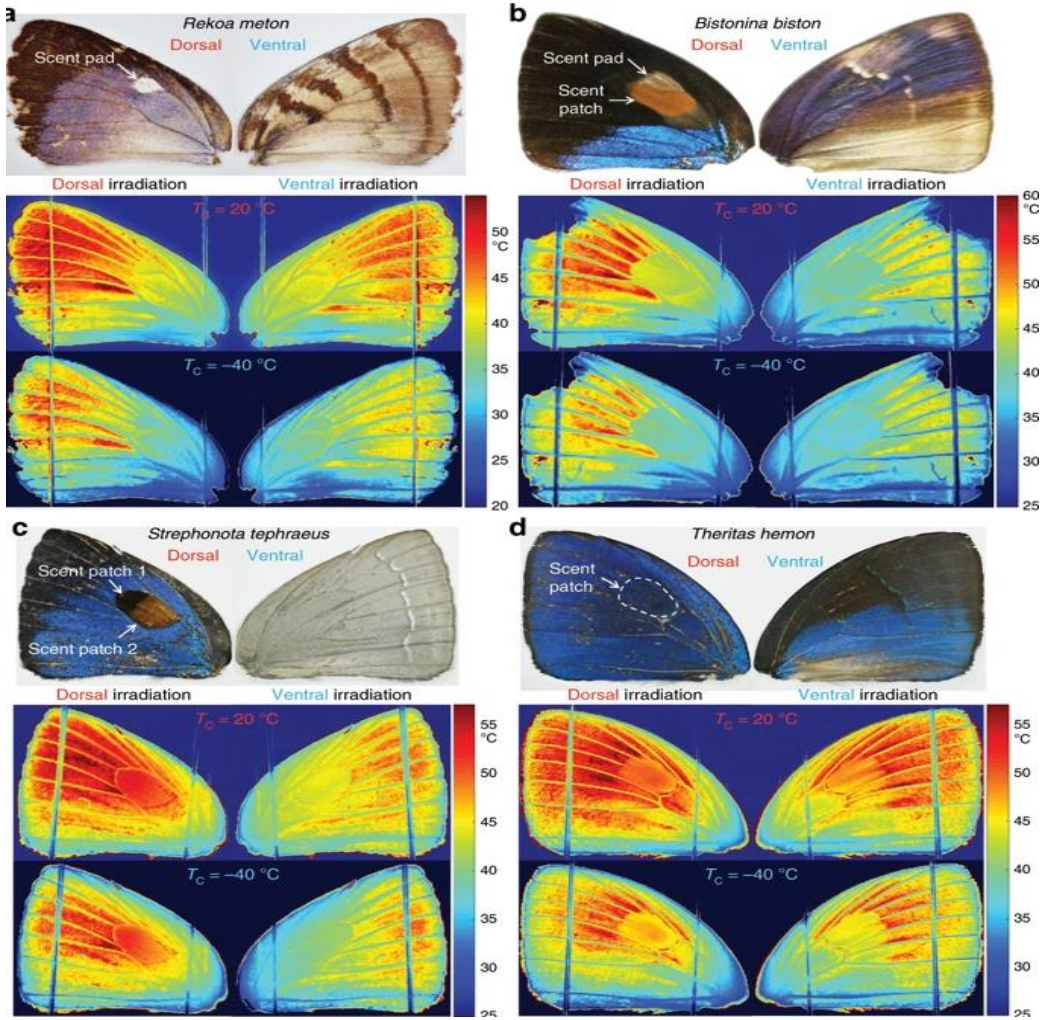


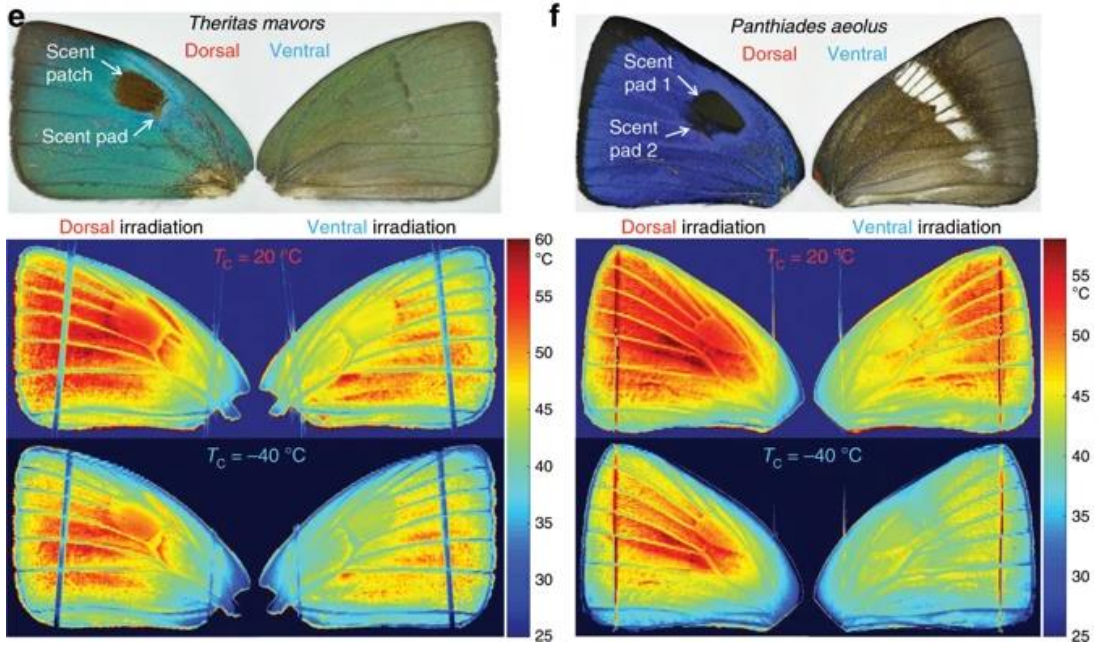
Scent patch scales are by far the most emissive amog all types of scales becouse of their unique nanostrucutres.

High emissivity of scent pad and wing veins is due to the physical thickness of their unfused membranes.

The infrared properties of the wings of individual adult representing more than 50 species have been characterized, founding that scent patches, scent pads and wing veins have without exception high thermal emissivity.

