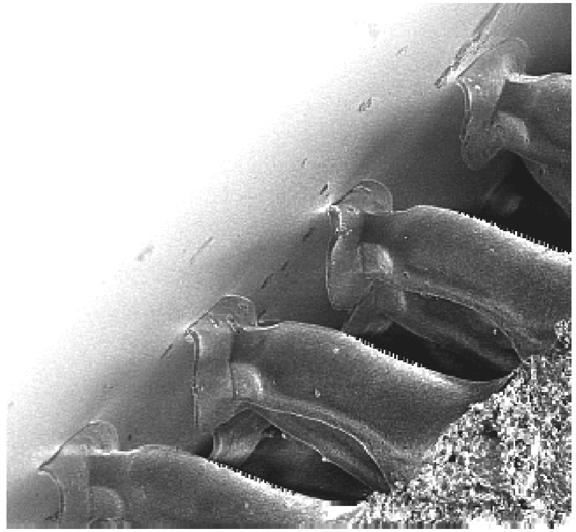
Zoological Institute, Universität zu Kiel, Germany



Stanislav N. Gorb

Naturprinzip und Biomimetik:

Wie haften Geckos und Fliegen an der Decke?

Surfaces and Interfaces

- sensorics
- attachment
- drag reduction
- optics (anti-reflection)
- grinding
- anti-friction
- sound generation
- respiration
- thermoregulation
- coloration pattern
- self-cleaning

etc., etc....

Goals

to understand functional principles

studies on ultrastructure, material properties, force range, motion in biological systems

to develop methods

microscopy techniques, measurements of stiffness, hardness, adhesion, friction at local and global scales

FUNCTIONAL PROJECTS

to understand evolutionary tendencies

broad comparative studies

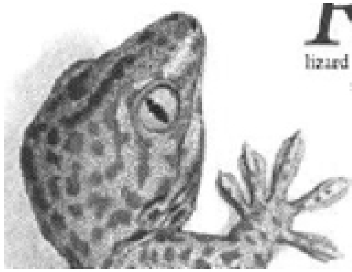
EVOLUTIONARY PROJECTS

to find interesting properties of systems

transfer of the natural design solutions in the material science

BIOMIMETCS PROJECTS

Get a Grip



cond, a
defy
lizard can get
sticking p
toe to
tire
uses
force
away
to tal
The

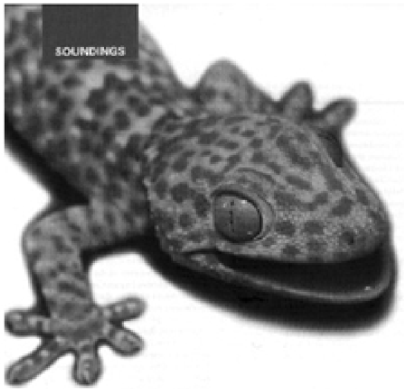
The gecko owes its superior climbing skills to atomic power

BioBriefs

GECKOS YIELD THEIR STICKY SECRETS

For more than a century, researchers have been trying to figure out how

many as
shaped



A (Non)Sticky Situation: How Geckos Climb Up Walls and Why We Should Care

Tiny robots that can skitter up walls and across ceilings . . . . A dry, non-chemical "glue" to hold together surgical incisions . . . . An adhe-

foot hairs. Their results were published in a recent issue of the journal *Nature* [v. 405, June 8, 2000.]

USA TODAY

Gecko feet may be step toward strange technologies

PORTLAND, Ore. (AP) The mystery of what makes geckos stick to just about anything a question that has puzzled scientifi minds since Aristotle finally has been solved, according to a new study. The answer involves the geometry, not the biochem of the lizard's feet, meaning scientists may be able to duplicate the same geometric principles to create things such as robot can walk on any surface in any direction, the researchers say. Another possibility is something as simple as Band-Aids that

Autumn et al. 2000; 2002; 2006

What Material Do We Want to Develop?

Sticky...

Do we want to use it
for walking on the wall and ceiling?

...and extremely fast

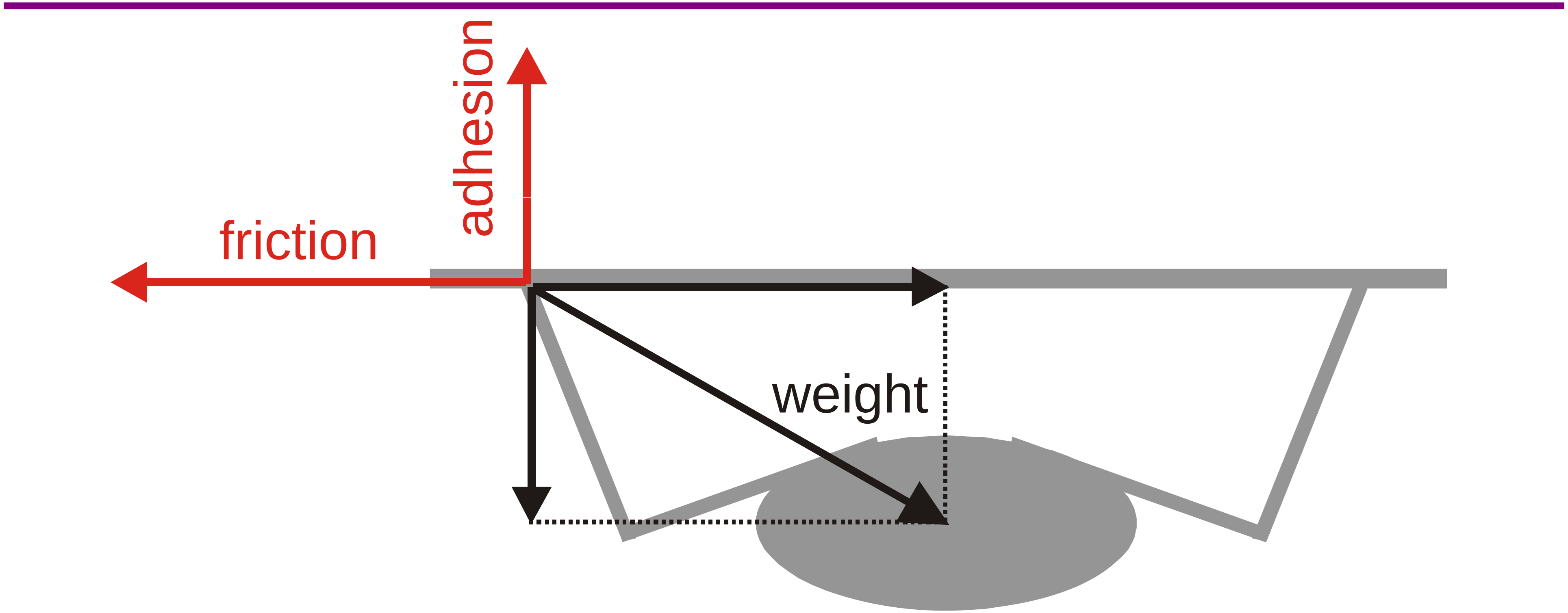
...to unpredictable surfaces

...and fast releasable (millions of cycles)

...non-conglutinating!

Ceiling Situation (Static)

Ceiling Situation



contact formation ⇨ **strong adhesion** ⇨ **contact breakage**

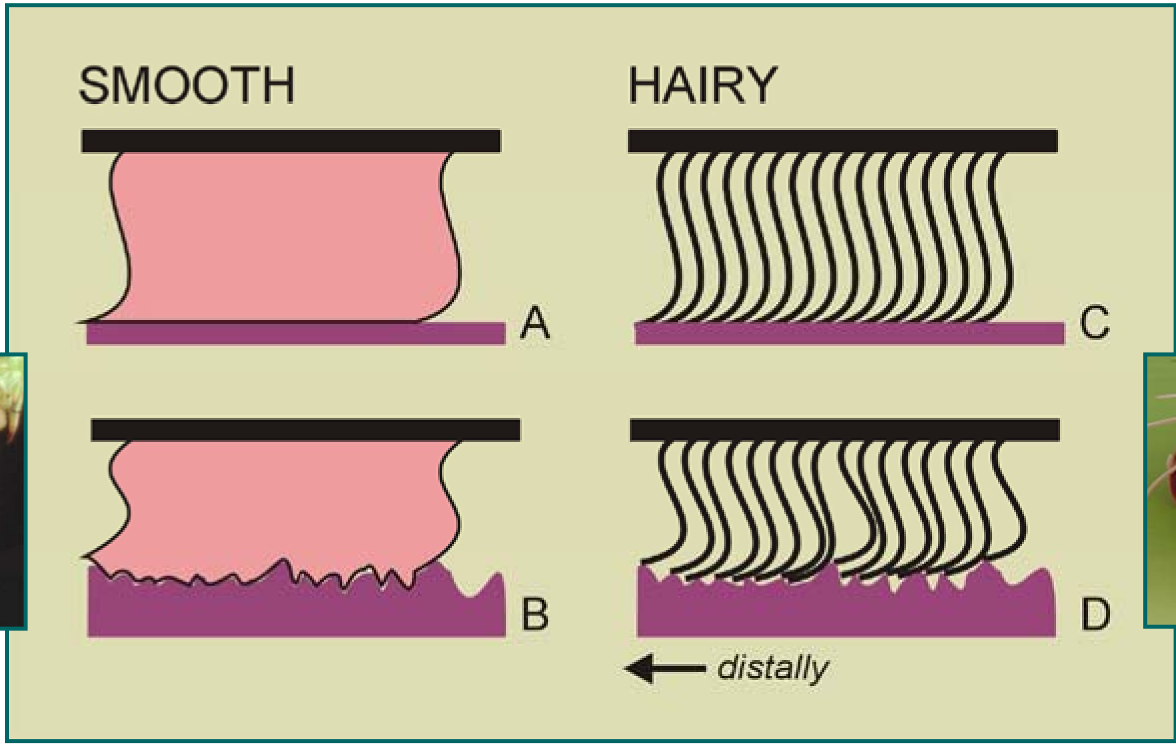
contact formation
- fast
- reliable
- minimal load on the ceiling

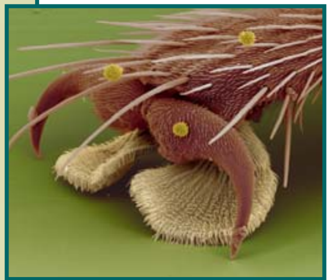
strong adhesion

contact breakage
- fast
- minimal force

Insect Terrain

Two Designs of Animal Attachment Pads





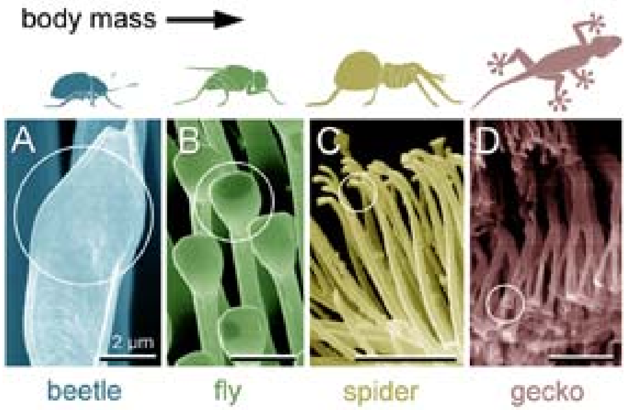
Blattaria
Orthoptera
Plecoptera
Hymenoptera
Homoptera
Heteroptera

over 300 species studied

Diptera
Coleoptera
Megaloptera
Raphidioptera

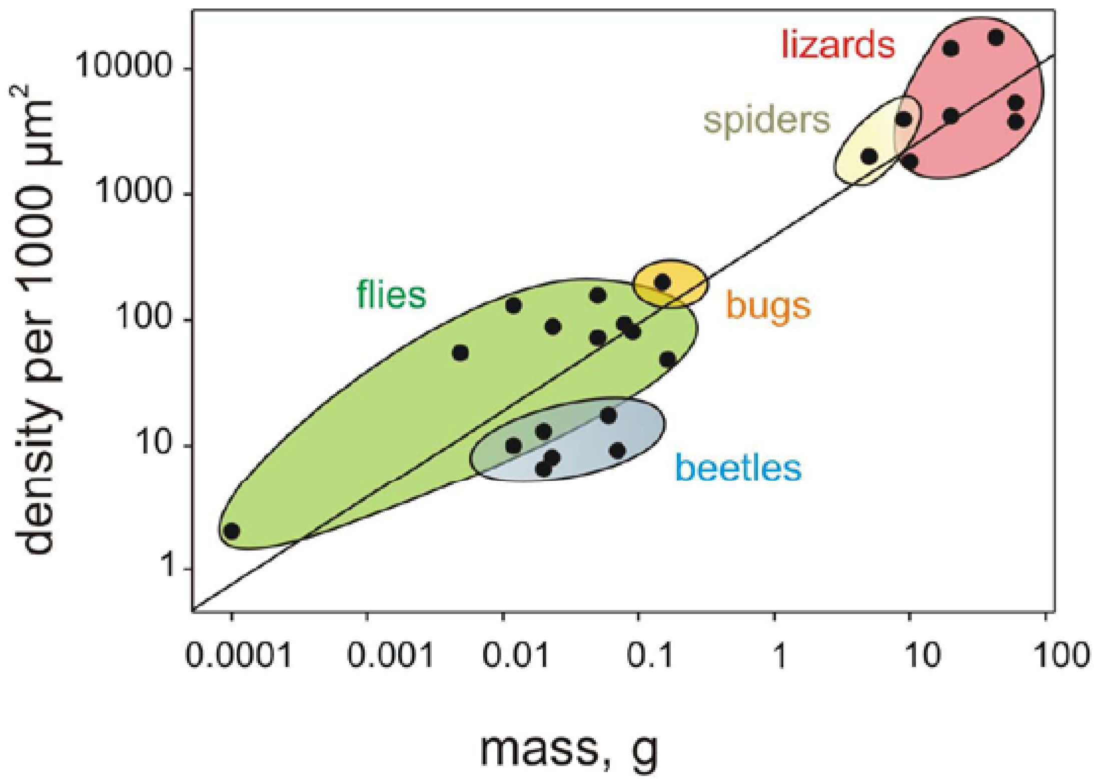
Dimension and Density of Setae

Scherge and Gorb, 2001 Springer Book
Arzt, Gorb, Spolenak, 2003, PNAS



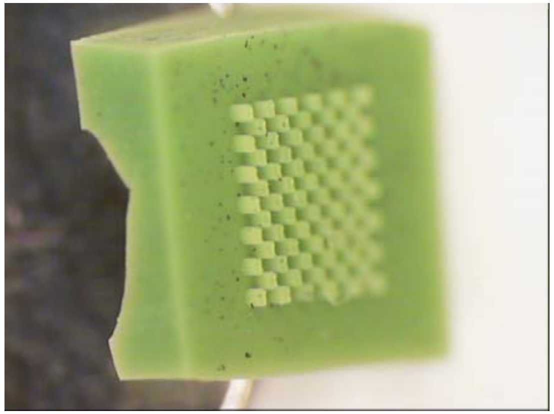
Dependence of the hair density (terminal elements) of the attachment pads on the body mass in hairy pad systems of representatives from diverse animal groups

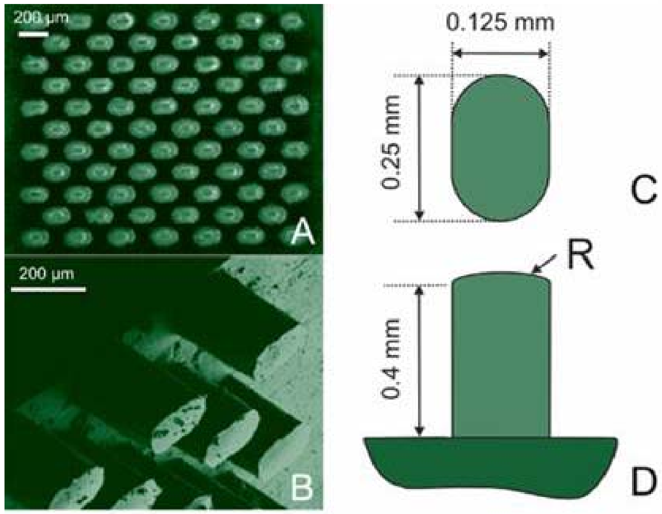
Setal density dependence on the body mass

