The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2063-17

# ICTP/FANAS Conference on trends in Nanotribology

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## Materials for reversible adhesion: from biological systems to wall-climbing robots

GORB Stanislav

*University of Kiel*
*Zoological Institute*
*Department for Functional Morphology and Biomechanics*
*Am Botanischen Garten 1-9, 24098 Kiel*
*Schleswig -Holstein*

## Surfaces and Interfaces


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

## Goals

**to understand functional principles**

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

FUNCTIONAL PROJECTS

**to develop methods**

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

**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


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

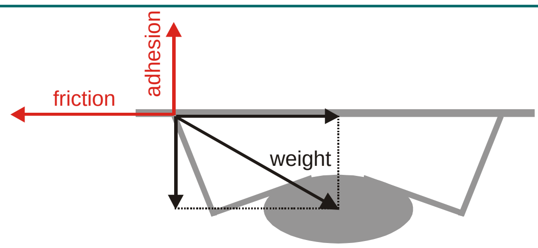
...to unpredictable surfaces

...and fast releasable (millions of cycles)

...non-conglutinating!

## Ceiling Situation (Static)

## Ceiling Situation




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

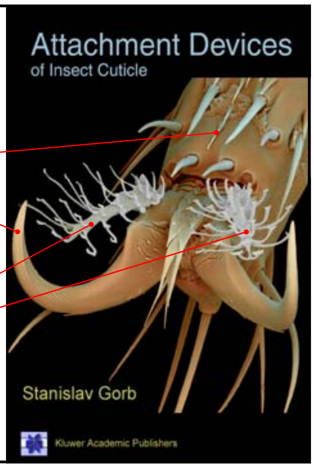
contact formation:
- fast
- reliable
- minimal load on the ceiling

contact breakage:
- fast
- minimal force

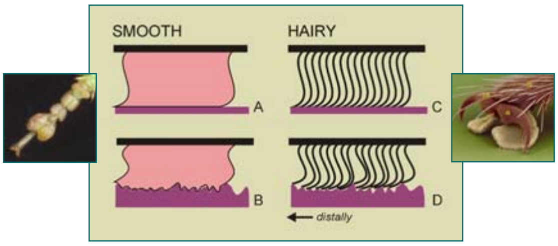
## Insect Terrain

structures for interlocking and friction enhancement on rough substrata
- claws
- stiff pointed hairs

structures for adhesion and friction enhancement on smooth substrata
- pulvilli
- arolia
- euplantulae
- etc, etc.



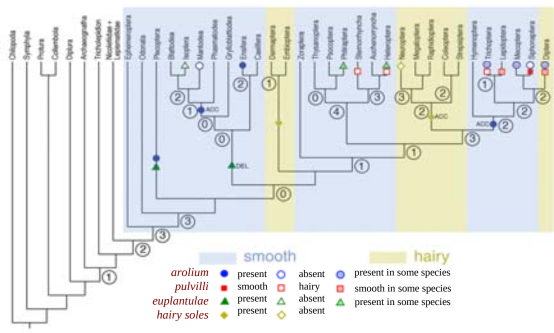

## Two Designs of Animal Attachment Pads



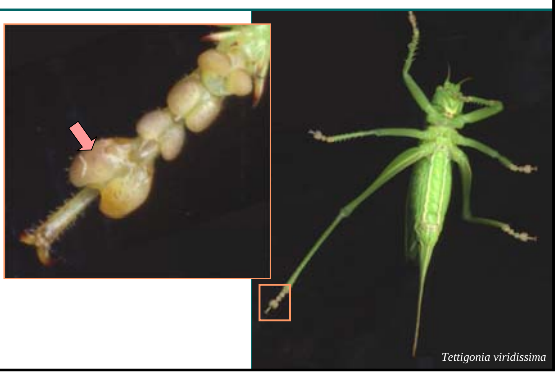

| | |
|---|---|
| Blattaria | Diptera |
| Orthoptera | Coleoptera |
| Plecoptera | Megaloptera |
| Hymenoptera | Raphidioptera |
| Homoptera | |
| Heteroptera | |