Simulated environmental conditions



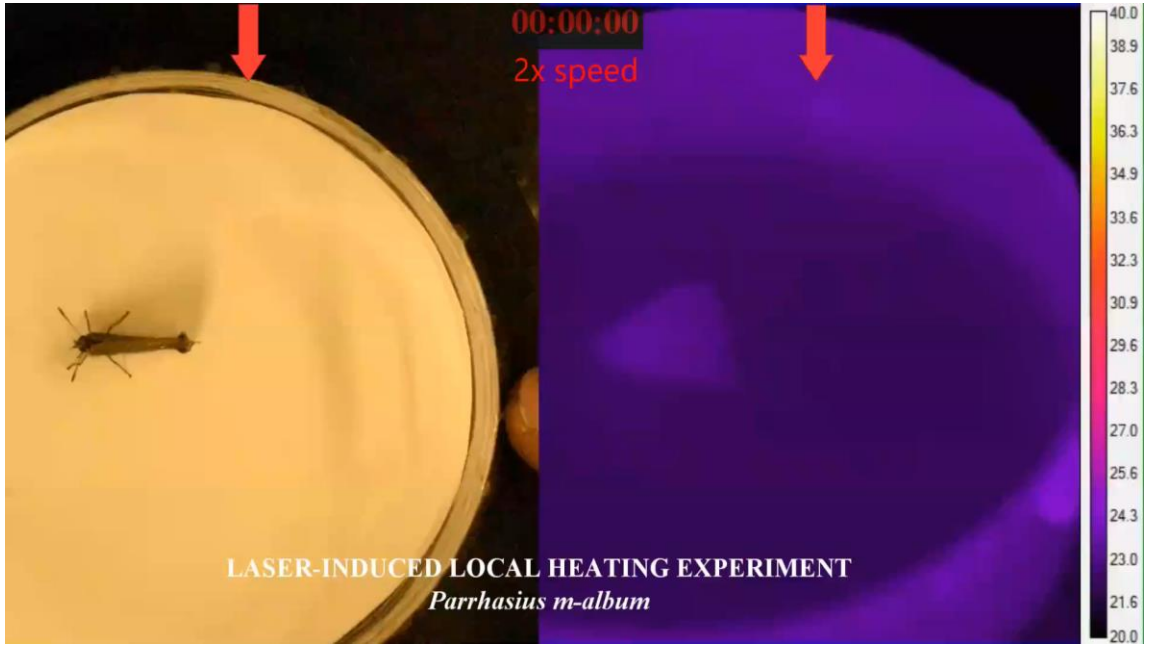


Measuring mid-infrared emissivity, transmissivity and reflectivity spectra of the wing, the thermal radiation generated directly by the wing can be found.

Under the condition of ventral irradiation, scent patches, pads, veins and margins rarely exceed 45°C → plausible explanation of why many butterflies tend to close their wings when resting of basking, and infrequently expose their dorsal wing surfaces.