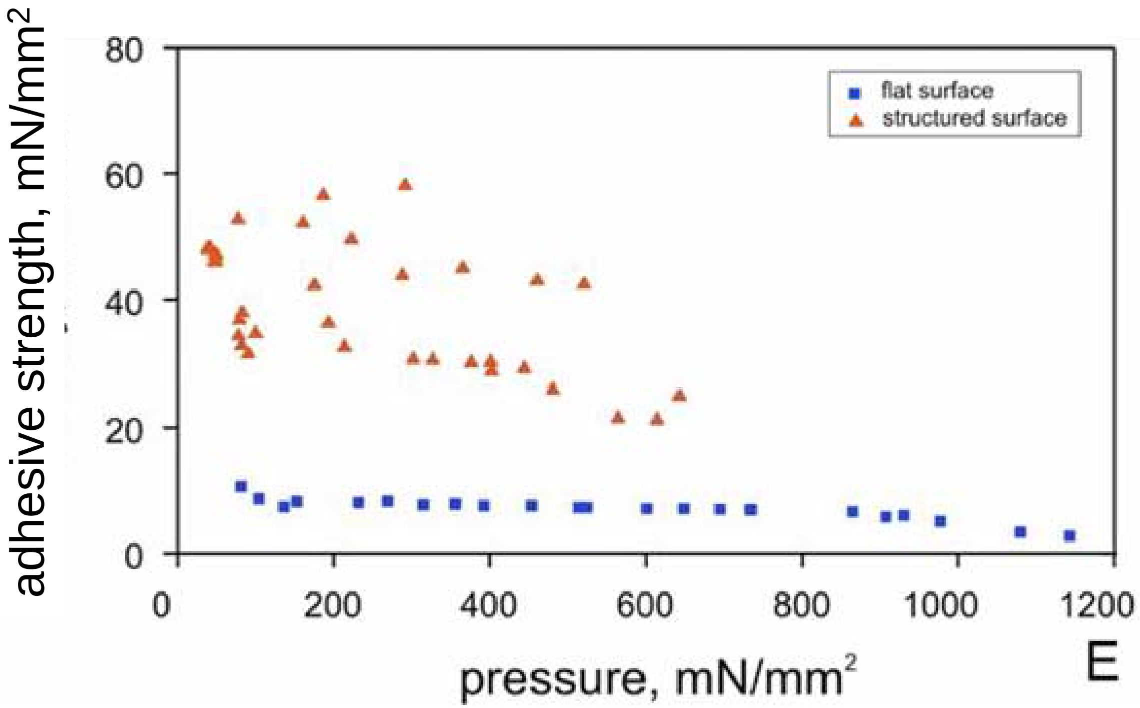


Experiment
with the Structured Polymer Surface

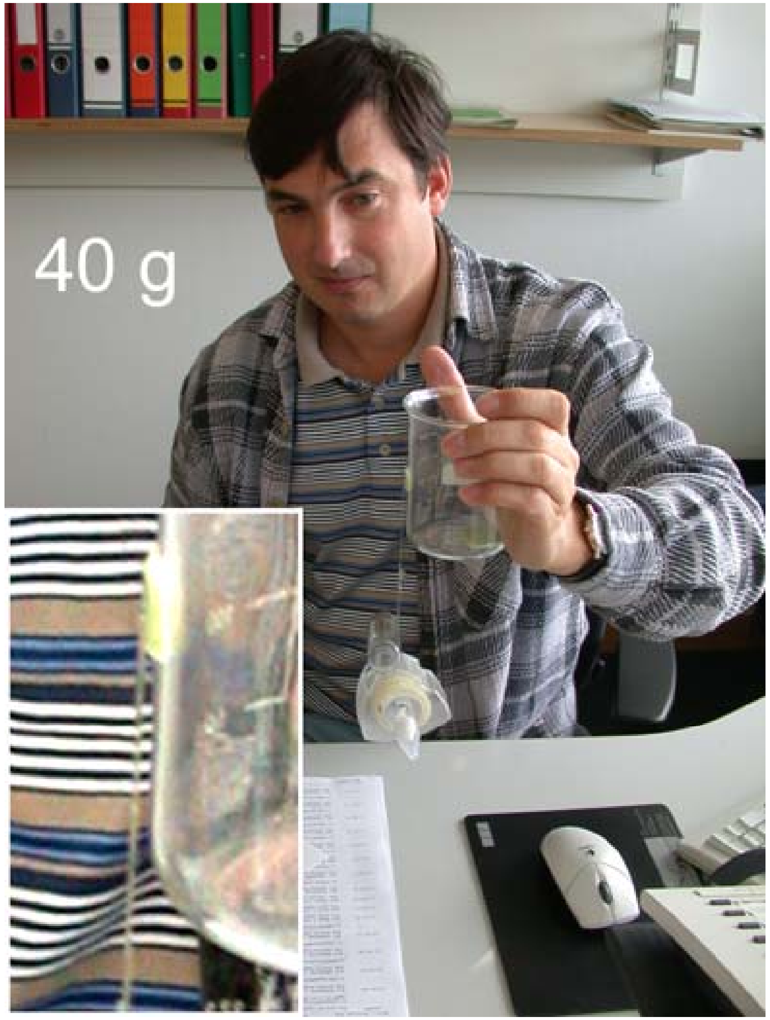
Peressadko and Gorb, 2004, J. Adhesion

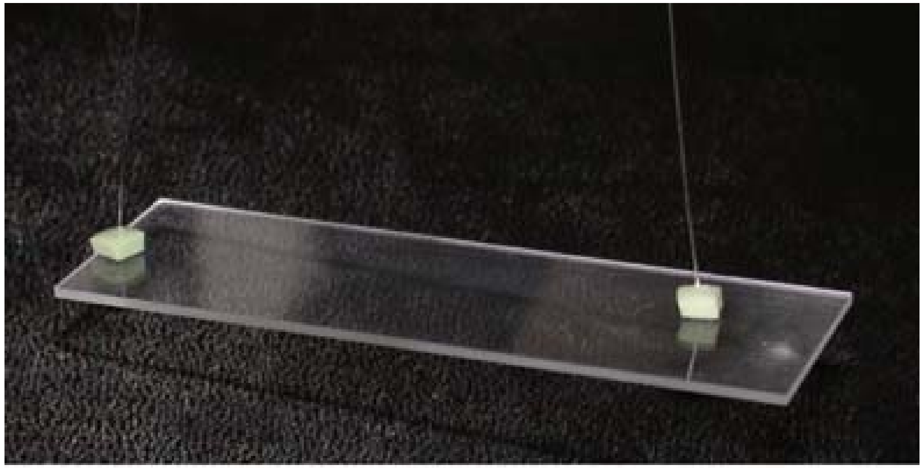


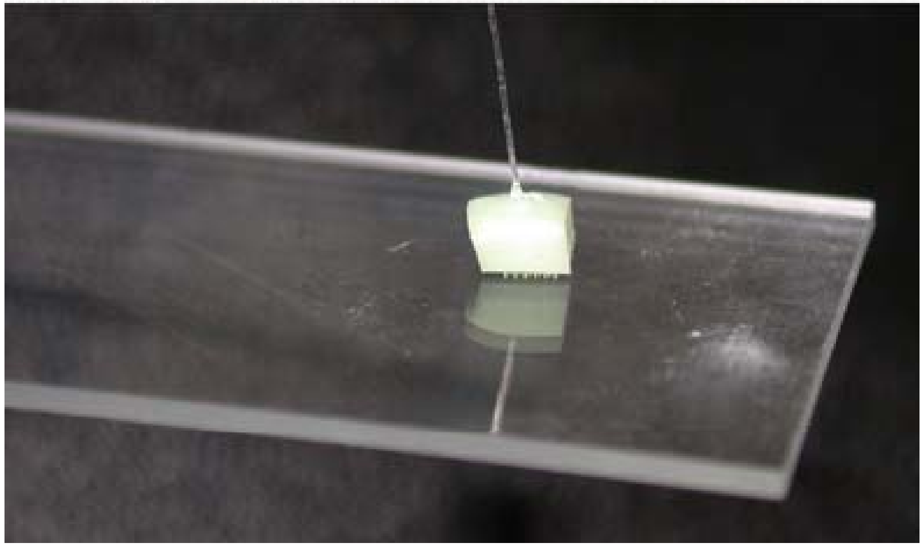




First Prototypes

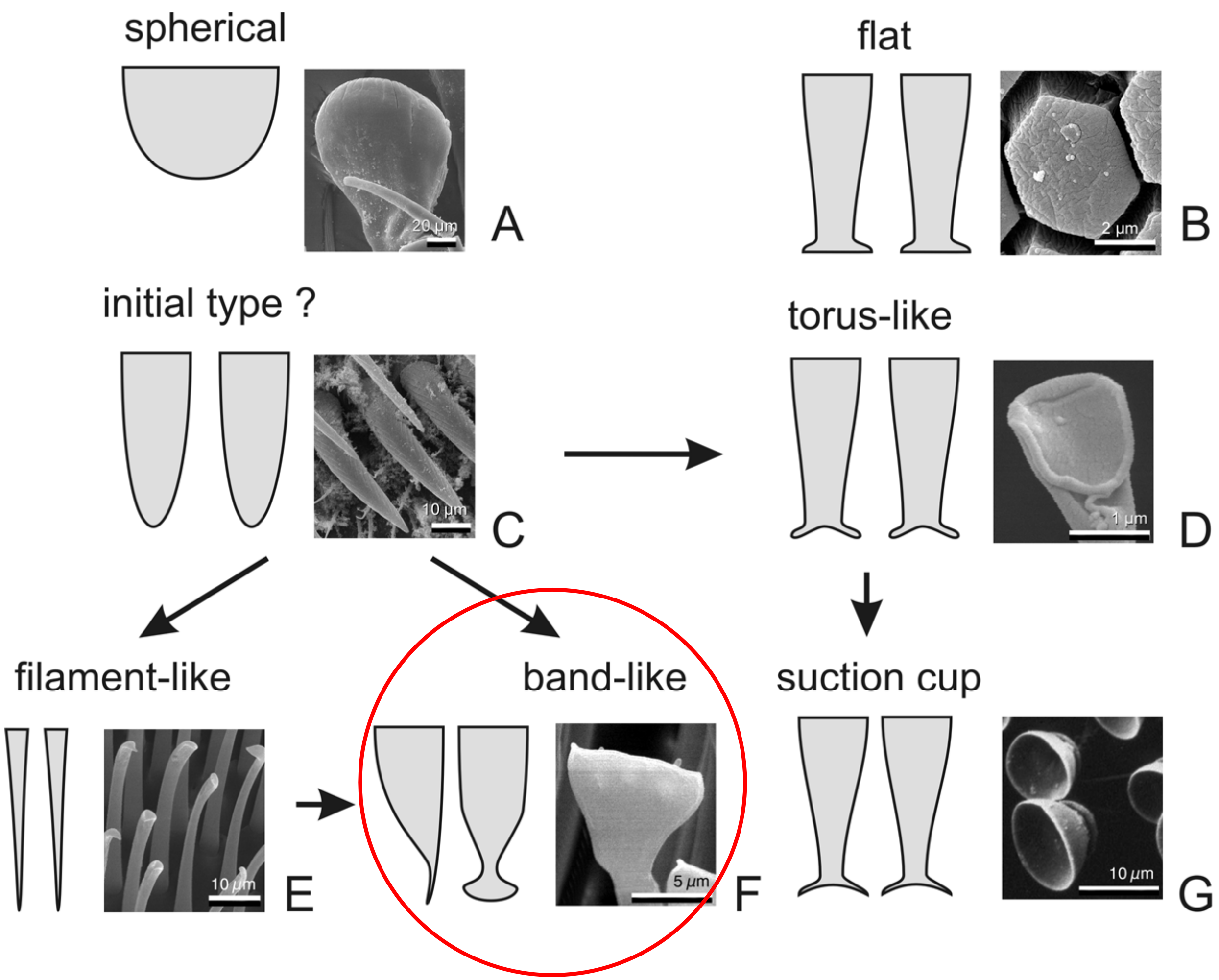






Contact Shape

Spolenak, Gorb, Gao, Arzt, 2004, Proc. Roy. Soc. A



A. Bug *Pyrrhocoris apterus*, smooth pulvillus

B. Grasshopper *Tettigonia viridissima*, surface of the attachment pad

C. Fly *Myathropa florea*, unspecialised hairs on the leg

D. Fly *Calliphora vicina*, seta of the pulvilli

E. Beetle *Harmonia axyridis*, seta of the second tarsal segment

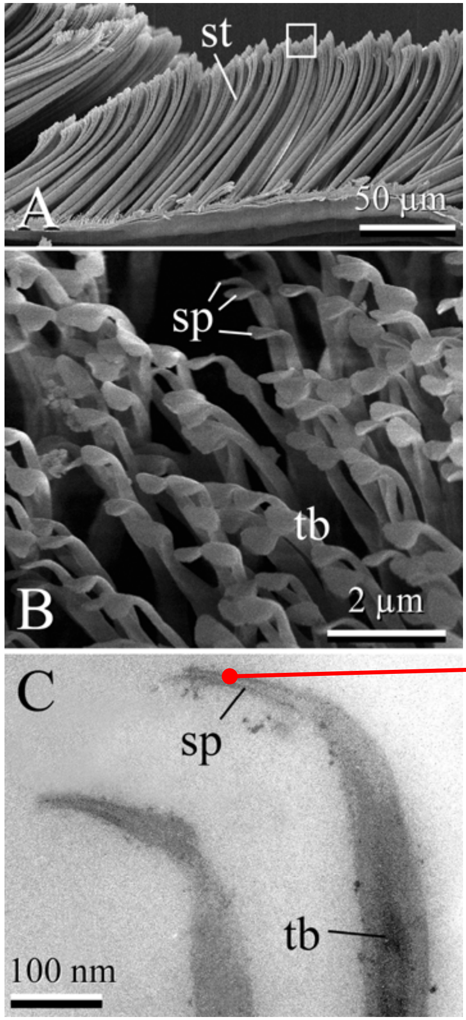
F. Beetle *Chrysolina fastuosa*, seta of the second tarsal segment

G. Male beetle *Dytiscus marginatus*, suction cups on the ventral side of the foreleg tarsi

Function of Terminal Elements

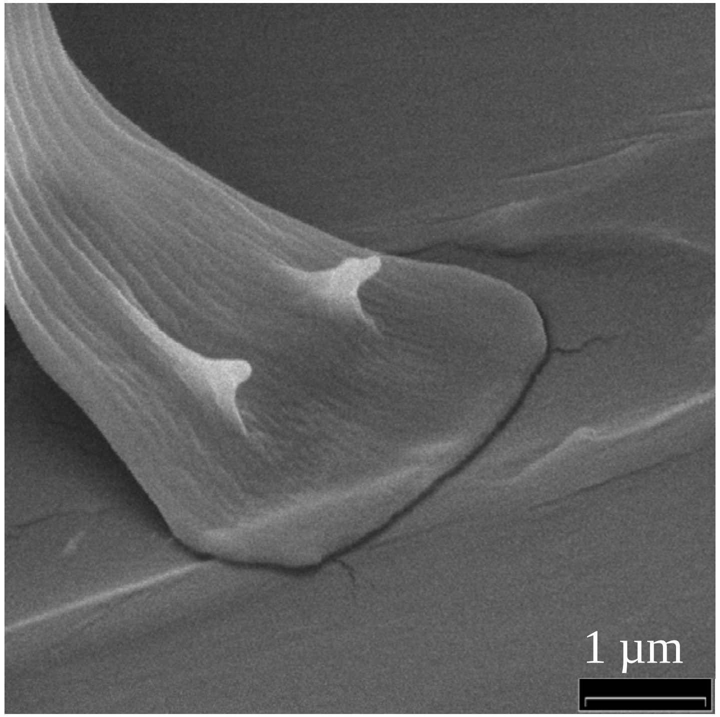
Gekko gecko

Persson and Gorb, 2003, J. Chem. Phys.



thickness of terminal elements ranges from 200 nm (in beetles) to 10-15 nm (in gecko)

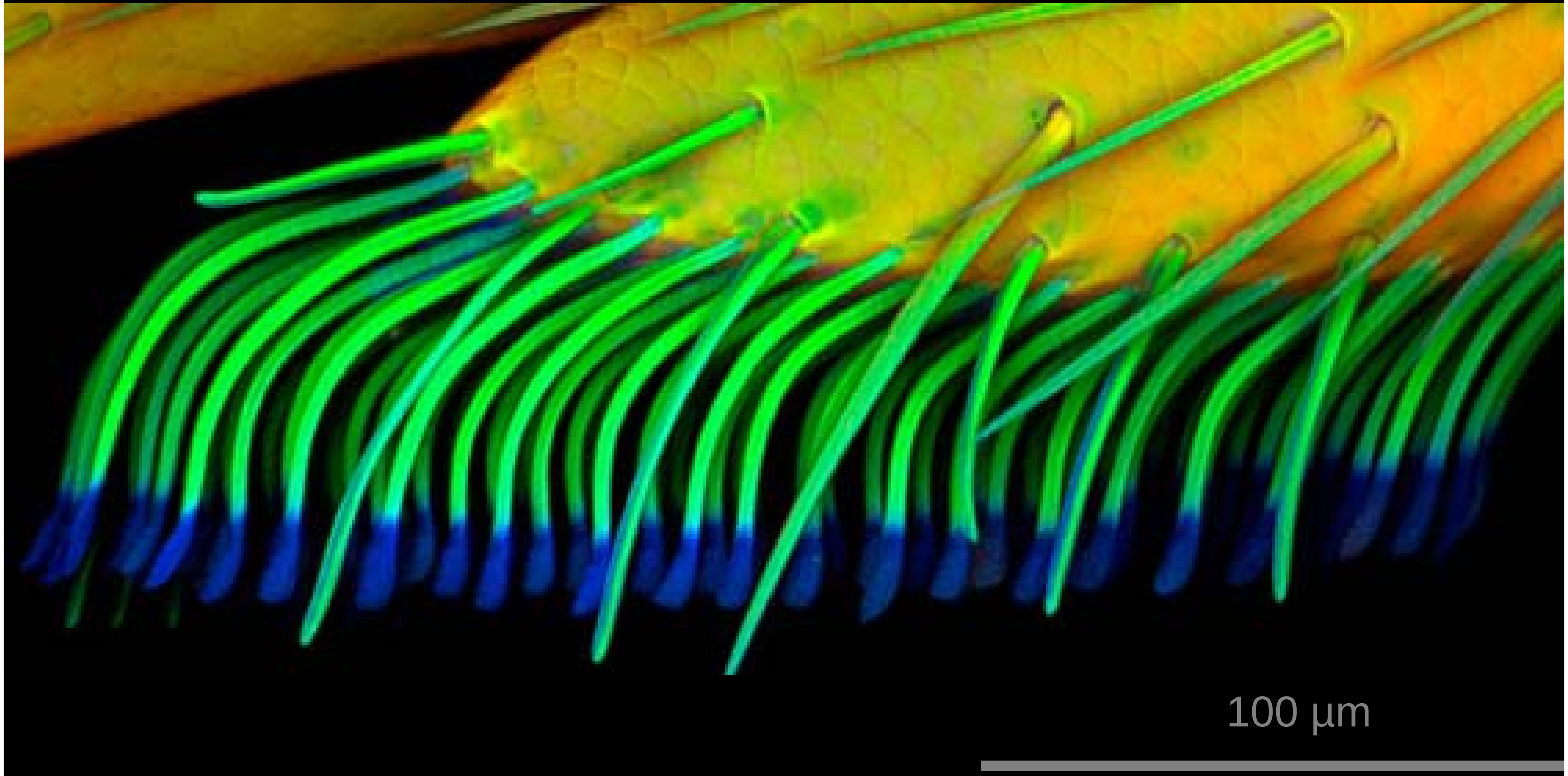
TE of the beetle *Chrysolina fastuosa* in contact



Functions: (1) Low bending stiffness of thin terminal plates enables an intimate contact with surface irregularities. (2) Easy contact formation by sliding. (3) Increasing of contact forces without normal load

Gradient Materials

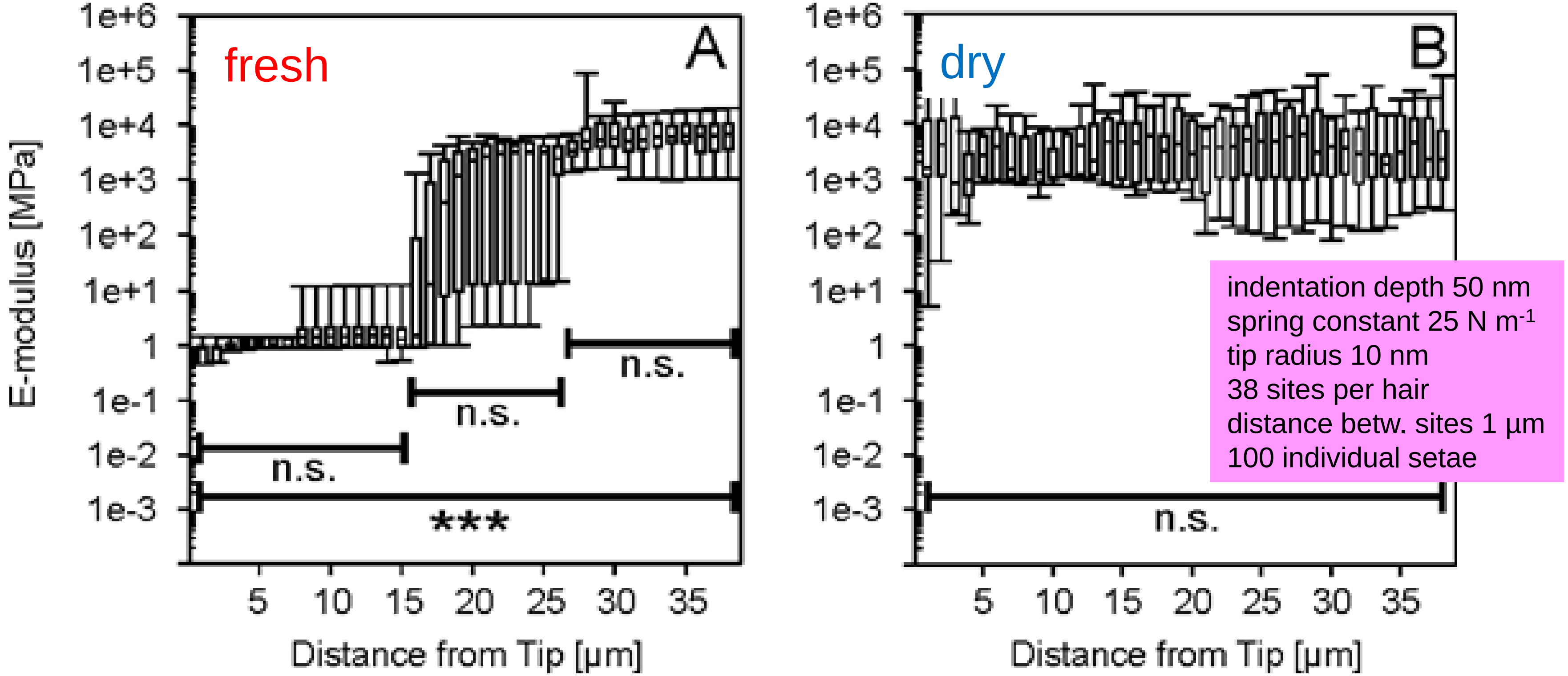
Peisker, Michels and Gorb, 2013, Nature Comm.