## Two Designs of Attachment Pads

*Gorb and Beutel, 2001, Naturwissenschaften*

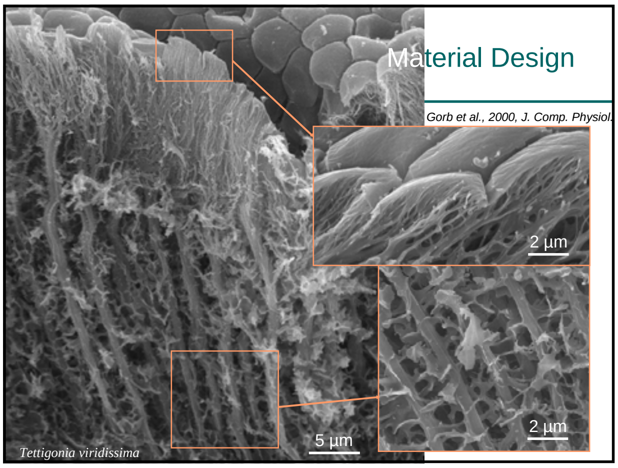



## Smooth Attachment System



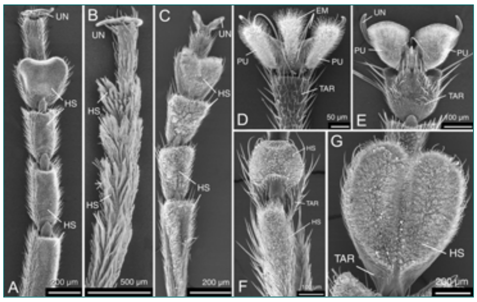

## Material Design

*Gorb et al., 2000, J. Comp. Physiol.*



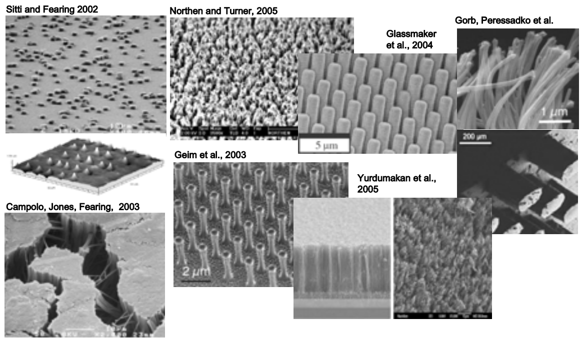
## Hairy Pads of Insects

*Beutel and Gorb, 2001, J. Zool. Syst. Evol. Res.*

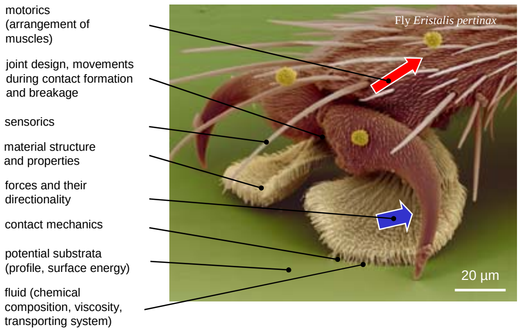



A. Dobsonfly *Sialis lutaria*
B. Beetle *Priacma serrata*
C. Beetle *Rhagonycha fulva*
D. Fly *Bibio nigriventris*
E. Fly *Episyrphus balteatus*
F. Earwig *Forficula auricularia*
G. Beetle *Cantharis fusca*