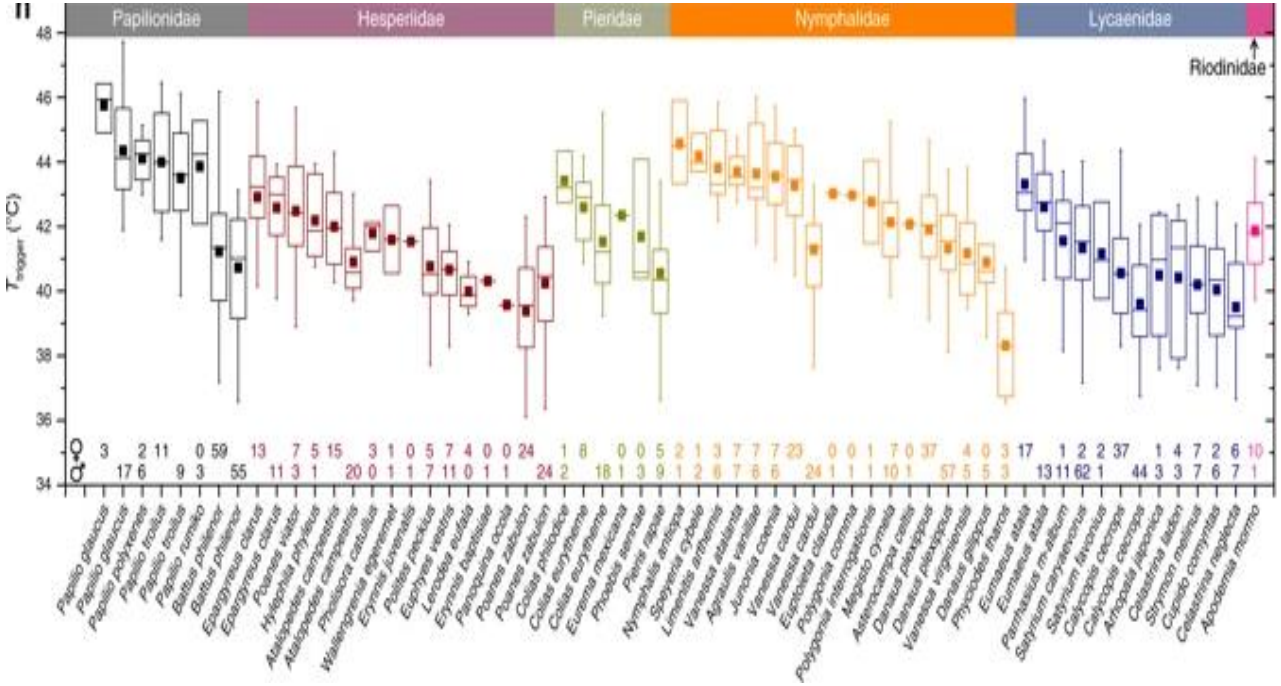
Great temperature reduction achieved by a combination of low solar absorption and efficient radiative heat dissipation.

Wings as sensors that modulate behavior



Butterflies were observed to move in characteristic ways to displace thermal stimuli applied to their wings.

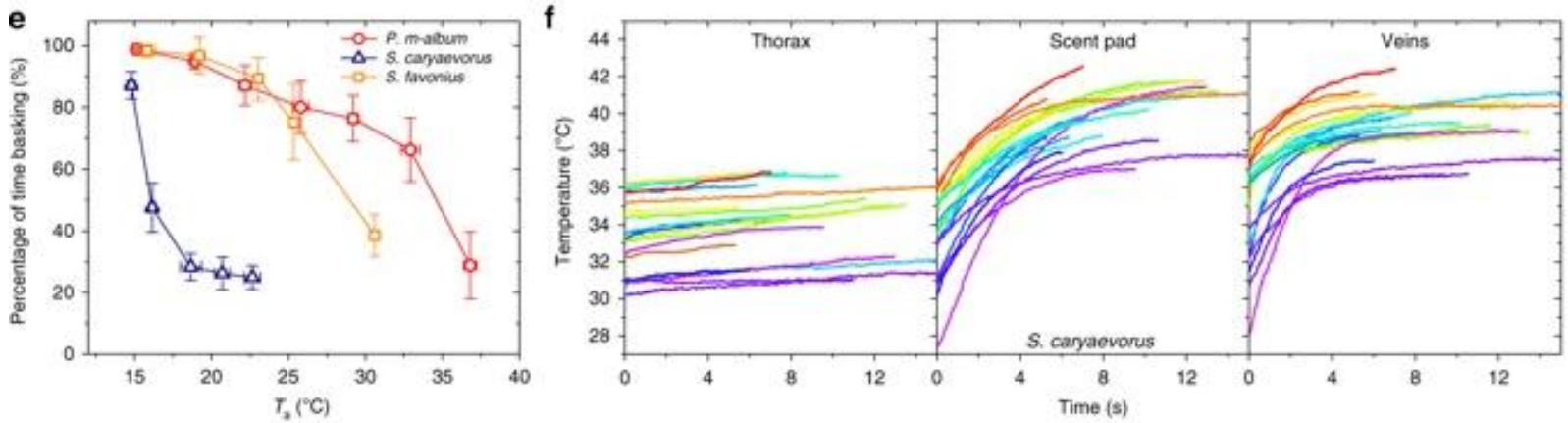
Butterflies across diverse families converge on a $T_{trigger} = 41.89 \pm 1.54°C$