Gradient Materials

Coccinella septempunctata

Peisker, Michels and Gorb, 2013, Nature Comm.

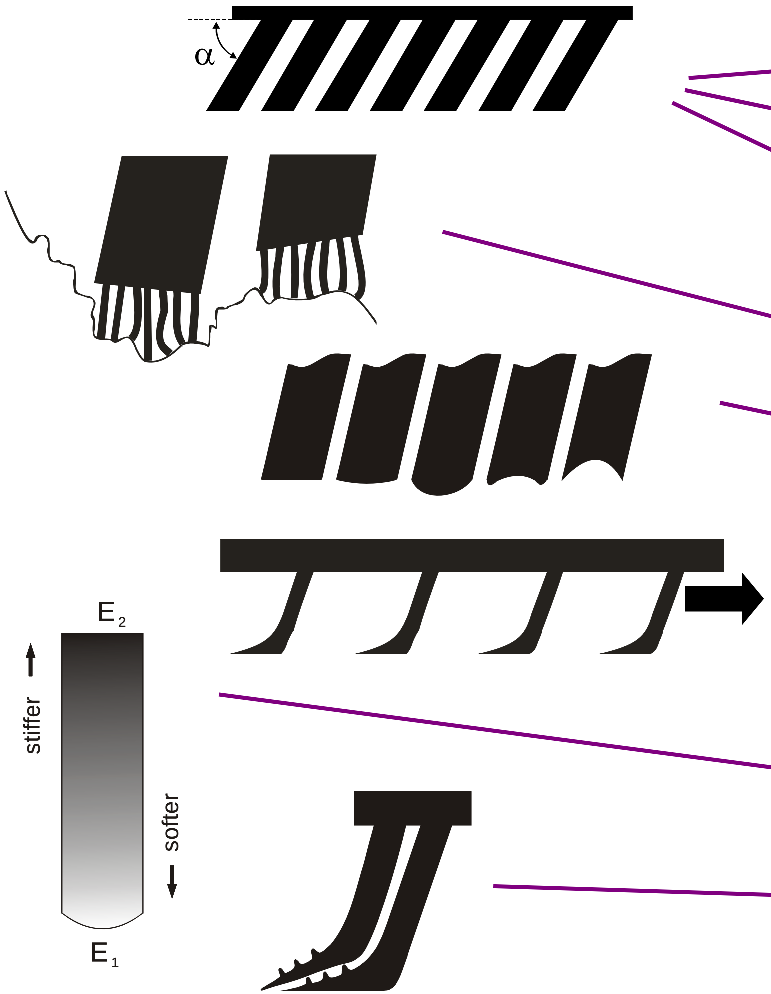


indentation depth 50 nm
spring constant 25 N m^{-1}
tip radius 10 nm
38 sites per hair
distance betw. sites 1 µm
100 individual setae

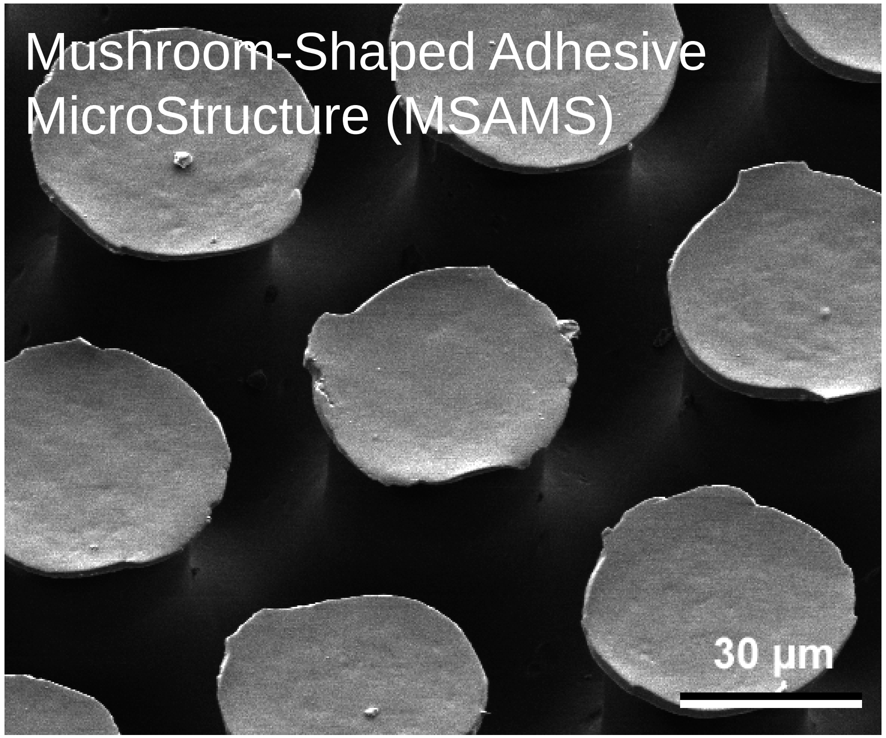
Box-and-Whisker plots showing the mean (n = 50) Young's modulus **of fresh (A)** and **dry (B)** adhesive tarsal setae from the second adhesive pads of first legs of female *Coccinella septempunctata* obtained by 38 AFM indentations (1 µm spacing) along each seta The borders of the boxes define the 25th and 75th percentiles, the median is indicated by a horizontal line, and the error bars define the 10th and 90th percentiles. (n.s. = not significant, *** = highly significant)

Challenge: to put all this together

Creton and Gorb, 2007 MRS Bulletin



- dimension and density
- aspect ratio
- slope
- hierarchy
- shape of the contact
- asymmetry
- proper movements
(during attachment and detachment)
- gradient materials
- non-conglutination



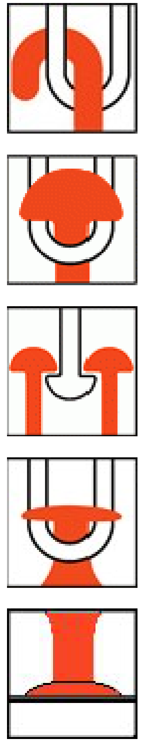
HOOK AND LOOP

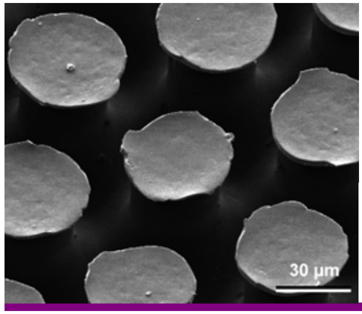
MUSHROOM FASTENER

DUOTEC ®

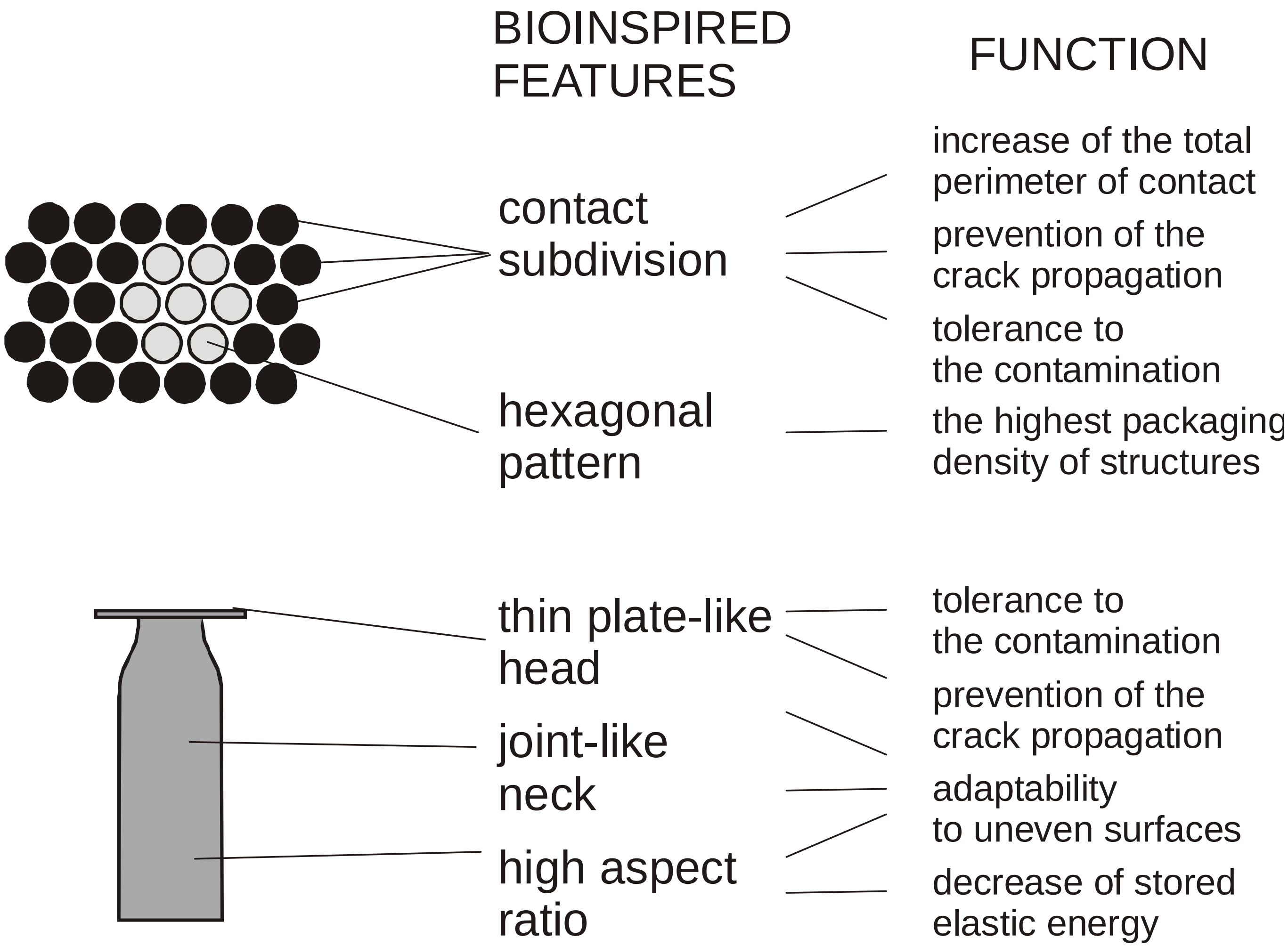
MICROPLAST ®

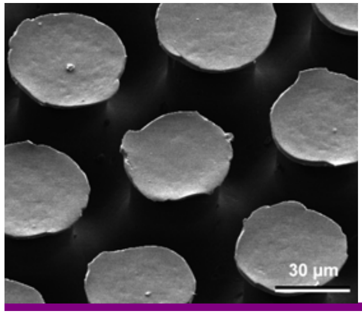
GECKO ®





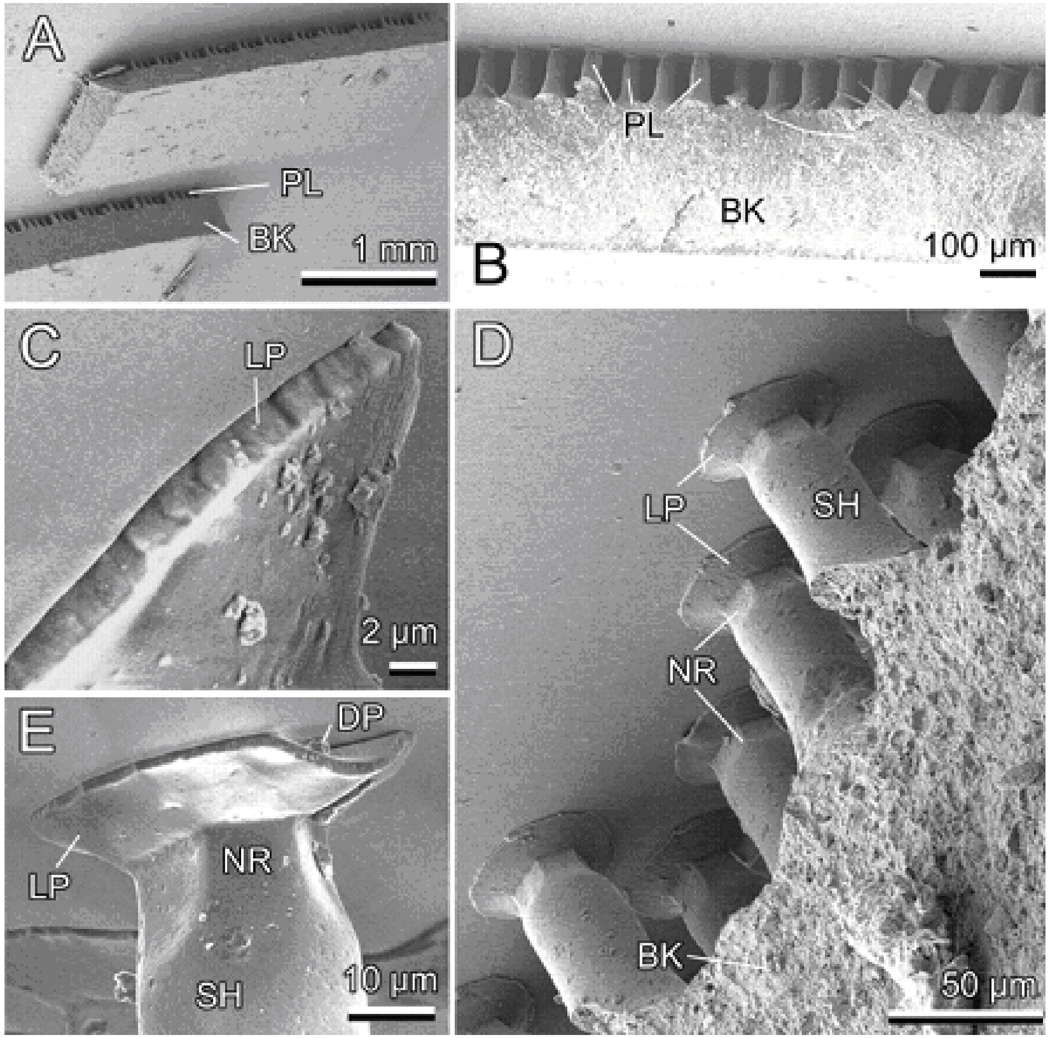
MSAMS: Bioinspired Features





MSAMS in Action

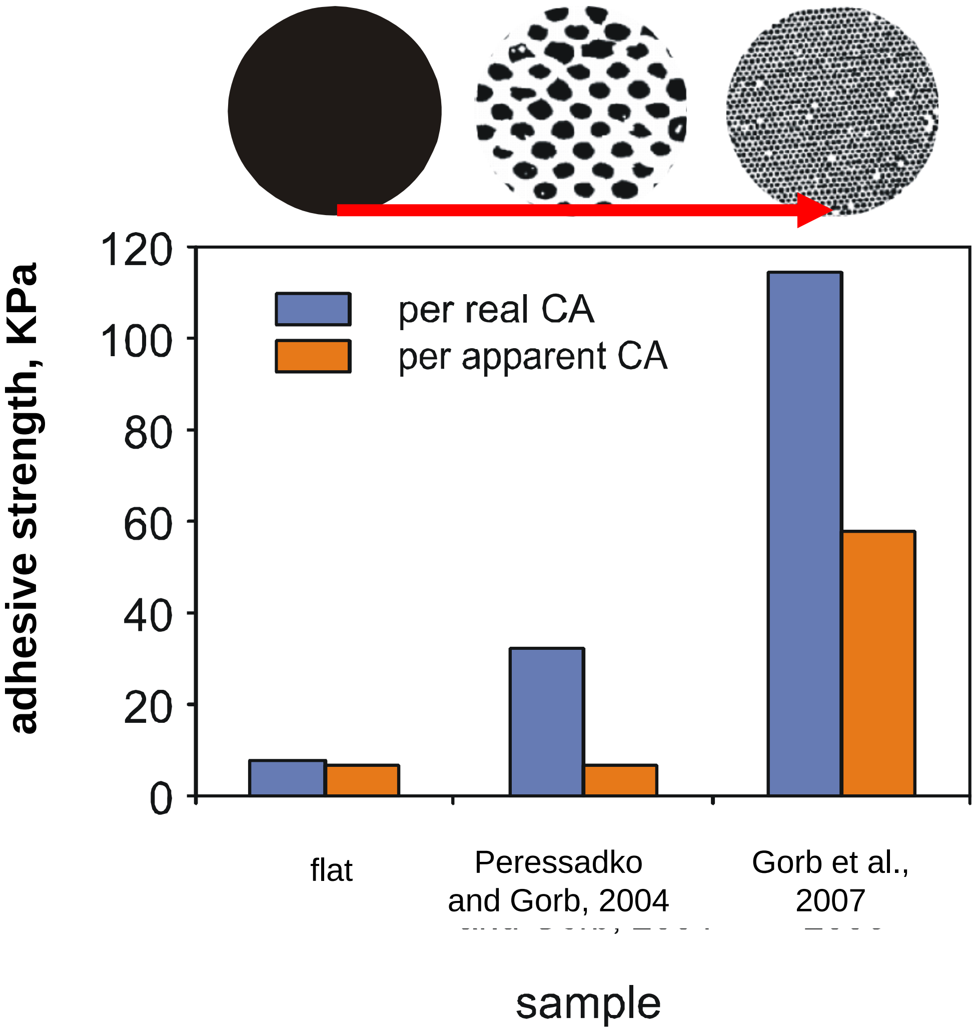
Gorb, Varenberg, Peressadko, Tuma, 2007, J. Roy. Soc. Interface



- **BK**, backing
- **DP**, dust particle
- **LP**, lip at the margin of the pillar tip
- **NR**, narrowing of the pillar close to the tip
- **PL**, pillars
- **SH**, shaft