## Bioinspired Patterned Surfaces




## Example of the Hairy Attachment Pad

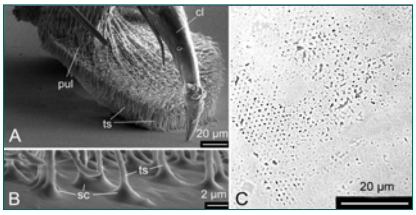



## Secretory Fluid

**Reduviid bugs**
Edwards and Tarkanian, 1970

**Flies**
Bauchhenss and Renner, 1977; Bauchhenss, 1979; Walker et al., 1985

**Beetles**
Ishii, 1987;
Eisner and Aneshansley, 2000




**A**. Pulvillus of the syrphid fly *Eristalis pertinax* in contact with the glass surface
**B**. Tenent setae tips surrounded by secretion
**C**. Footprints on a glass surface. Note the regular pattern of droplets

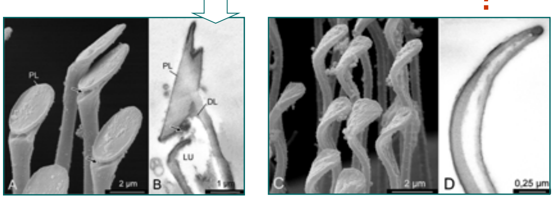
cl, claw
pul, pulvillus
sc, secretion
ts, tenent setae

## Design of Adhesive Setae

*Gorb, 1998, Proc. Roy. Soc. B*

is adapted for the release of adhesive substances close to the area of contact

?




TEM and SEM micrographs of the two types of tenent setae in the syrphid fly *Episyrphus balteatus*. Setae of the type 2 (A, B) are located distally in the pulvillus, whereas setae of the type 1 (C, D) are located at the basis of the pulvillus. DL, dense layer; LU, lumen; PL, end plate.

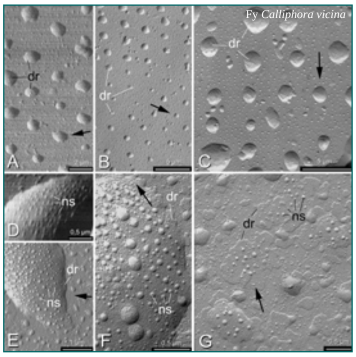
## Microemulsion

*Gorb, 2001*

Carbon-Platinum replicas of the frozen footprints (black arrows indicate direction of coating)

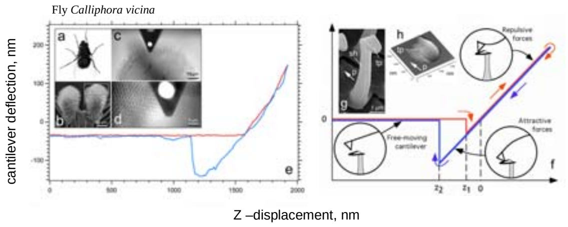
**SEM (A, D)**
**TEM (B-C, E-G)**
**A-F. Fresh prints**
**G. Dry prints**

**dr, drops**
**ns, nano-drops**



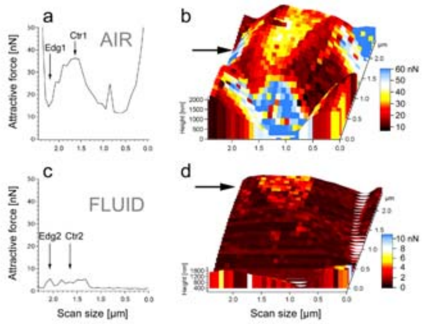
## AFM-Measurements of Attractive Forces