Basking behavior

The percentage of time the butterflies spent basking decreased as the ambient temperature increased

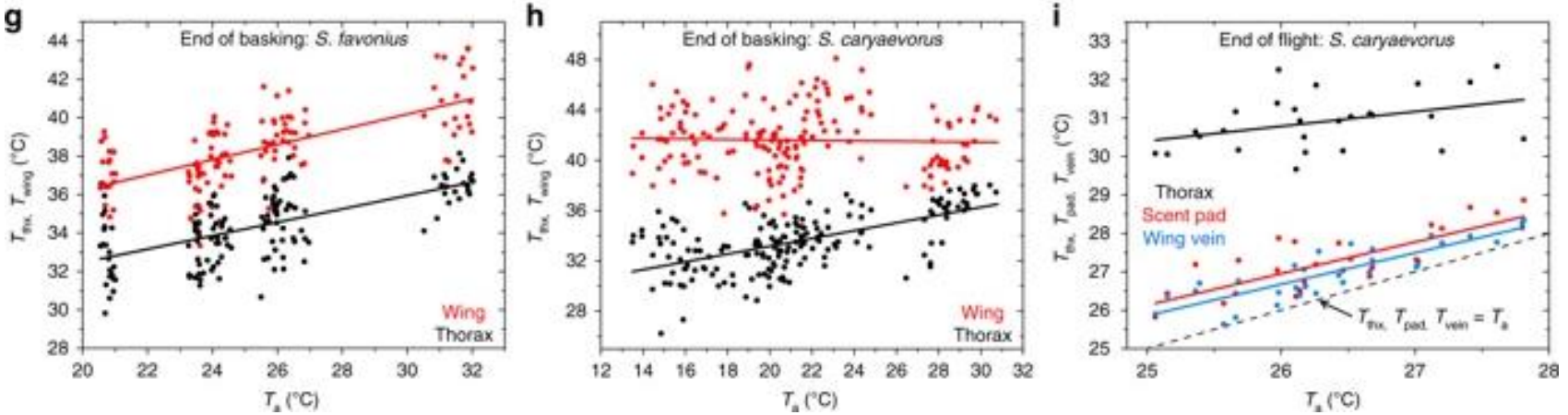
The effect of basking on heating yp the wings was considerably stronger and faster than its effect on heating up the thorax becouse of the relatively small thermal capacity of the wings → the cessation of basking occurs when wing temperatures are too high, whereas thoracic temperatures remains relatively constant during basking.



Basking behavior

In field studies, it has found that *S. caryaevorus* almost always bask in the sun within a few seconds after ceasing flight: at that moment the thoracic temperature is reasonably high as a result of the metabolic heat generated by the flight muscles, but the wings have T close to ambient temperature due to the strong convection during flight.

Basking behavior may be elicited by cold wings → T of the wings must be sufficiently high for optimal function of sensilla



Conclusions

- This work emphasizes the interactions of the wings as physical structures with the abiotic electromagnetic environment, including solar and thermal radiation
- Selection has favored adapatations such as heterogeneous cuticle thickness, specialized scale nanostructures, contrasting dorsal and ventral wing coloration, and finely-tuned behavioral reactions to protect the vulnerable living tissues within wings
- When butterfly close their wings, the thermal emissivity is larger than that of a single wing due to their increased physical thickness → dorsal basking with open wings and lateral basking with closed wings could have different effects on the thermodynamics of the butterfly wings
- The physical and behavioral adaptations underscore the importance of wings as highly responsive living structures and the centrality of wing thermoregulation to lepidopteran biology.

GRAZIE PER L'ATTENZIONE