MSAMS Adhesion

Gorb, Varenberg, Peressadko, Tuma, 2007, J. Roy. Soc. Interface

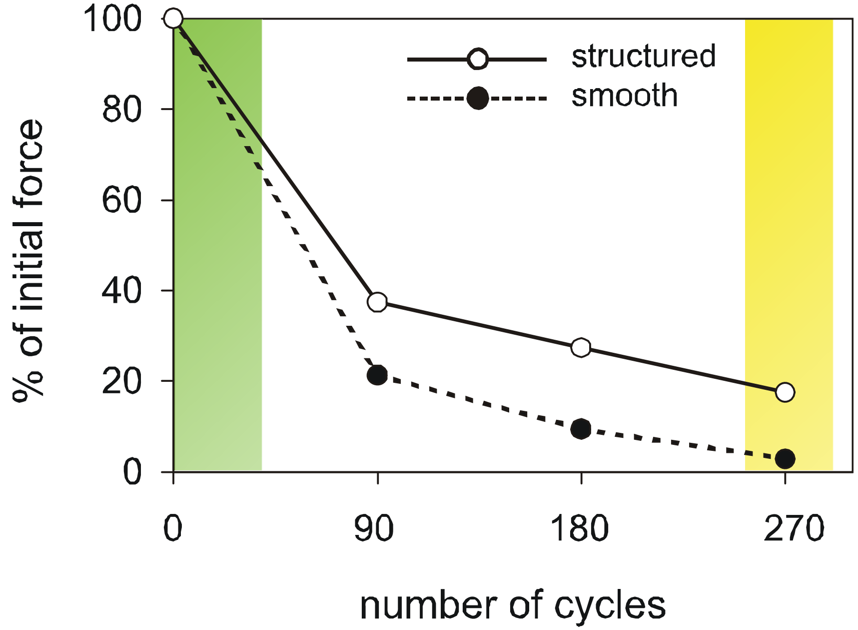


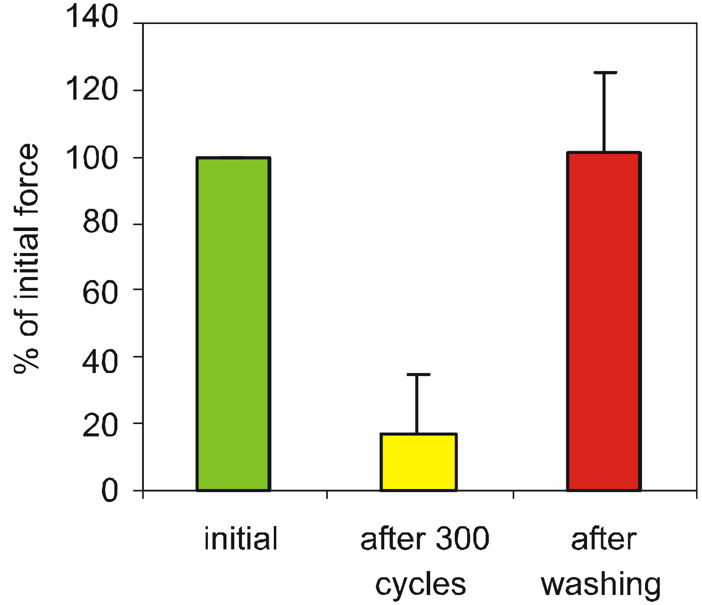
Enhanced adhesion of mushroom-shaped microstructure relies on combination of **van der Waals forces** and **crack-trapping mechanism** (e.g. *Hui et al. 2004, J. R. Soc. Interface; Carbone et al. 2011, Soft Matter*)

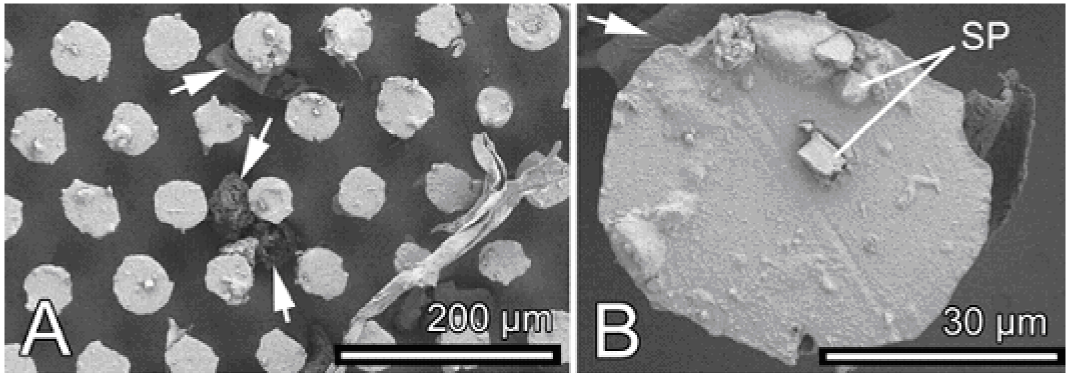
Daltorio et al. 2005, CLAWAR
Kim, Sitti 2006, Appl. Phys. Lett.
Gorb et al. 2007, J. R. Soc Interface
Varenberg, Gorb 2007, J. R. Soc Interface
Gorb, Varenberg 2007, JAST
del Campo et al. 2007, Langmuir
Varenberg, Gorb 2008a, J. R. Soc Interface
Varenberg, Gorb 2008b, J. R. Soc Interface
Davies et al. 2009, Int. J. Adhes. Adhes.
Sameoto, Menon 2009, J. Micromech. Microeng.
Murphy et al. 2009, Appl. Mater. Interfaces
Murphy et al. 2009, Small
Kim et al. 2009, Langmuir
....
....

Contamination of MSAMS

Gorb, Varenberg, Peressadko, Tuma, 2007, J. Roy. Soc. Interface

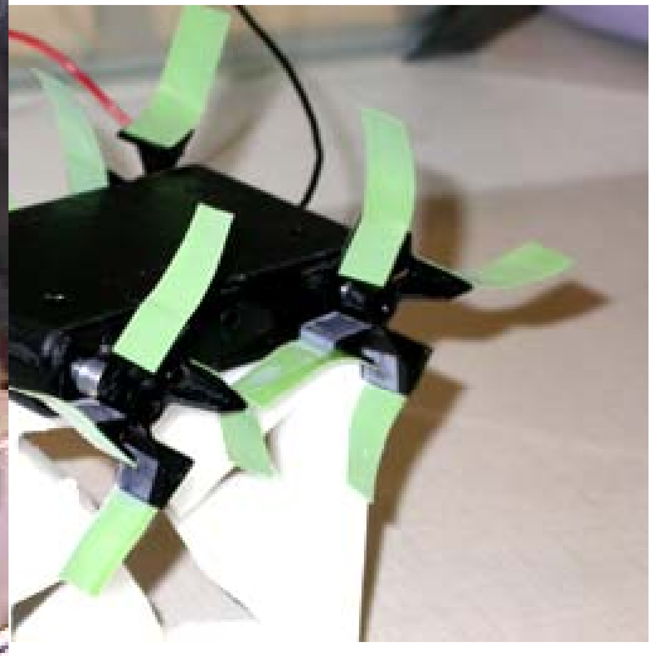






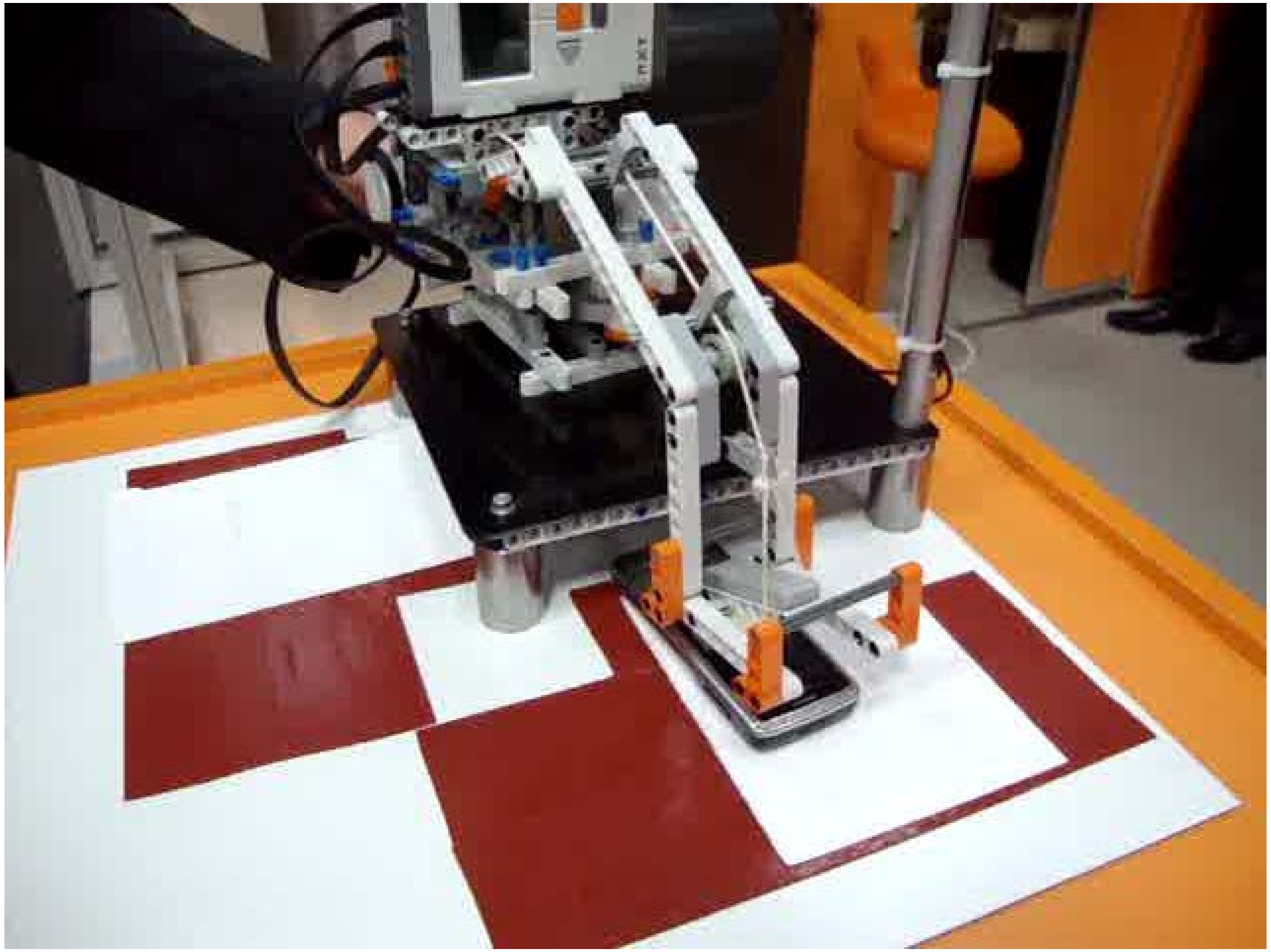
Wall Walking Using MSAMS

Daltorio et al., 2005, CLAWAR Conference



with Daltorio, Horchler, Ritzmann, Quinn
Case Western Reserve University, Cleveland, OH, USA

2010 – MSAMS in Pick-and-Drop Process



LEGO toy-robot
at Hannover
Fair 2010

120 cycles per h
960 per day
4800 during 5 days
withot cleaning

Company FESTO
2011 constructed first
commercial flat
gripping device
based on MSAMS:
long-term test
= about 20 Mio cycles

2011

Crazy Tape Holds Weight of Man:

Discovery News

Insects inspire mother of all adhesives

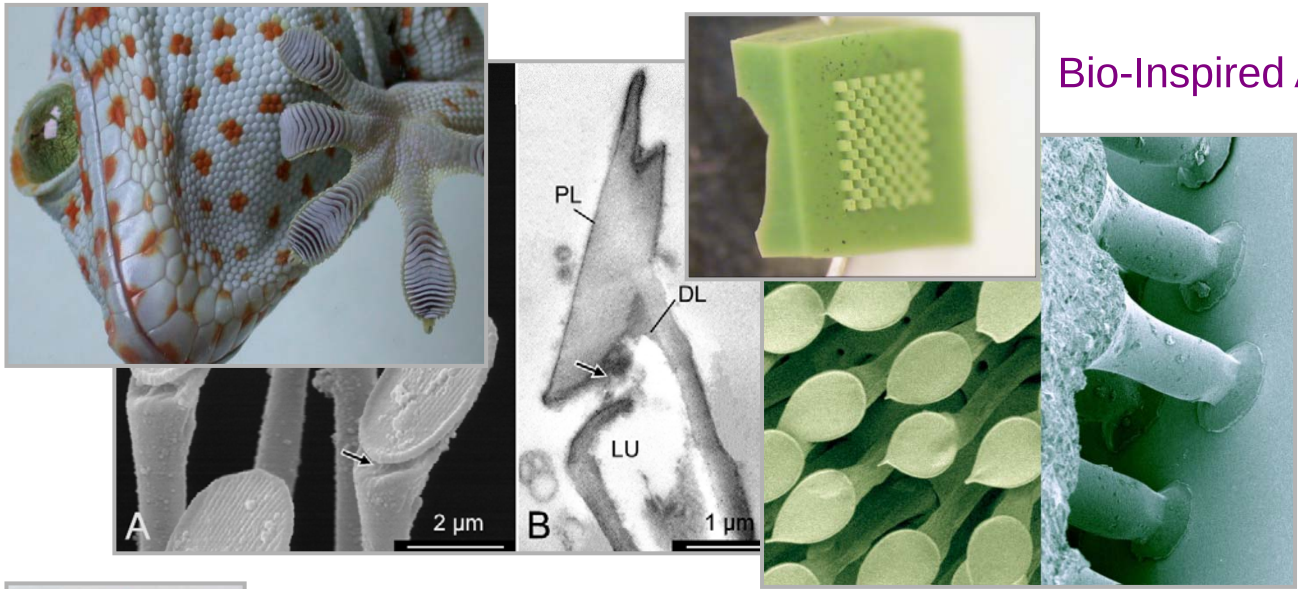
University of Kiel's Super-Adhesive Takes Inspiration from Beetles

A new tape uses some of nature's tricks to stick

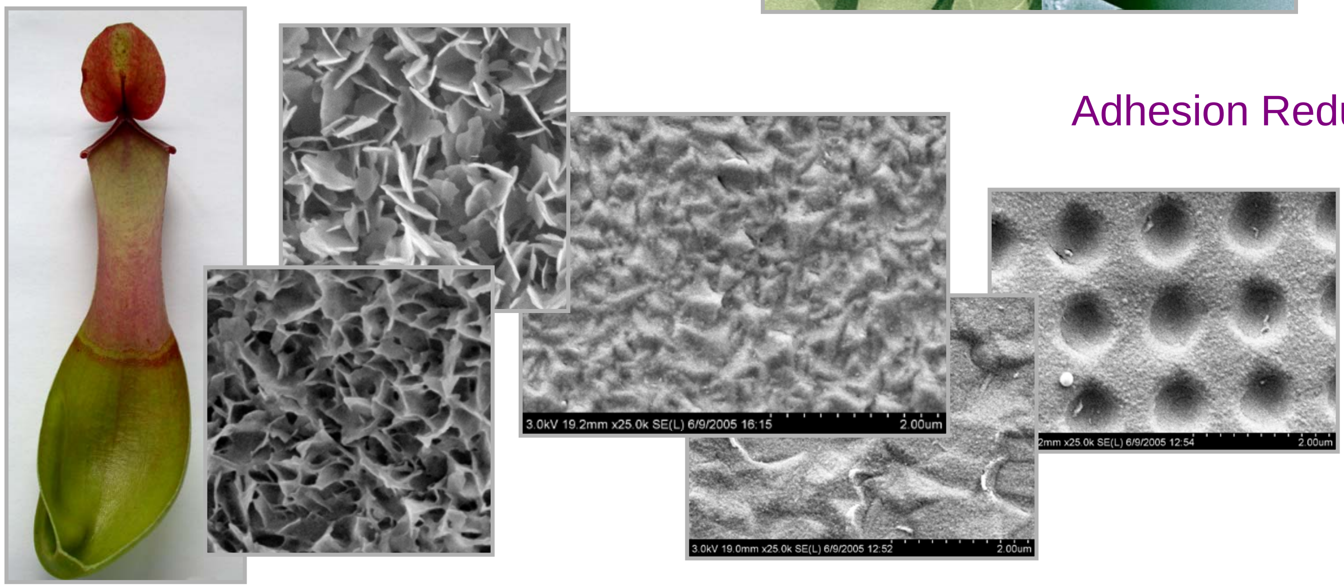
Biologically inspired adhesive tape can be reused thousands of times

Bioinspired Dry Tape Brings Spider-Man A Little Closer

Industrial Collaboration



Bio-Inspired Adhesives



Adhesion Reduction

FESTO

satisloh

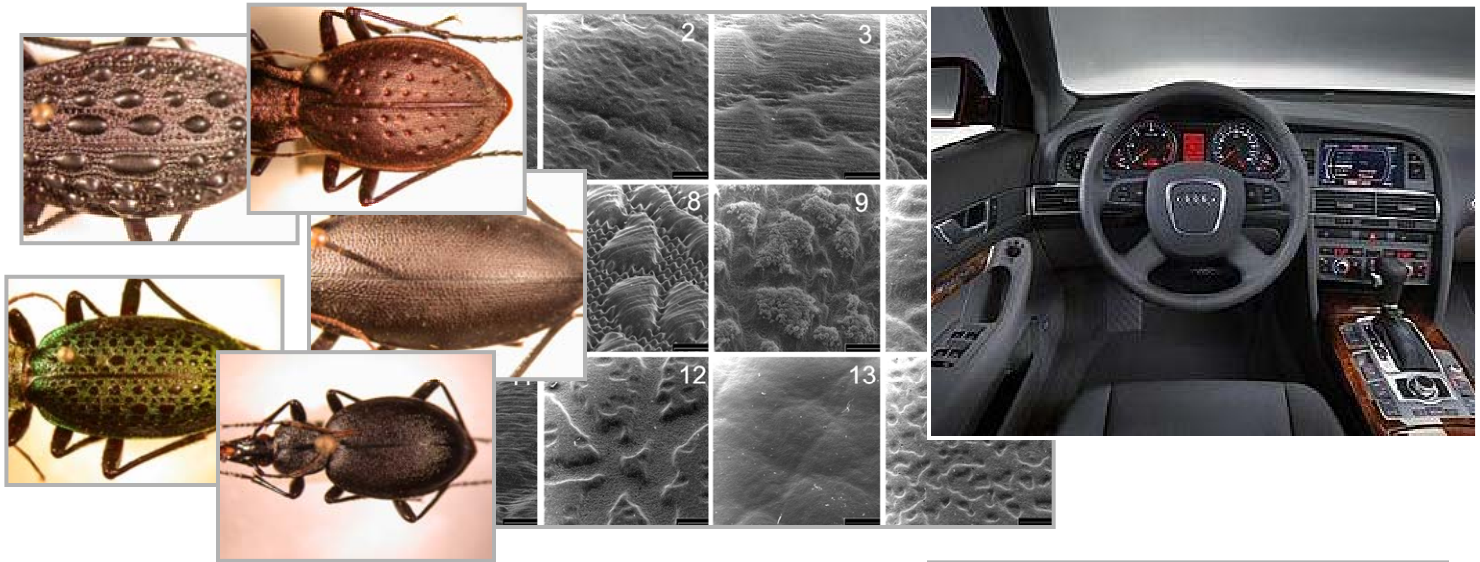
binder-band 1798

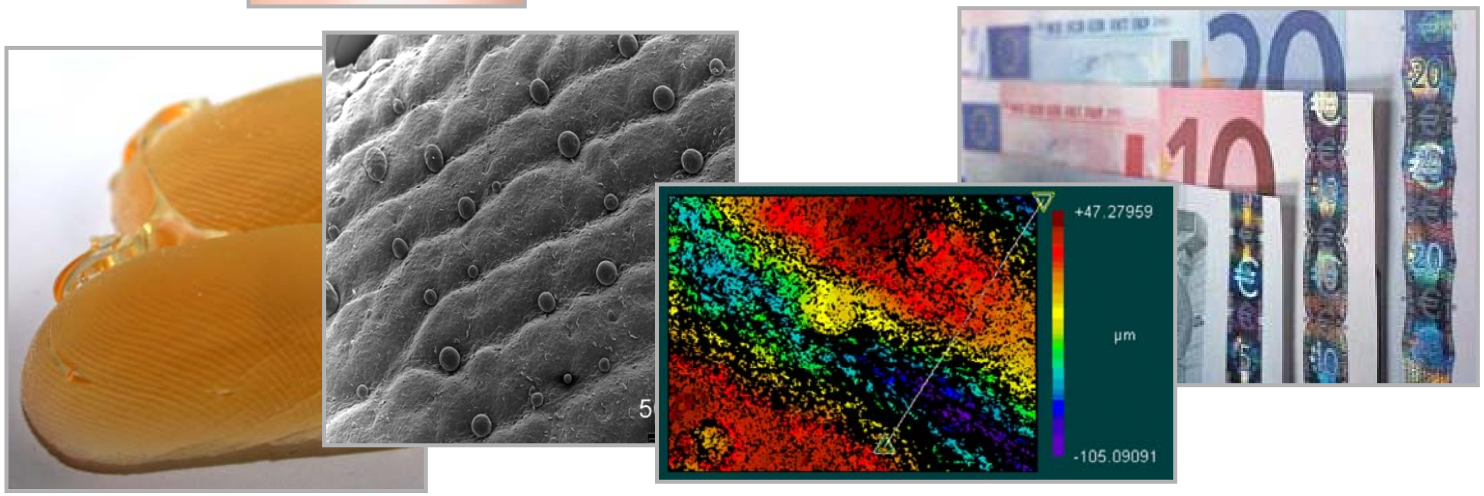
3M

OVD KINEGRAM
A member of the Kurz Group

Industrial Collaboration

Biologically Inspired Surfaces for Haptics

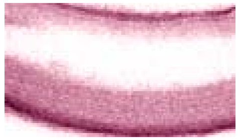




RECTICEL
The passion for comfort

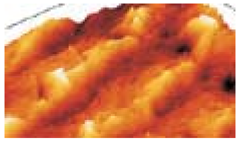
OVD KINEGRAM
A member of the Kurz Group

Expertise



Microscopy Techniques

- Cryo Scanning Electron Microscope Hitachi 4800 with Gatan Cryo Prep. System
- Transmission Electron Microscope (FEI Tecnai), Cryotomy and Ultramicrotomy
- Fluorescence Microscopy
- µCT (SkyScan, 0,7 µm resolution)