*Langer, Ruppersberg, Gorb, 2004, Proc. Roy. Soc. B*



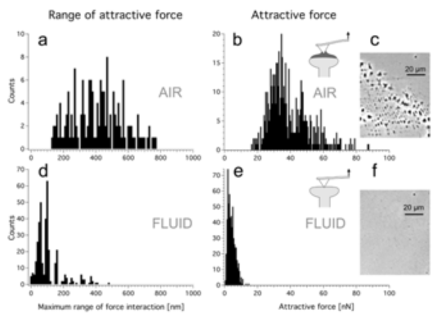

## Force Mapping of Single Setal Tip

*Langer, Ruppersberg, Gorb, 2004, Proc. Roy. Soc. B*



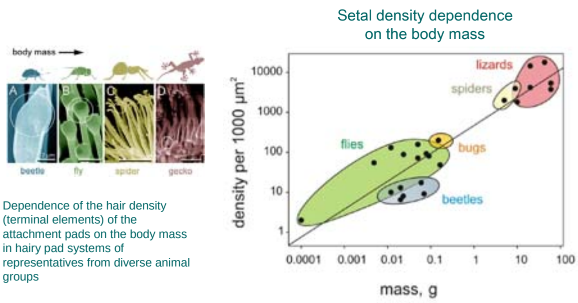

## Range of Attractive Forces

*Langer, Ruppersberg, Gorb, 2004. Proc. Roy. Soc. B.*




## Dimension and Density of Setae

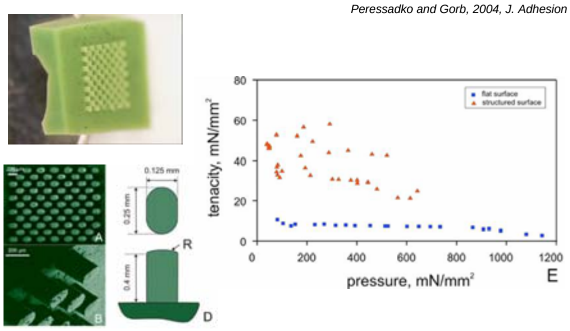
*Arzt, Gorb, Spolenak, 2003, PNAS*



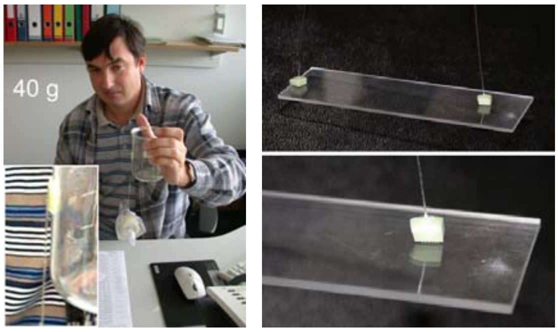

Dependence of the hair density (terminal elements) of the attachment pads on the body mass in hairy pad systems of representatives from diverse animal groups

## Experiment with the Structured Polymer Surface

*Peressadko and Gorb, 2004, J. Adhesion*

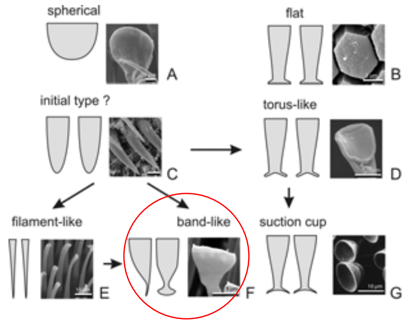



## Prototypes



## 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

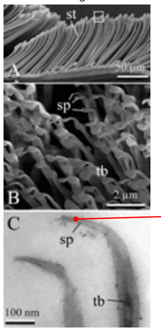
F. Beetle *Chrysolina fastuosa*, seta of the second tarsal segment

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

## Function of Terminal Elements

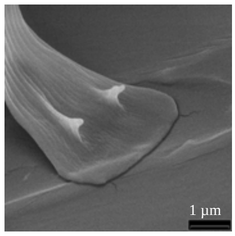
*Persson and Gorb, 2003, J. Chem. Phys.*

*Gekko gecko*




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

TE of the beetle *Chrysolina fastuosa* in contact



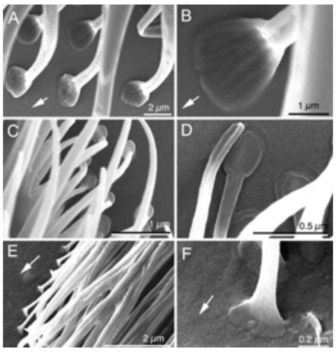

Functions: (1) Low bending stiffness of thin terminal plates enables an intimate contact with surface irregularities. (2) Easy contact formation by sliding. (3) Increasing of contact forces without normal load