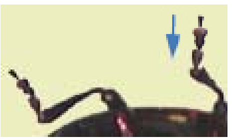


Surface Characterisation

- White Light Interferometer Zygo New View 6000
- High Speed Contact Angle Measurement Device, Dataphysics OCA-200
- 2 Confocal Laser Scanning Microscopes, Zeiss CLSM 410 and 710
- AFM JPK Nano-Wizard
- Nanoindenter MTS SA2
- Surface energy estimation (Dataphysics OCA-200)

Adhesion and Friction Measurements

- Microtribotesters Basalt 01, Basalt 02, Basalt 03, (MUST, Tetra)
- Custom Made Microtribotester Based on WP-100
- AFM JPK Nano-Wizard



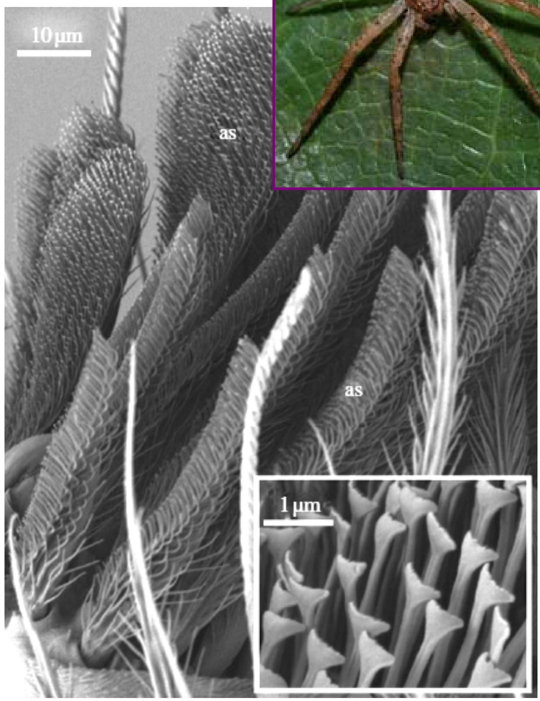
Motion Analysis

- High-Speed Videorecording (Photron Fastcam SA4 and ULTIMA, up to 200.000 fps)

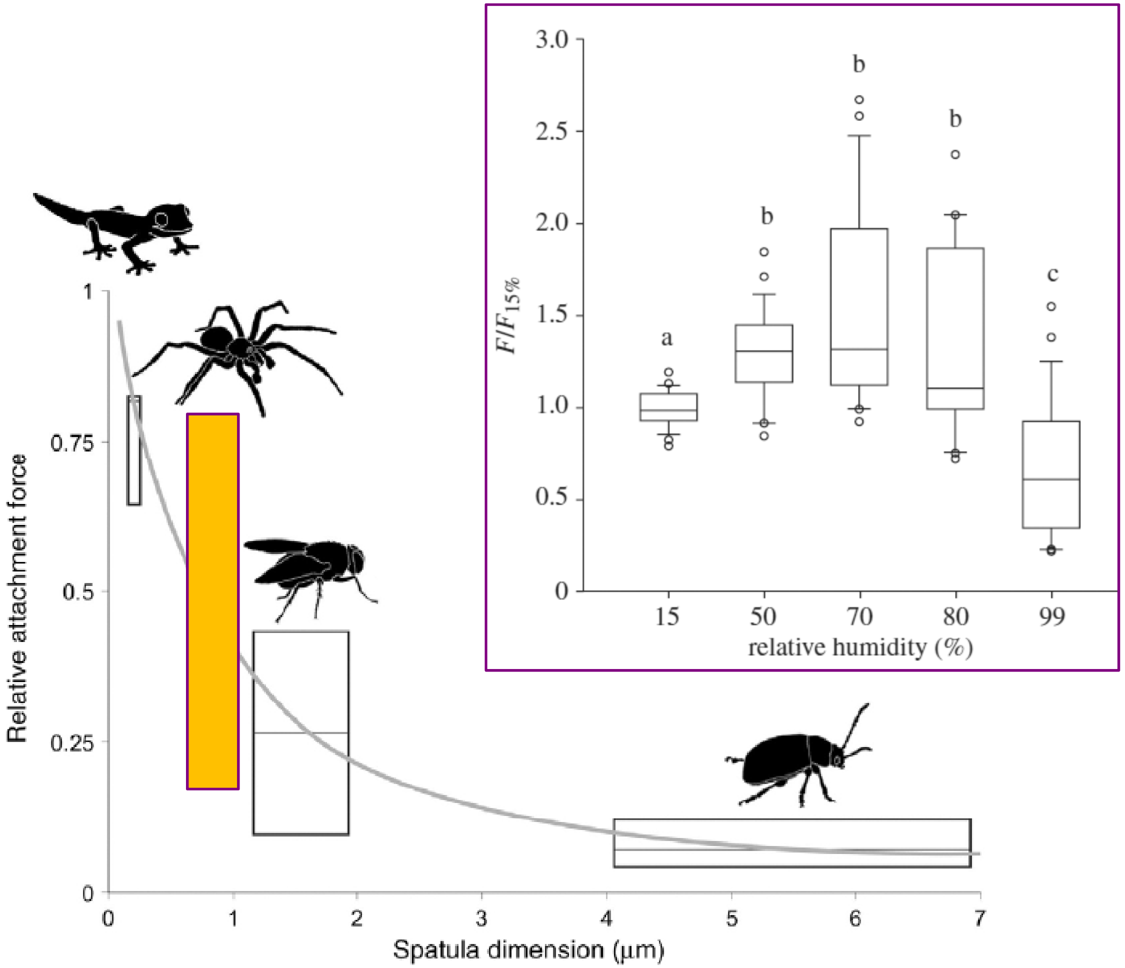
Structure and Function of Adhesive Pads

Dr. Constanze Grohmann
Jonas Wolff

Wolff and Gorb, 2012. J. Exp. Biol.
Wolff and Gorb, 2012. Proc. Roy. Soc. B



Philodromus dispar

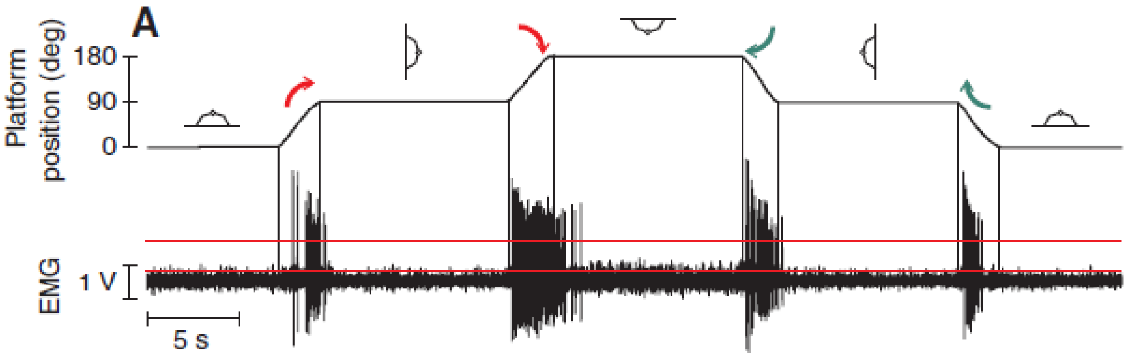


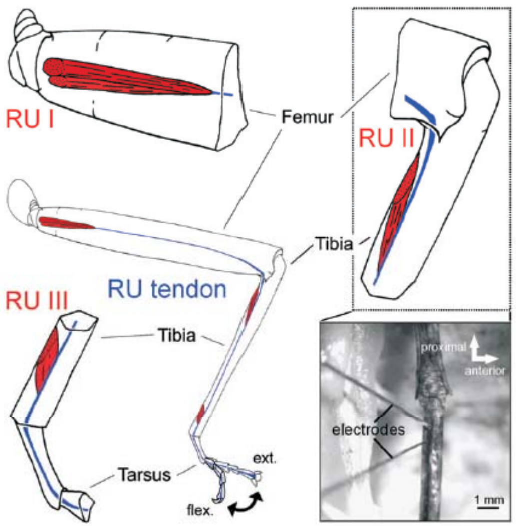
Adhesion Control During Locomotion

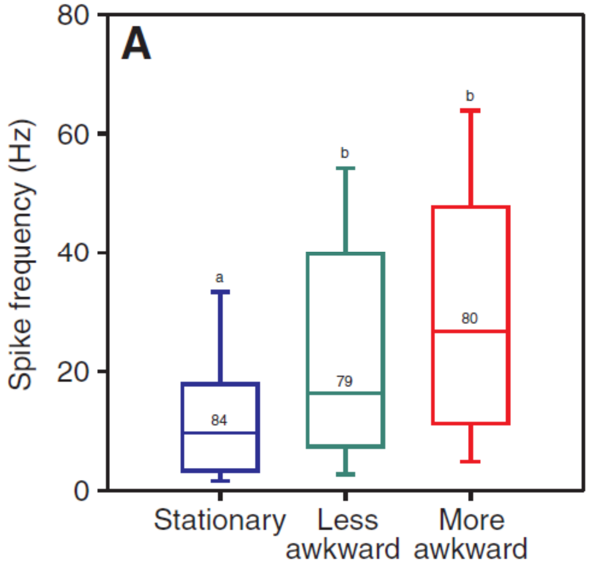
Philipp Busshardt

Busshardt, Gorb, Wolf, 2011. J. Exp. Biol.
Busshardt, Wolf, Gorb, 2012. Zoology

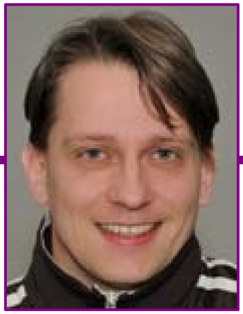
Carausius morosus



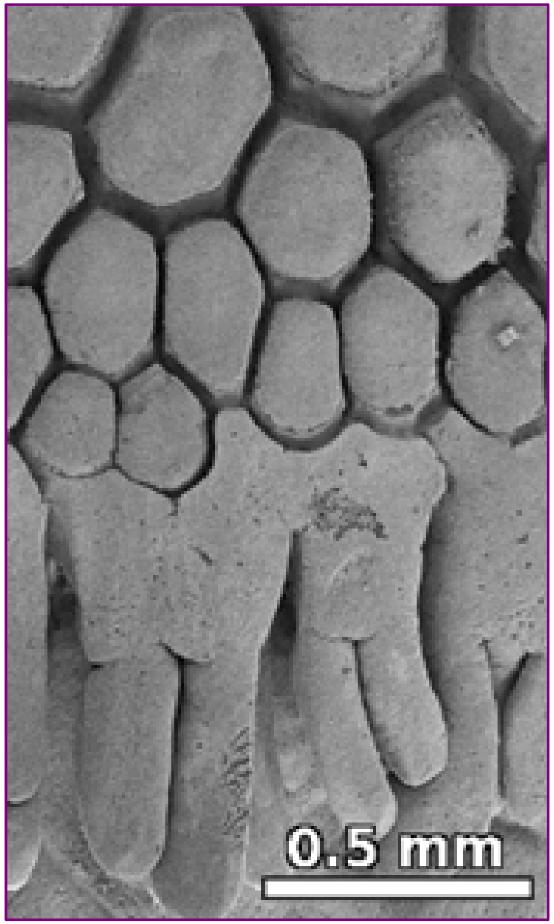


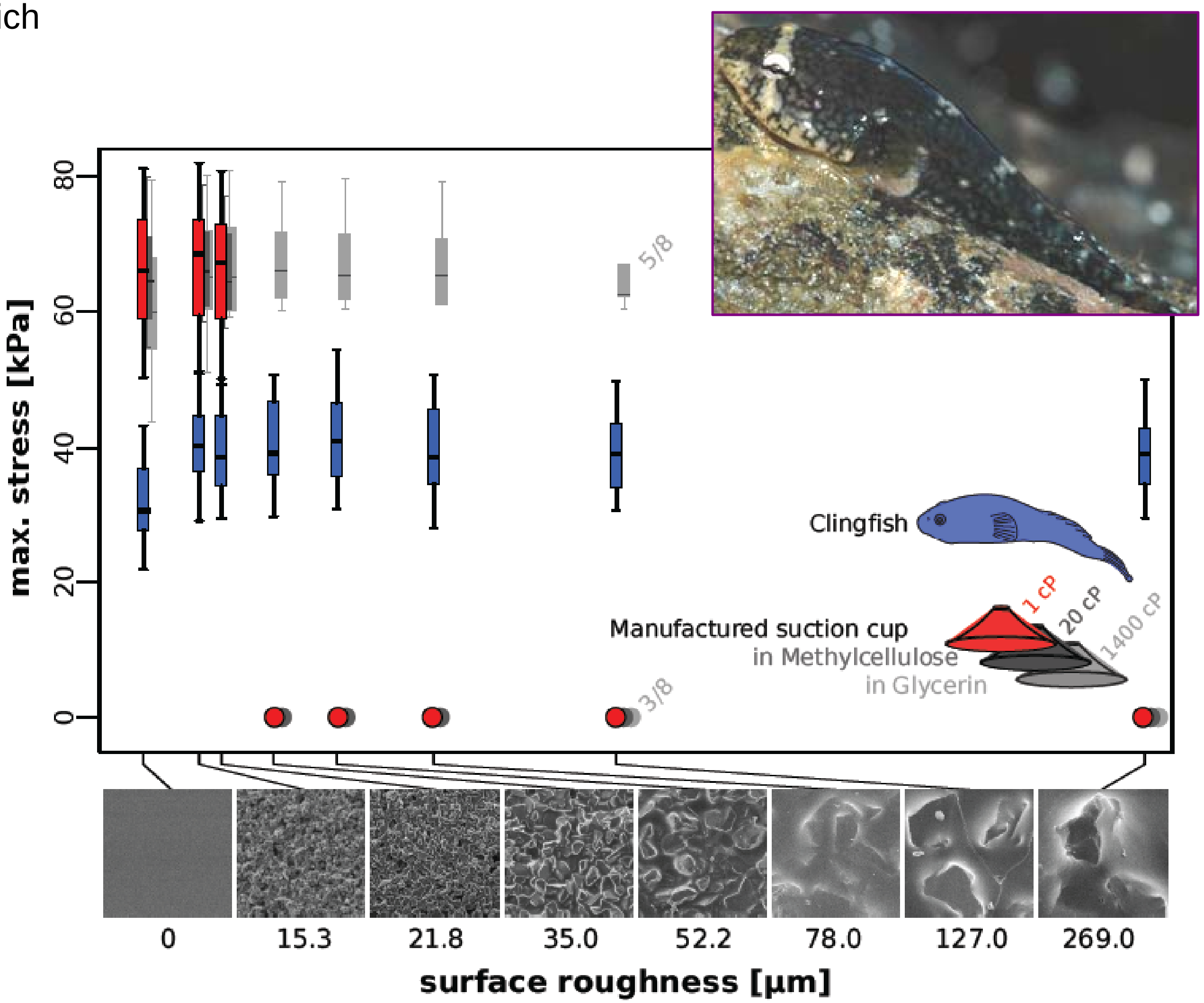


Underwater Adhesion



Dr. Thomas Kleinteich



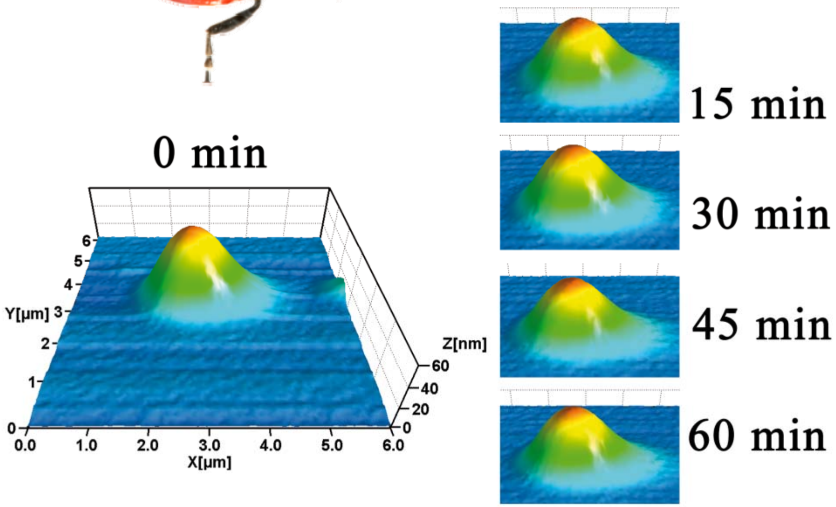


Secretory Fluids: AFM

Dr. Henrik Peisker

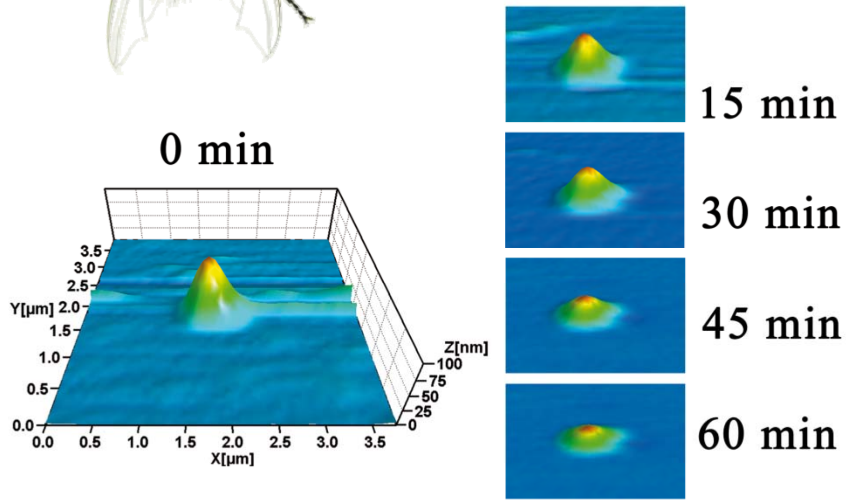
Peisker and Gorb, 2012. J. Exp. Biol.