## Spatula Contacts (Cryo-SEM)

Fly

Spider
(data of
S. Niederegger and P. Walther)

Gecko



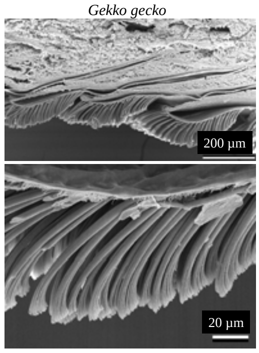

## Slope


Functions: (1) To decrease the bending stiffness of setae. (2) To enhance adaptability of single contacts. (3) Part of the built-in detachment mechanism

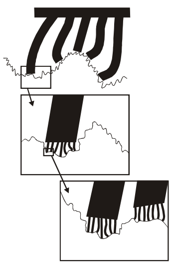
*Gekko gecko*

LAMELLAE

SETAE



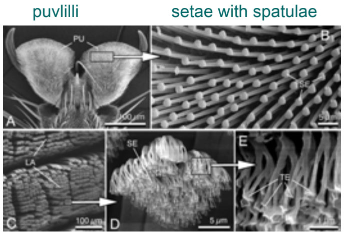

## Hierarchy



Function: To enhance adaptability of single contacts at roughness of different levels of magnitude (reflection of real fractal world)

Insects

puvlilli setae with spatulae

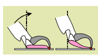



lamella setae spatulae

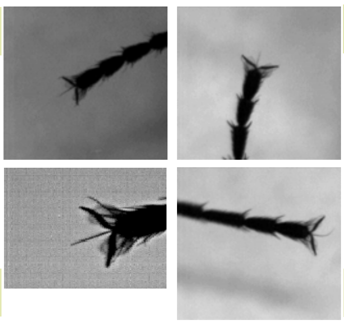
Gecko

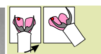
## Detachment Movements in the Fly

*Niederegger and Gorb, 2003, J. Insect Physiol.*



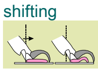
rotation



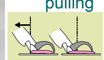


twisting

shifting

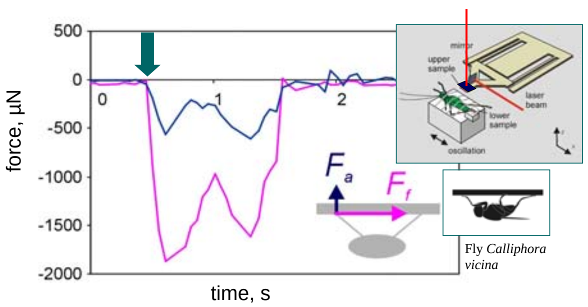


pulling



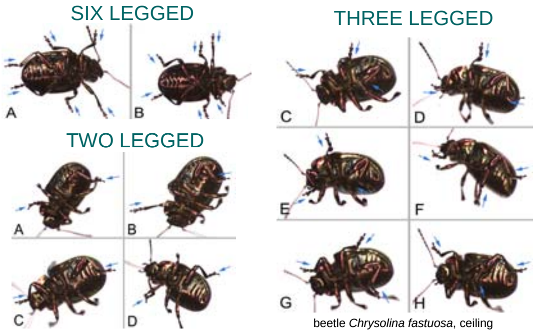
## 2D Force Measurements on the Leg of the Freely-Walking Fly