evaporation
dynamics



3°

evaporation
dynamics

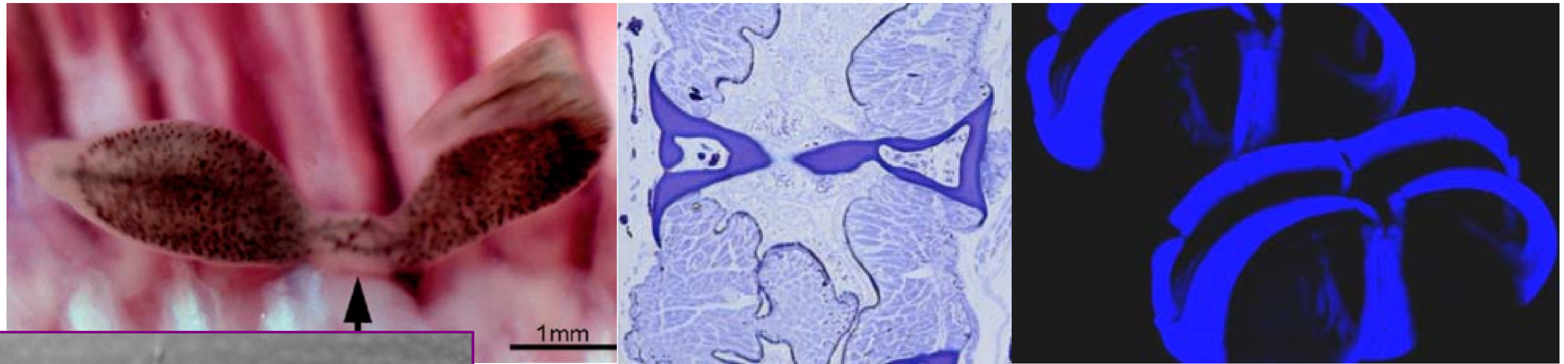


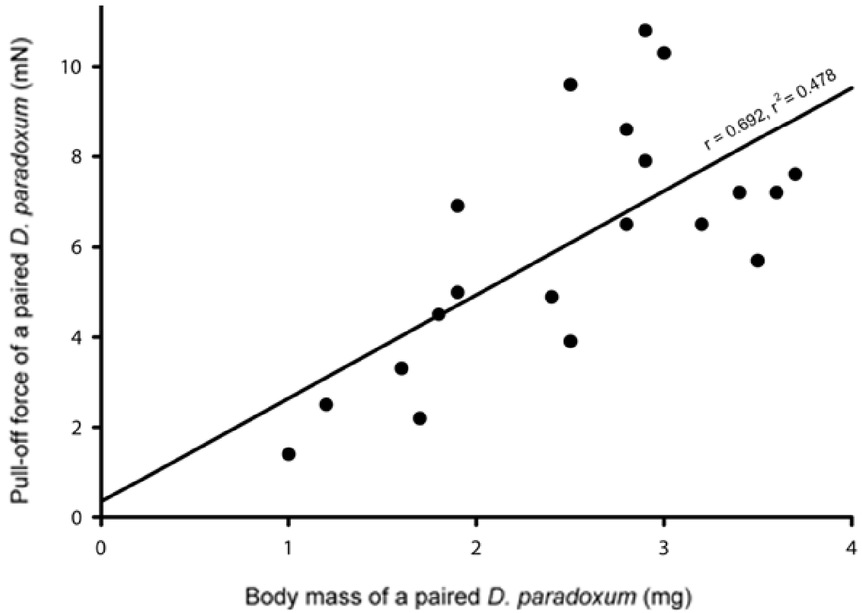
21°

Adhesion of Parasites

Dr. Wei Lim Wong

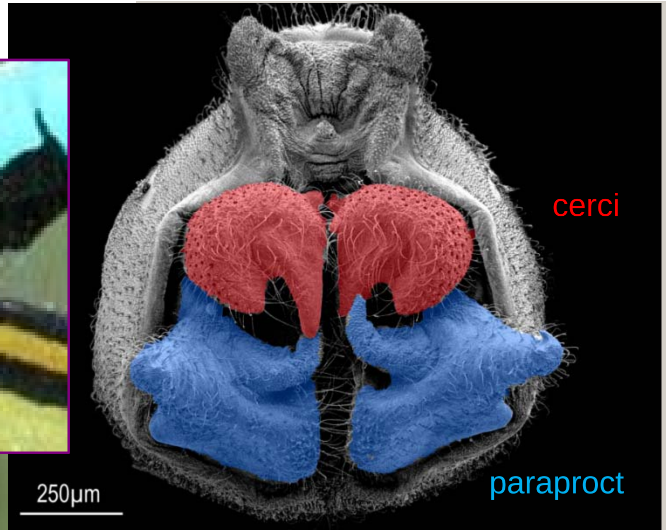
Wong, Michels, Gorb, 2012. J. Parasitology

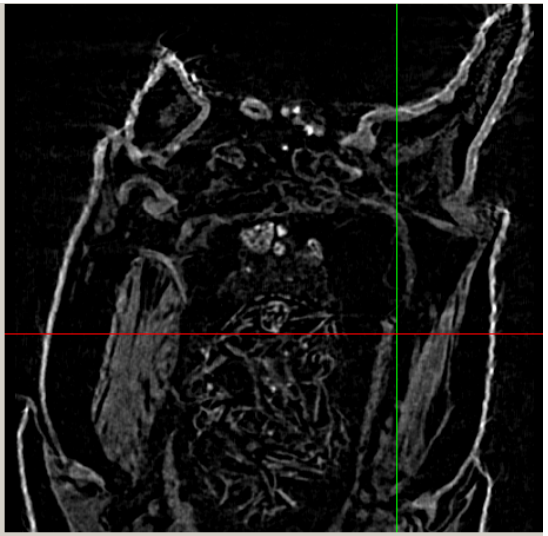


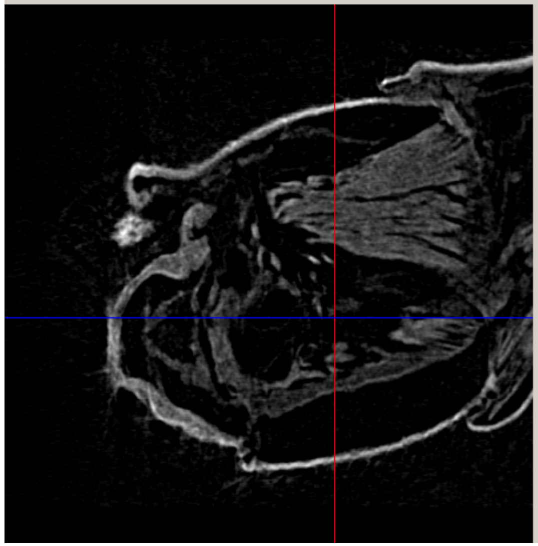


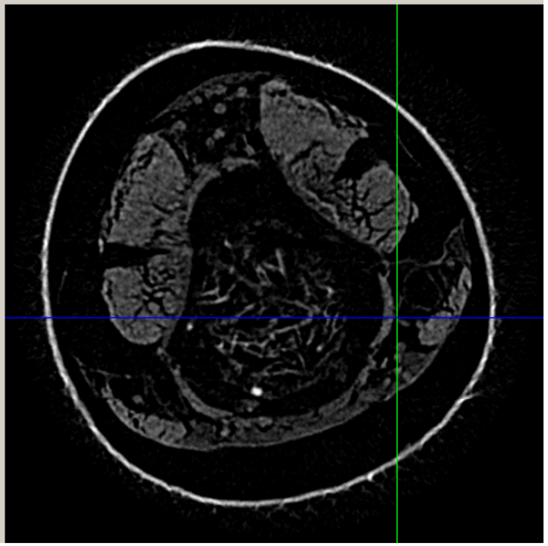
Clamp Structures

Dr. Jana Willkommen





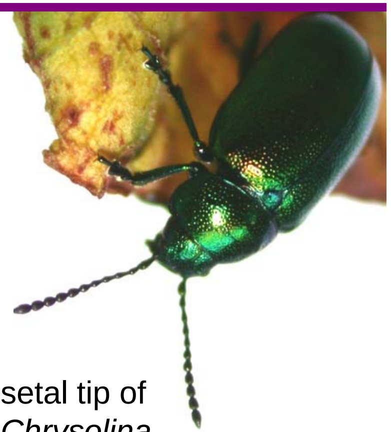




Anti-Adhesive Surfaces in Plants

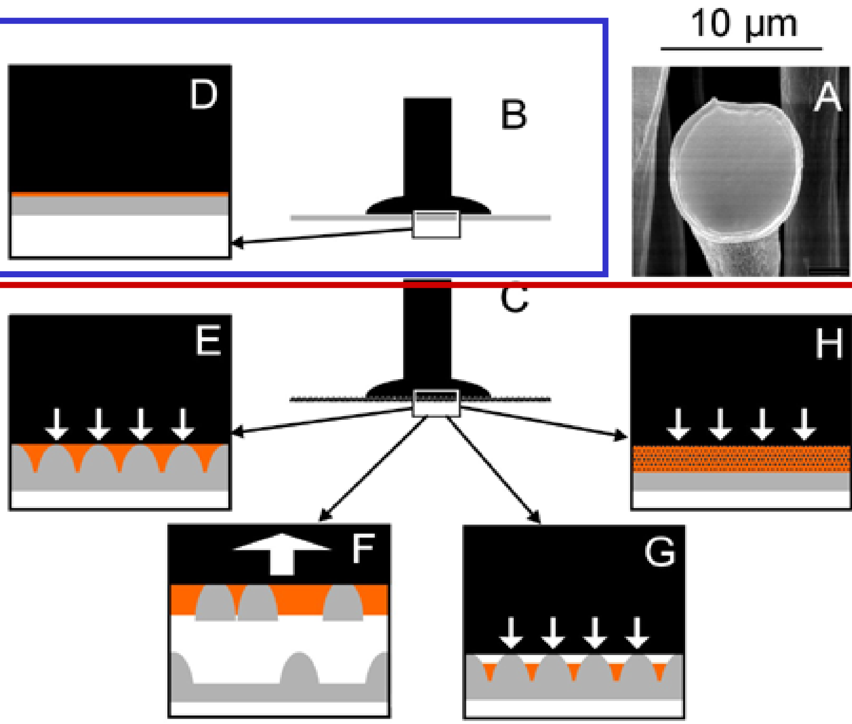
Dr. Elena Gorb
Julia Purtov
Nadine Jacky
Martina Baum

Gorb and Gorb, 2002. Ent. Exp. Appl.
Gorb et al., 2005. J. Exp. Biol.
Gorb et al., 2010. J.R.S. Interface



Nepenthes alata

smooth surface



setal tip of *Chrysolina fastuosa*

reduction of the real contact area

increase of the fluid layer thickness

waxy surface

pad contamination

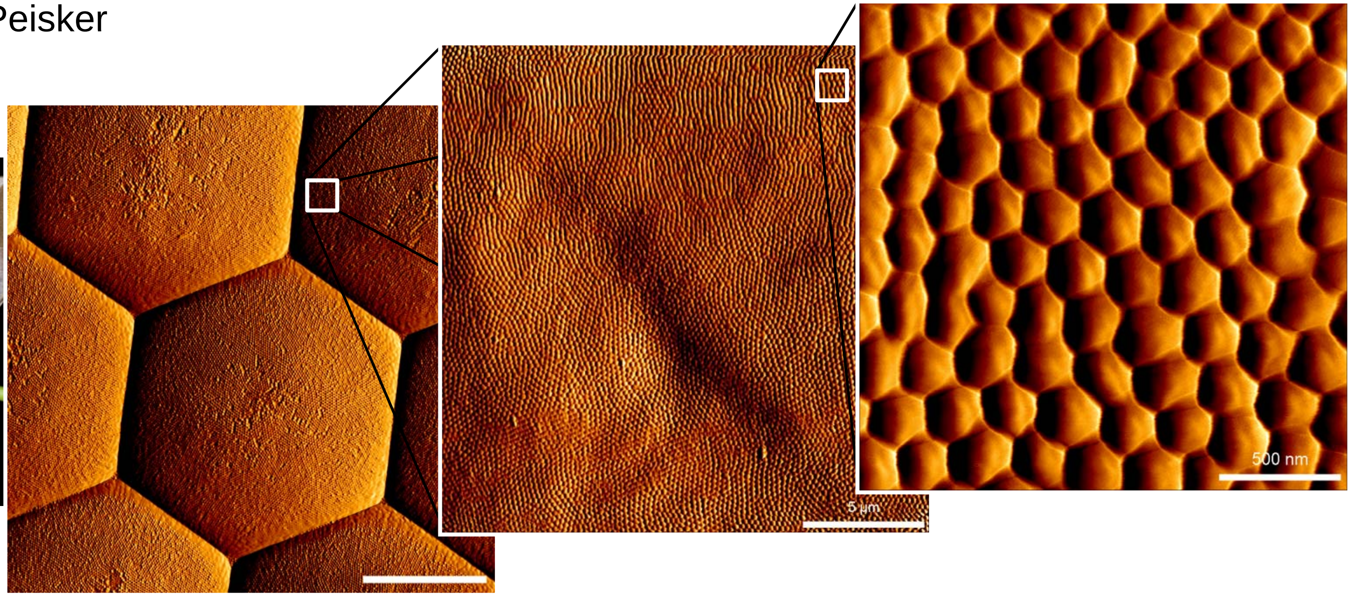
fluid absorption

Ommatidia Gratings: AFM

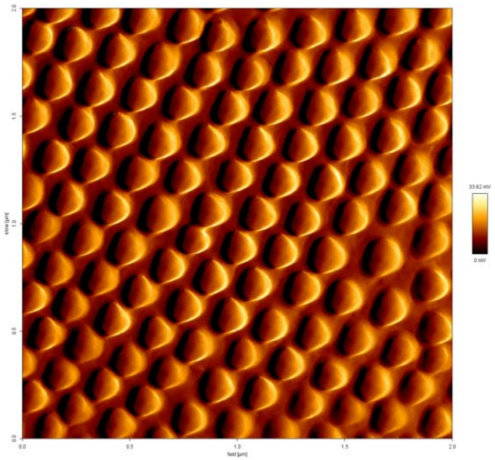
Peisker and Gorb, 2010, J. Exp. Biol.

Dr. Henrik Peisker

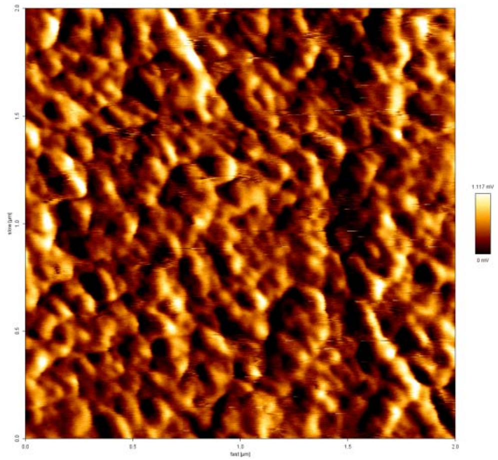
Laothoe populi



Volucella pellucens

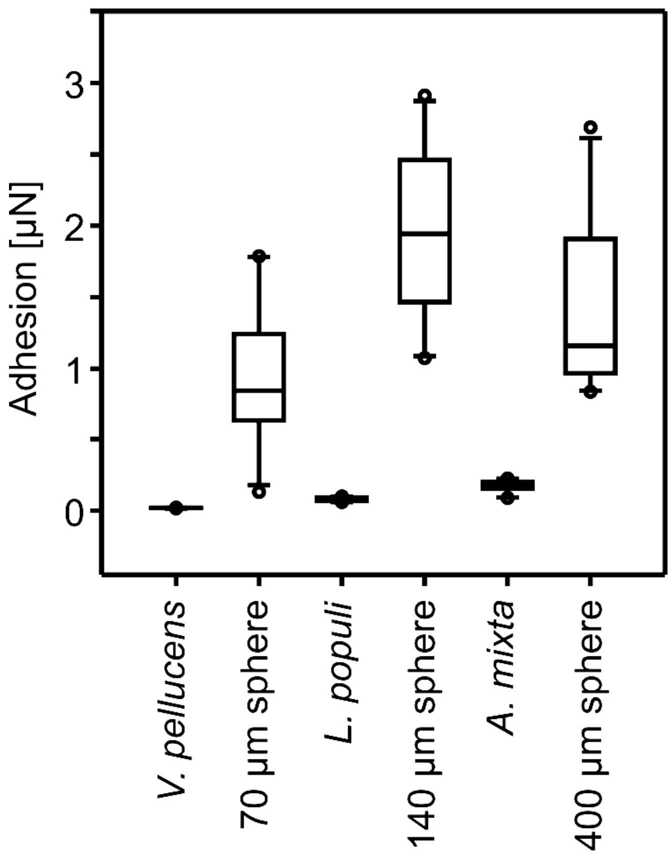


Aeshna mixta



Ommatidia Gratings: AFM

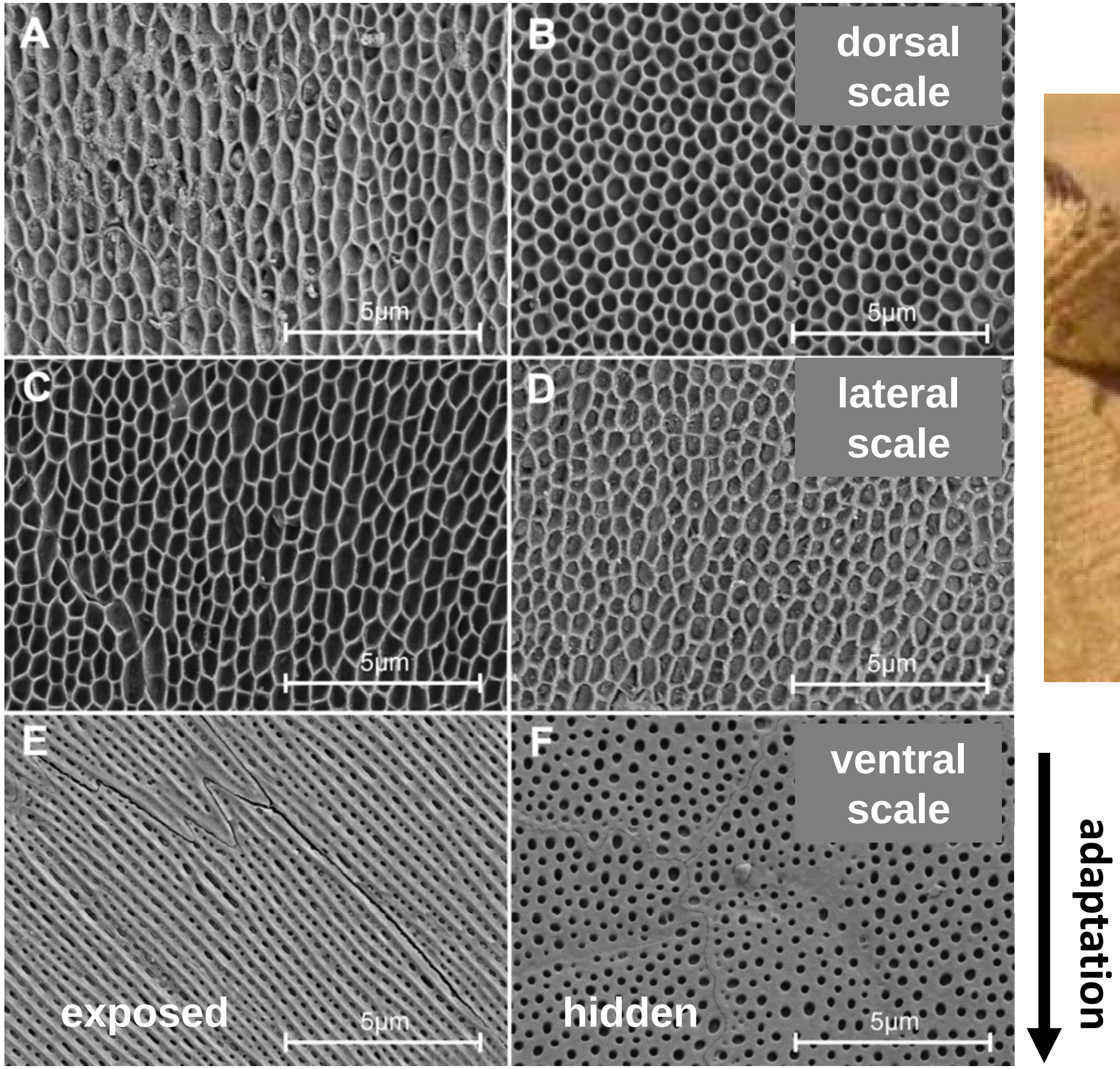
Peisker and Gorb, 2010, J. Exp. Biol.



	A. mixta	***L.populi***	***V. pellucens***
Calculated $\boldsymbol{F}_{pull\text{-}off}$ [µN] (control)	3.3	2.9	2.5
Measured $\boldsymbol{F}_{pull\text{-}off}$ [µN] (control)	1.2	1.9	0.9
Calculated $\boldsymbol{F}_{pull\text{-}off}$ [nN] (ommatidia)	-	90	23
Measured $\boldsymbol{F}_{pull\text{-}off}$ [nN] (ommatidia)	178	77	19

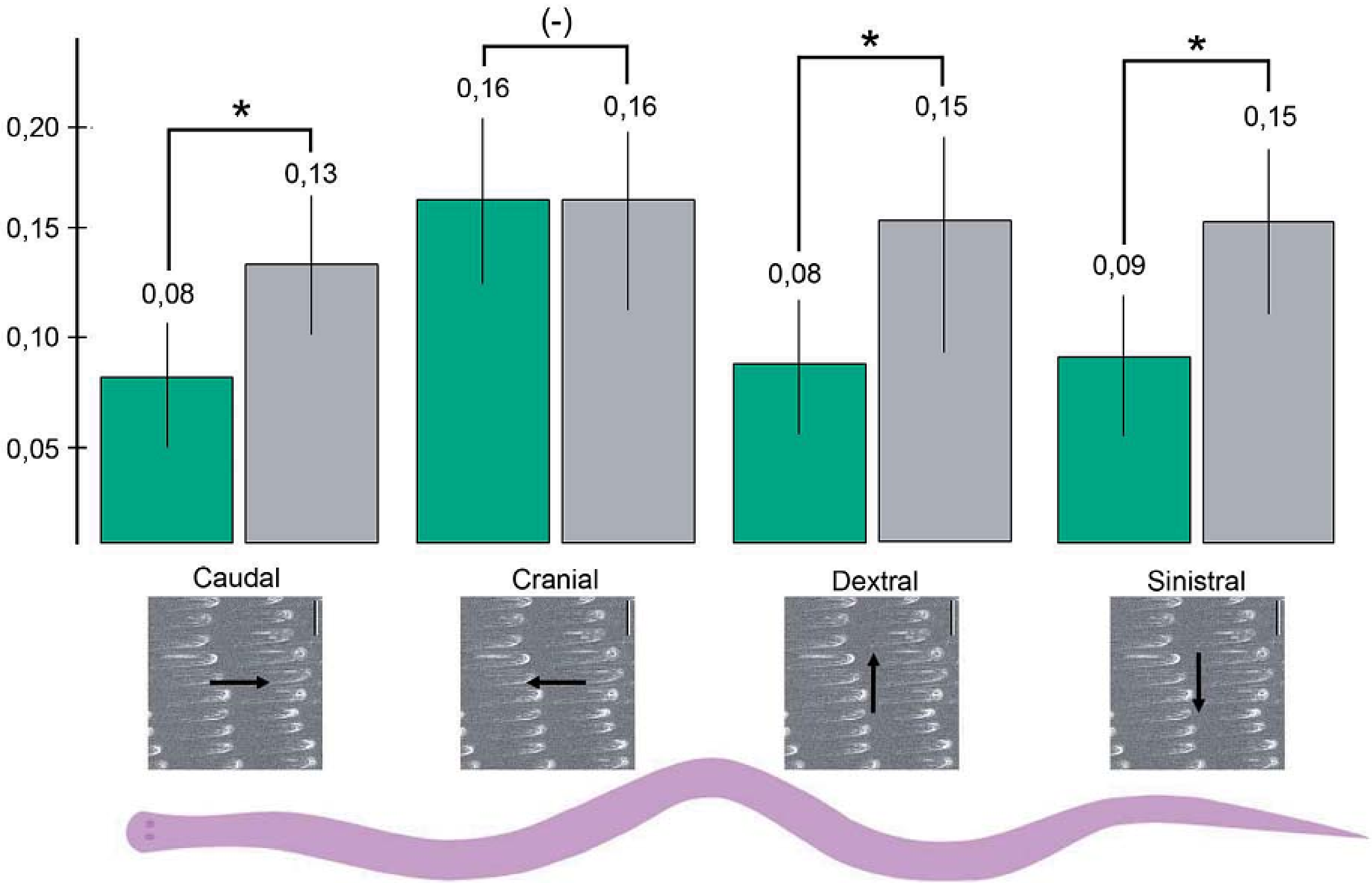
Sliding Locomotion: Frictional Anisotropy

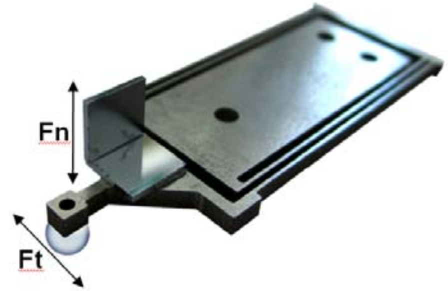
Berthé, Westhoff, Bleckmann, Gorb, 2009



Snakes: Friction Control

Martina Baum





μ

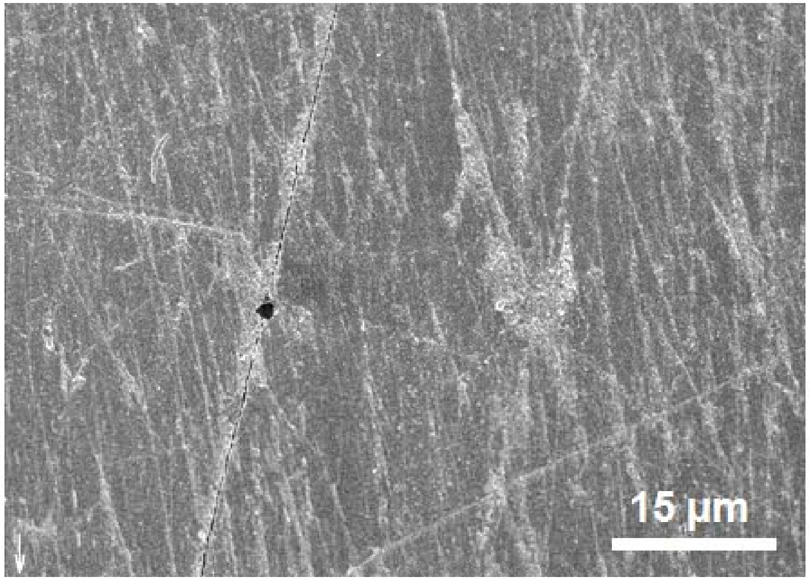
Cushioned
Uncushioned

Lampopeltis getula

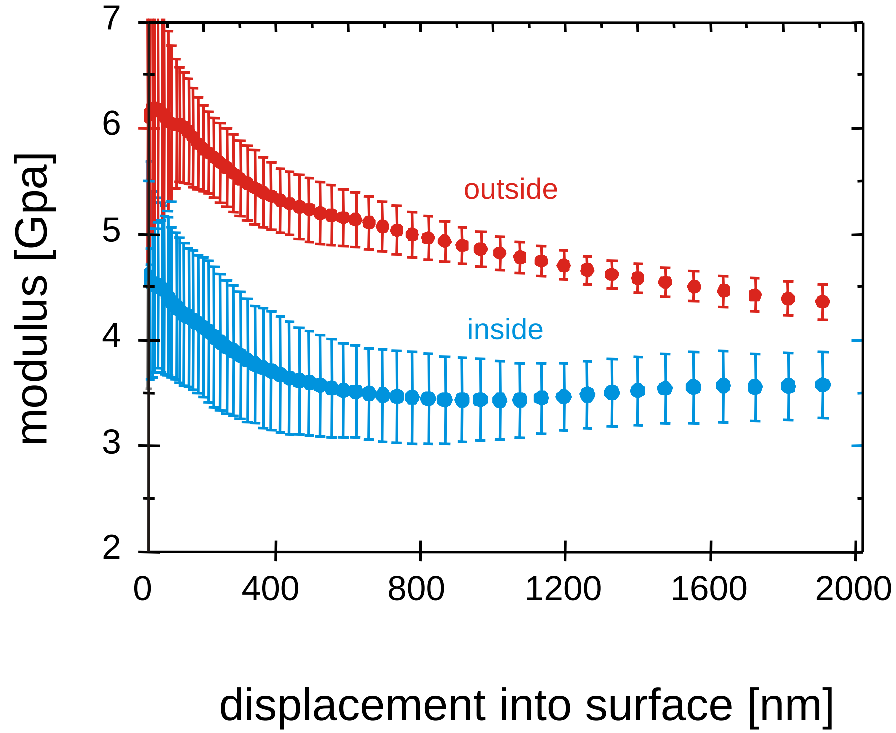
Snakes: Wear Resistance

Marie-Christin Klein

Klein , Deuschle, Gorb, 2010. J. Comp. Physiol. A
Klein and Gorb, 2012, J.R.S. Interface