Gorb et al., 2007




Fly *Calliphora vicina*

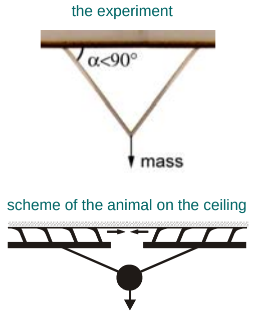
## Pad Orientation

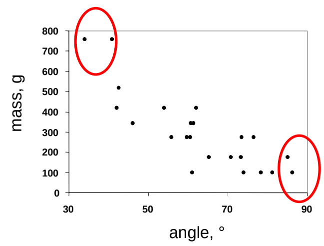



beetle *Chrysolina fastuosa*, ceiling

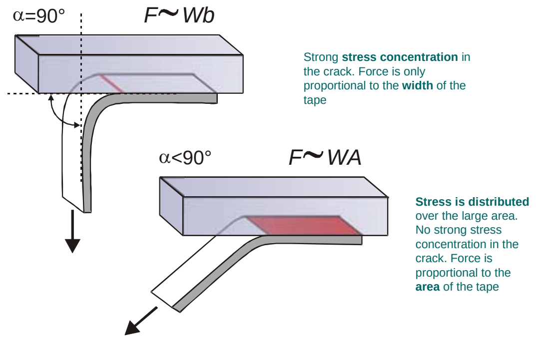
## Peeling of Two Sticky Tapes

Gorb et al., 2007

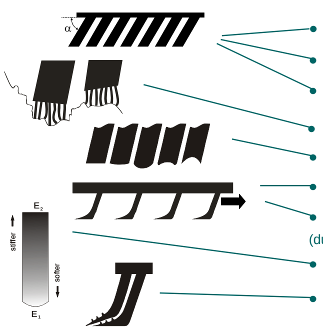



## Peeling



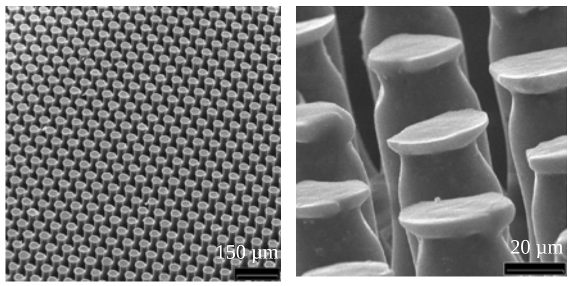

## Challenge: to put all this together




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

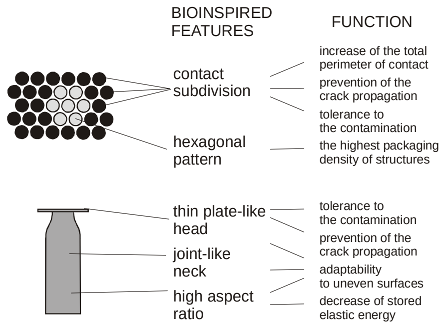
## Dry Adhesives

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



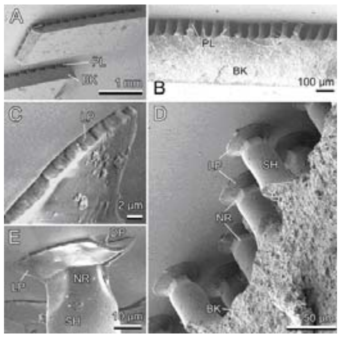

*with Binder GmbH (Holzgerlingen, Germany)*

## Dry Adhesives




## Dry Adhesives

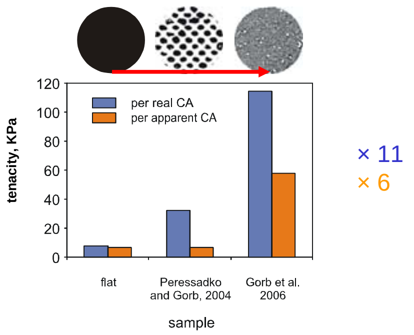
*Gorb, Varenberg, Peressadko, Tuma, 2007, J. Roy. Soc. Interface*