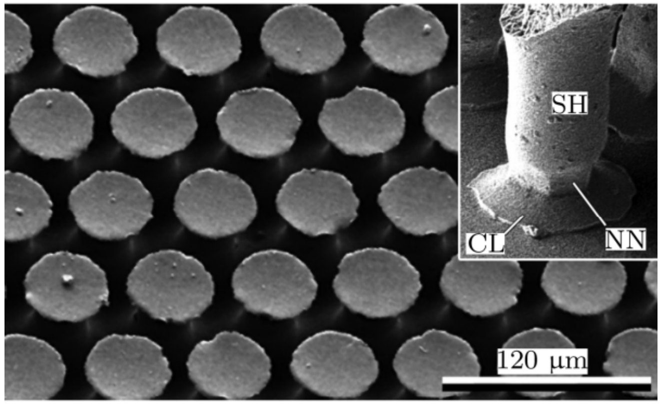
Gongylophis colubrinus

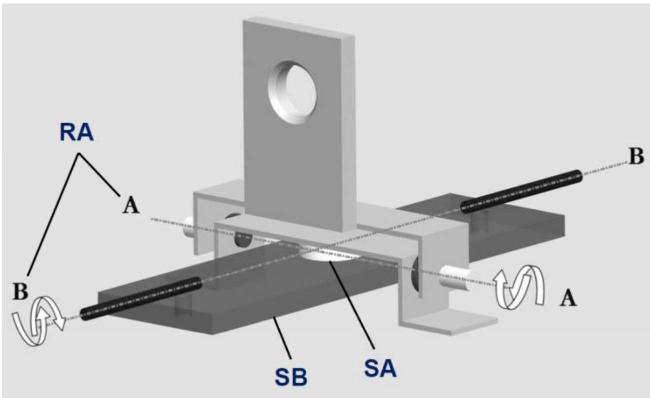


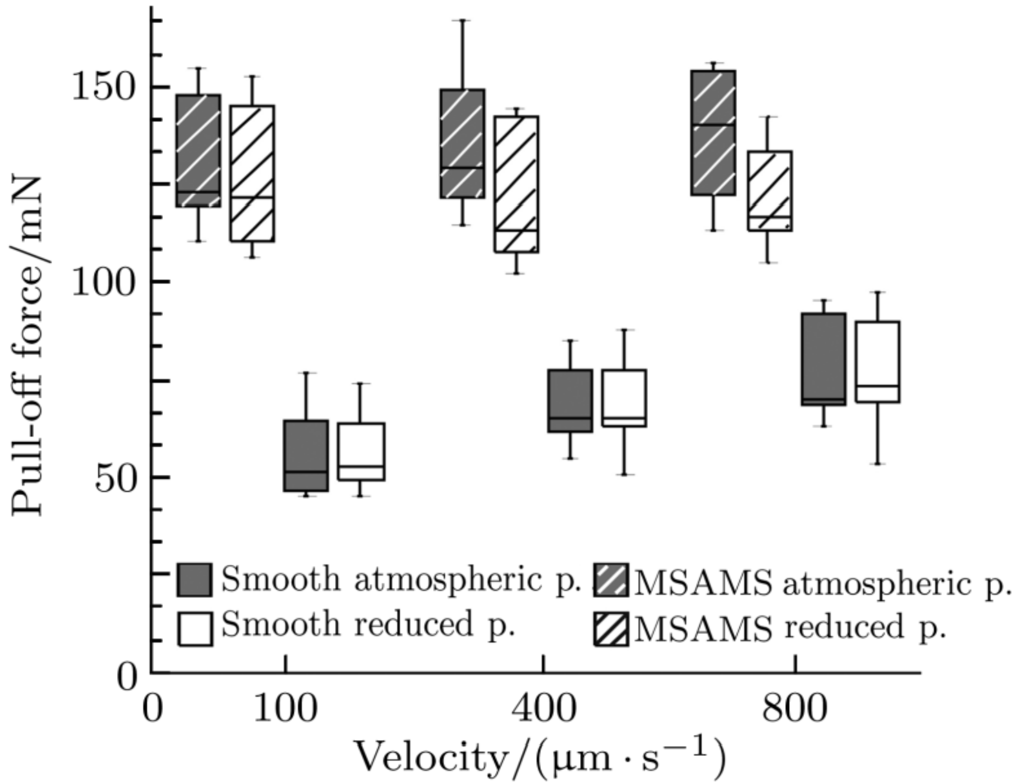
Contact Mechanics at Microscale

Lars Heepe
Emre Kizilkan

Heepe, Varenberg, Gorb, 2010. J.R.S. Interface



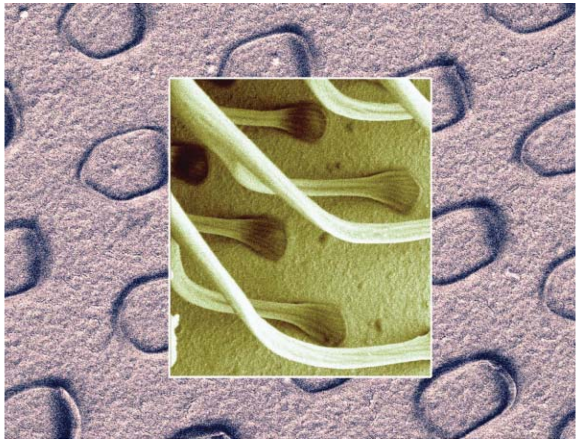


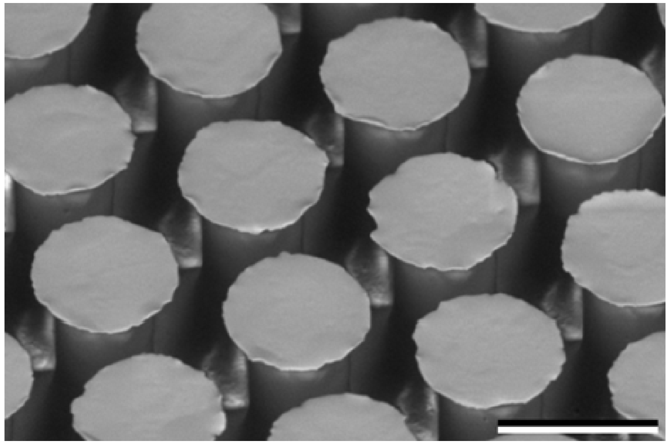


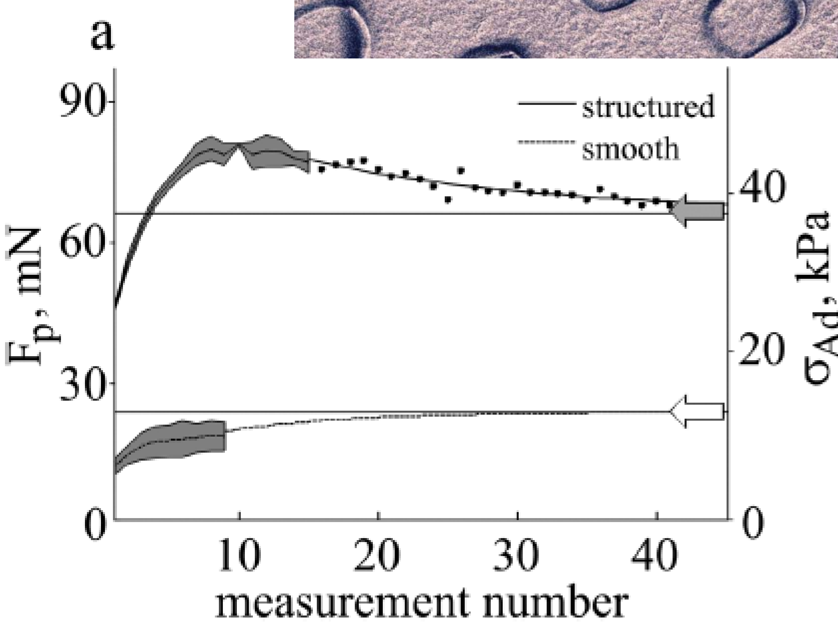
Wet Adhesion

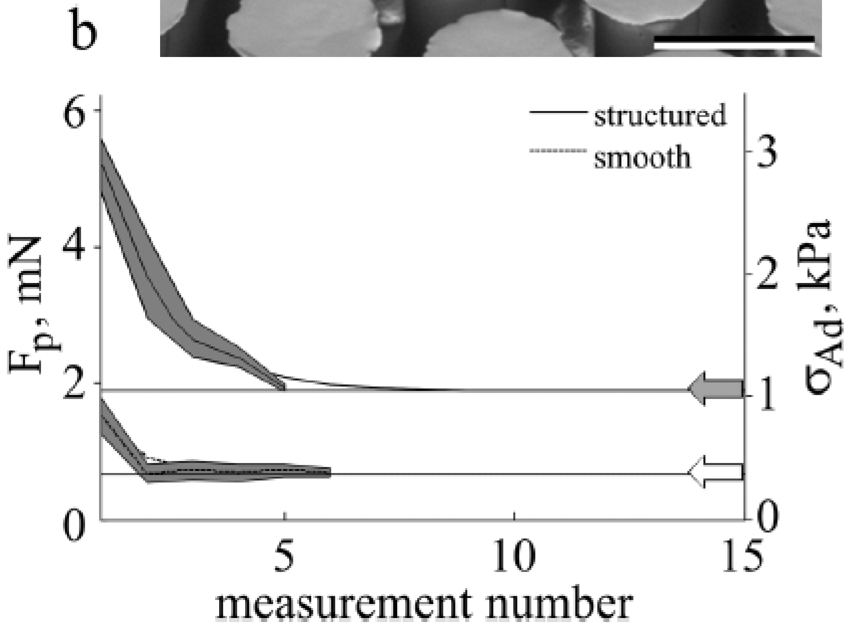
Dr. Alexander Kovalev

Kovalev, Varenberg, Gorb, 2012. Soft Matter





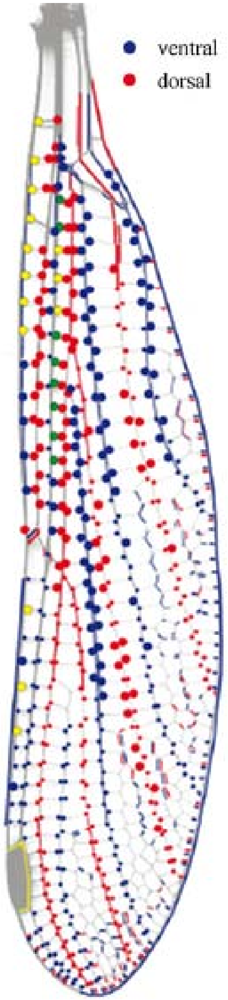


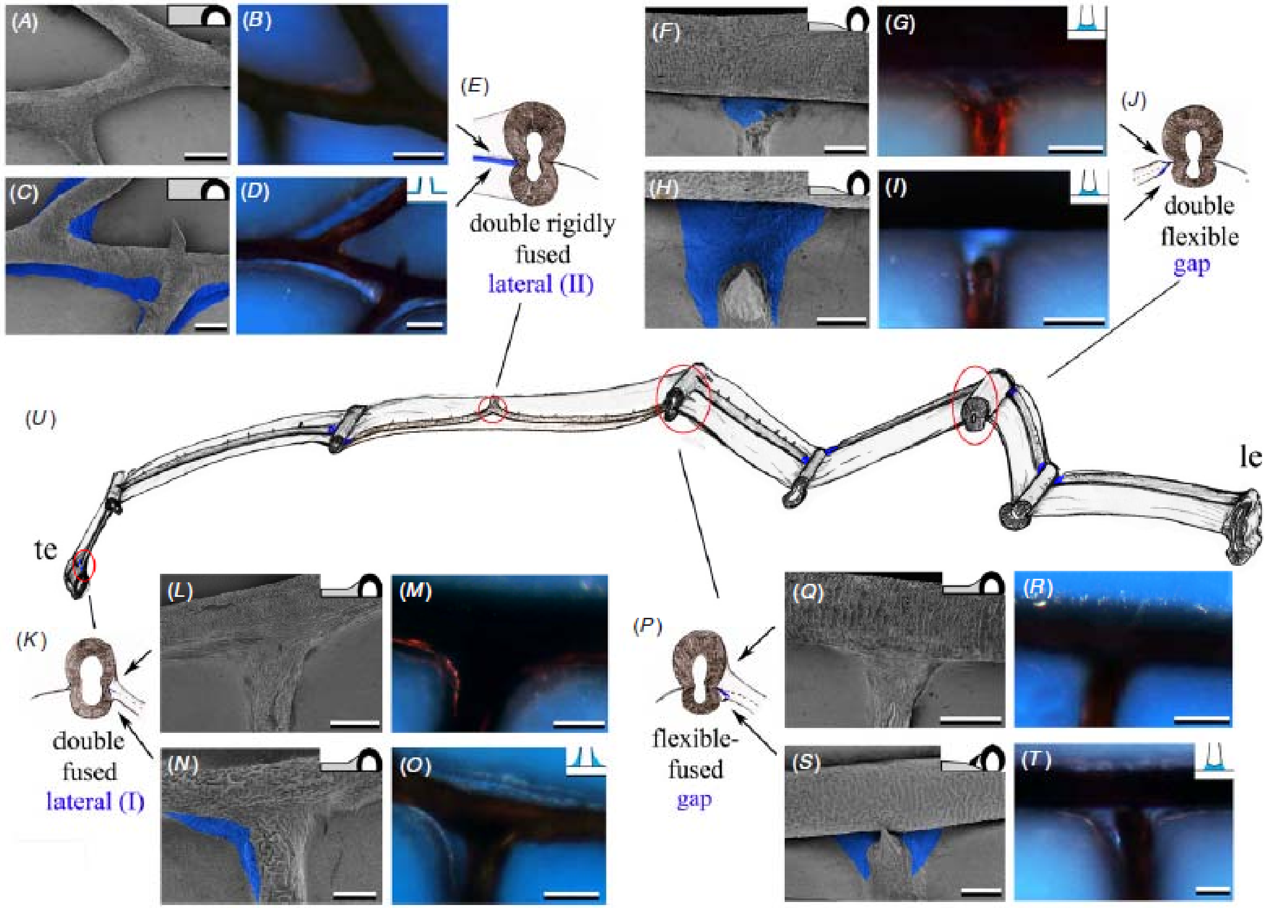


Dragonfly Wing Microjoints

Esther Appel

Appel and Gorb, 2011. Bioinsp. and Biomim.



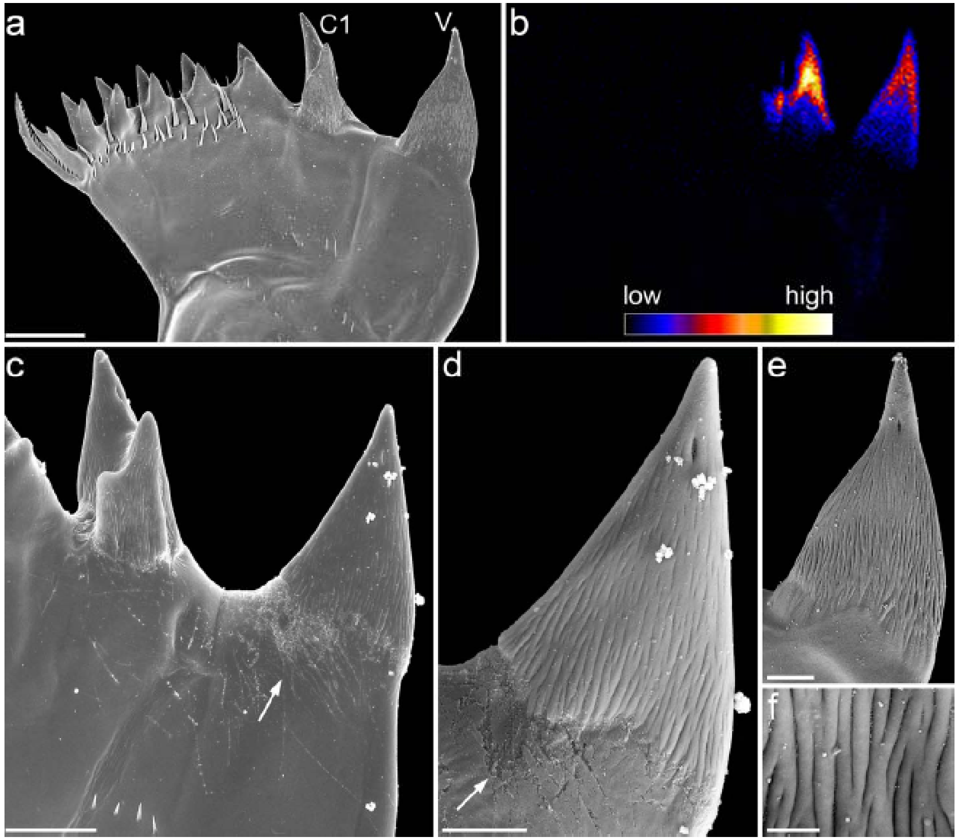


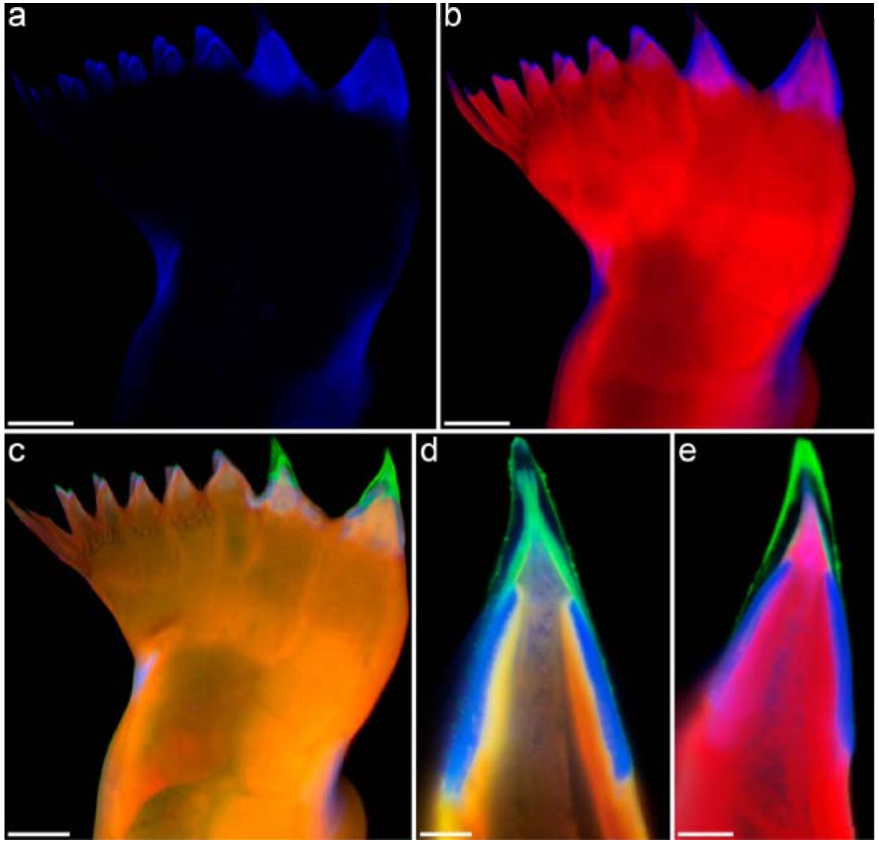
Gradient Materials

Dr. Jan Michels

Michels, Vogt, Gorb, 2012, Sci. Rep.

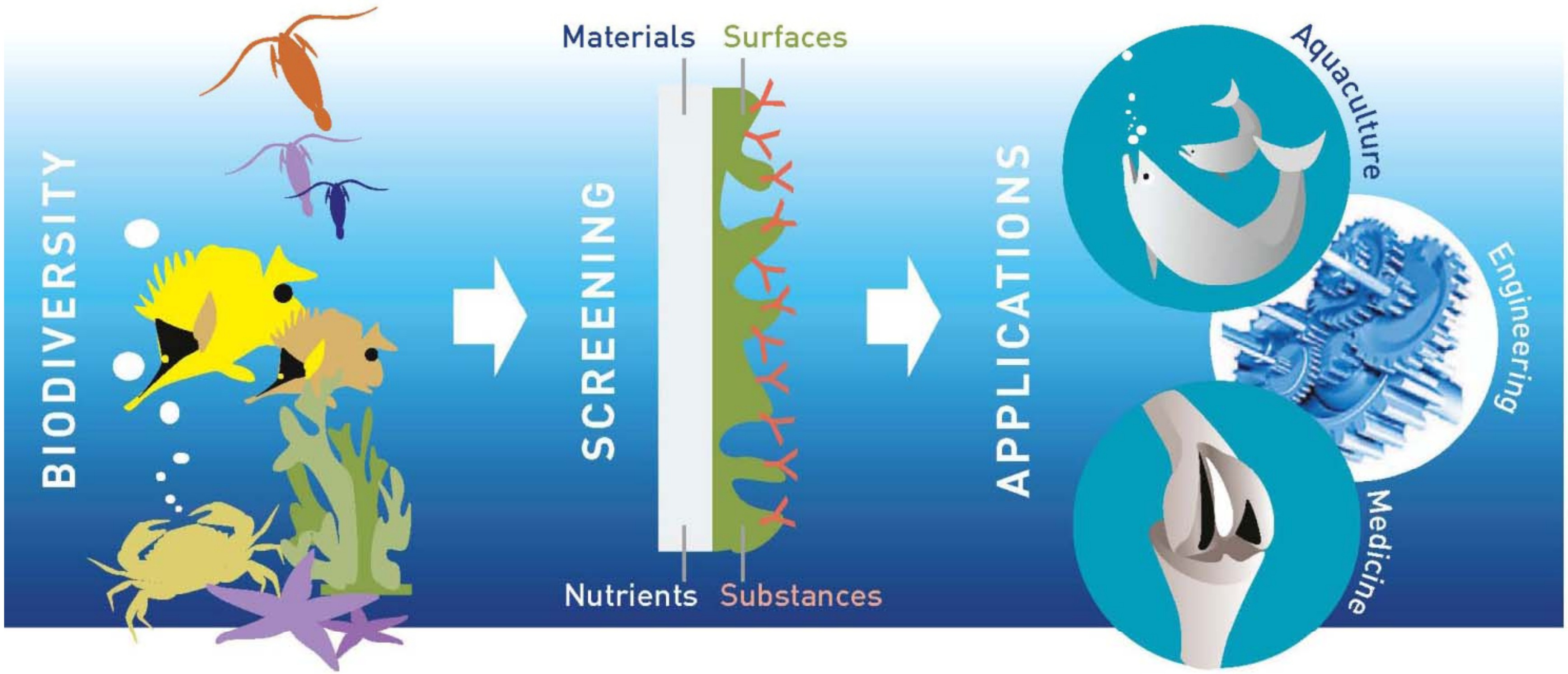
Centropages hamatus





Phase 2 – Research Topic R4: Ocean Innovation

How can ocean biological substances and material be used to support technological innovations for a range of applications benefitting human society?

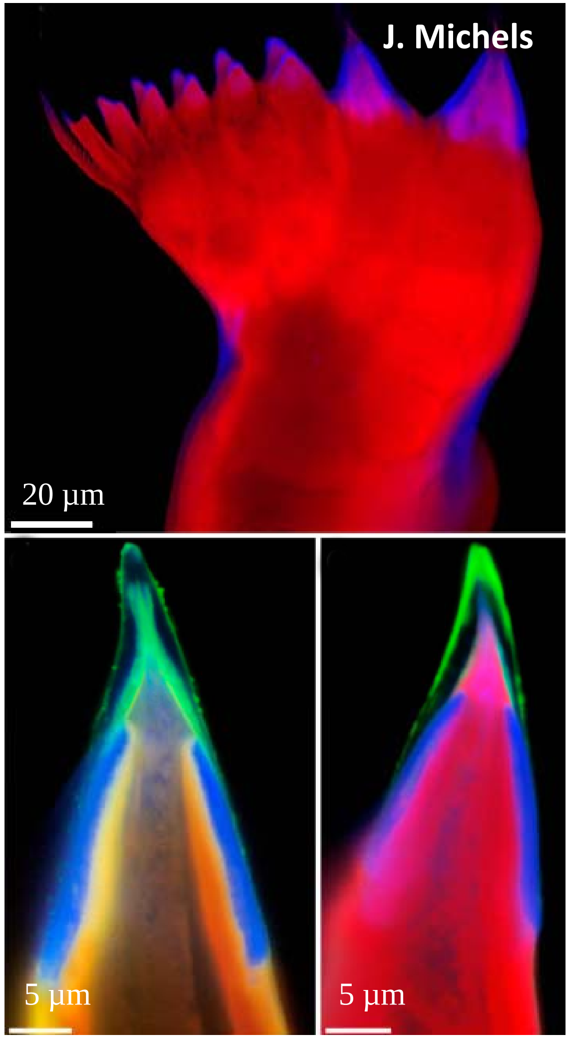


Phase 2 – Research Topic R4: Ocean Innovation

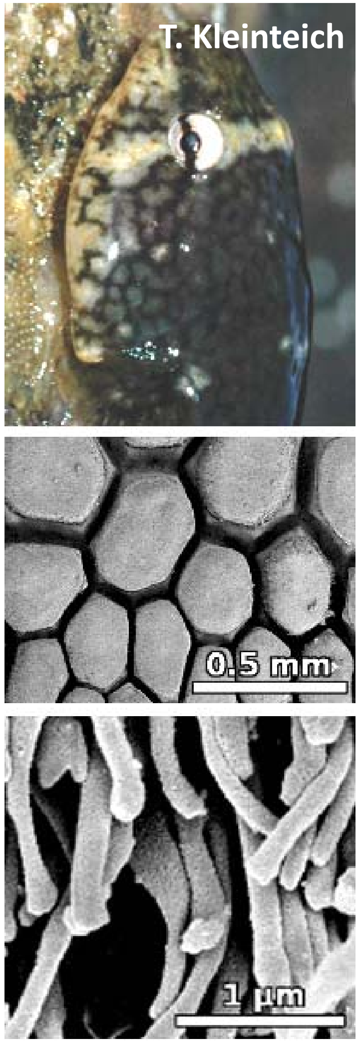
Screening: Surface geometry, material composition and properties

J. Michels, T. Kleinteich, S. Gorb

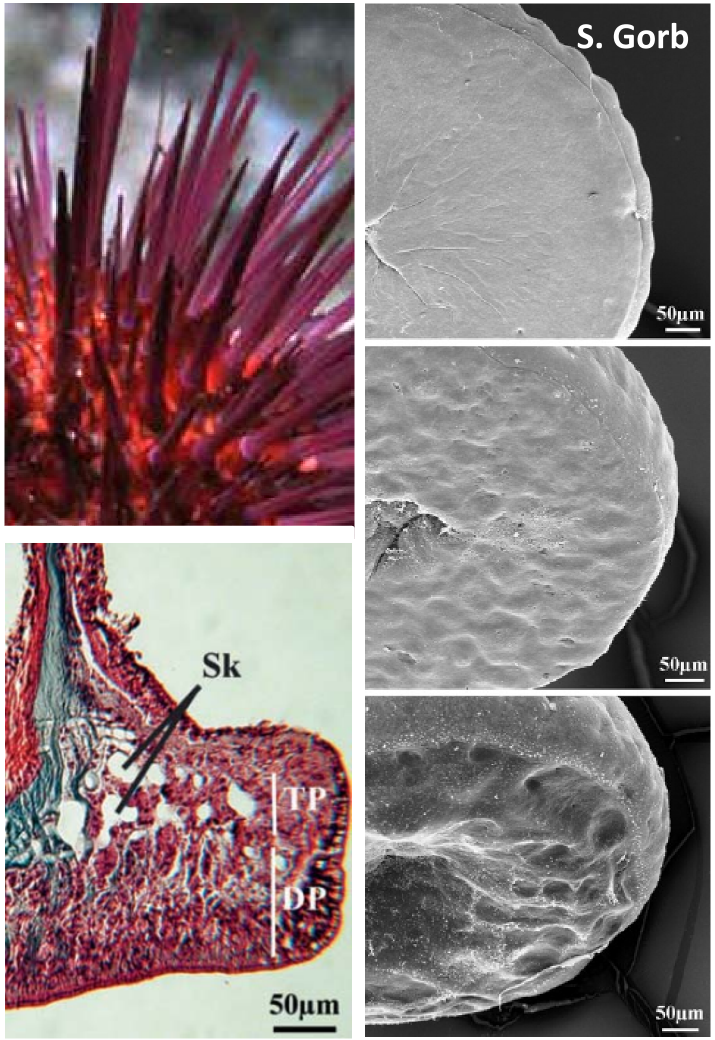
copepod *Centropages hamatus*



fish *Gobeisox meandricus*



sea urchin *Paracentrotus lividus*



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