- **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

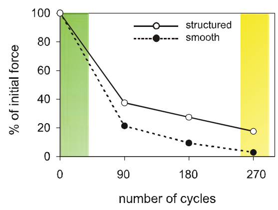
## Properties of Dry Adhesives

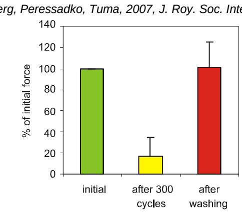
*Gorb, Varenberg, Peressadko, Tuma, 2007, J. Roy. Soc. Interface*

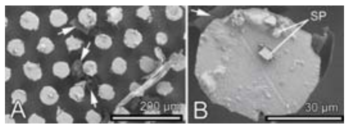



## Contamination of Dry Adhesives

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



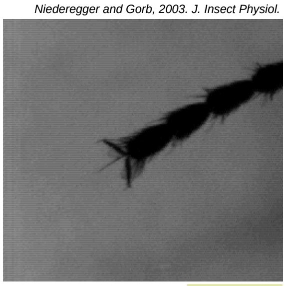



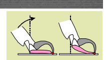

## Wall Walking Using Dry Adhesives

*Daltorio et al. 2004, IROS Conference*

*Niederegger and Gorb, 2003. J. Insect Physiol.*

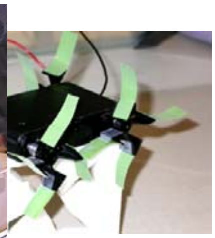


***together with Quinn Lab** (Daltorio, Horchler, Ritzmann, Quinn), Case Western Reserve University, Cleveland, OH, USA*



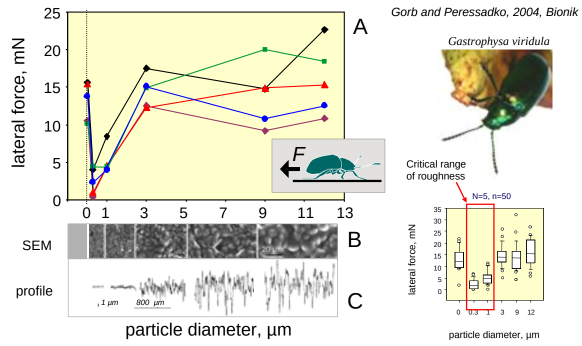
## Wall Walking Using "Dry Adhesives"

*Daltorio et al., 2005, CLAWAR Conference*

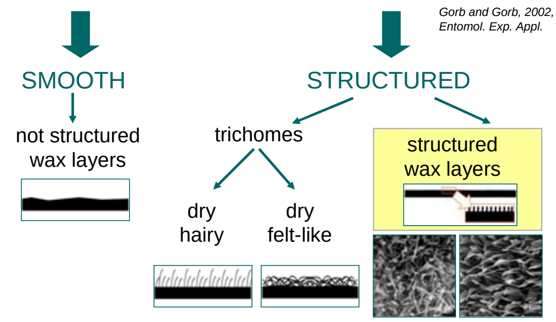


*with Daltorio, Horchler, Ritzmann, Quinn*
*Case Western Reserve University, Cleveland, OH, USA*

## Roughness Effects on Hairy Pad Attachment




## Plant Surfaces




## Pruinose Plant Surfaces

*Lactuca serriola* (leaf, lower)
*Chelidonium majus* (leaf, lower)
*Robinia pseudoacacia* (leaf, upper)
*Chenopodium album* (leaf, upper)

*Brassica oleracea* (leaf, lower)
*Acer negundo* (stem)
*Prunus domestica* (fruit)

## Group

*www.flyfoot.de*

**Post docs:**
Elena Gorb
Alexander Kovalev
Jan Michels
Katja Steffen
Dagmar Voigt

**PhD students:**
Martina Benz
Philipp Bußhardt
Marie-Christin Klein
Henrik Peisker

**Technicians:**
Astrid Ingwersen
Joachim Ösert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German Science Foundation
Alexander von Humboldt Foundation
Schlößmann Foundation
Foundation of Baden Württemberg