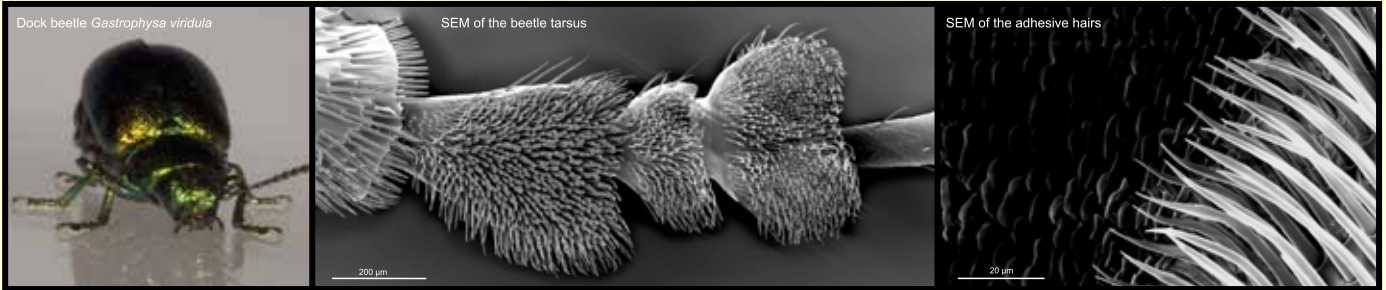
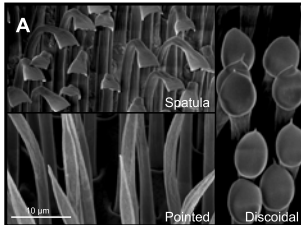


## 1. How do beetles attach to smooth surfaces and how do the hairs function?

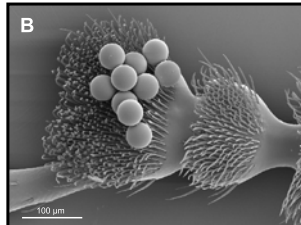
## 2. How do beetles detach from surfaces and are their pads direction-dependent?



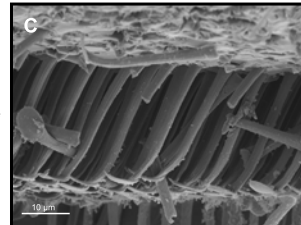
### Why are beetle pads important models for biomimetic adhesives?



A. Diverse hair designs allow attachment to **smooth** and **rough** surfaces, and prevent crack propagation.



B. An impressive **self-cleaning** ability allows the pads to be continually re-used, without becoming contaminated.



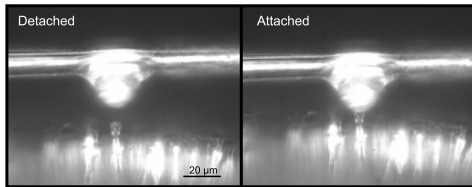
C. The angle of the hairs and anisotropic tip shapes allow rapid and **effortless detachment** during running.

→ Hairs adhere using the capillary forces of secreted fluids

### 1. Single hair measurements

#### In vivo recordings of individual hairs

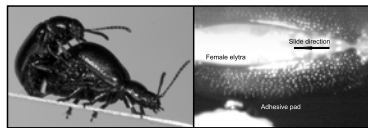
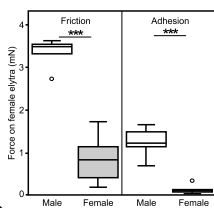
Experiments performed using a self-built micro bending beam



#### Measuring the adhesive properties of single hairs

→ Using the glass bending beam, the adhesive forces of individual hairs could be measured in a live beetle. Discoidal, male-specific hairs perform better on smooth surfaces:

Force on discoidal hair:  $919 \pm 105$  nN    Force on spatula hair:  $582 \pm 56$  nN



Slides of pads across female elytra show the male's adaptation to mating.

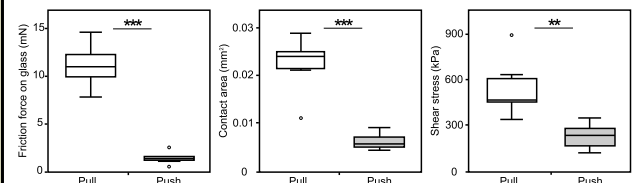
### 2. Direction-dependence

#### Pulling and Pushing Slides of the distal pad

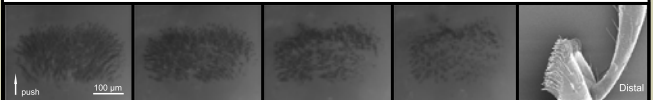
Friction Force

Contact Area

Shear Stress

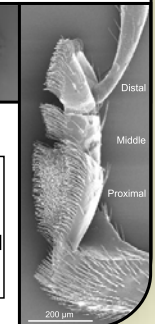
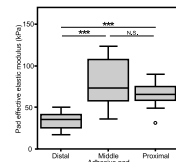


During the push: Force, contact area and stress all decrease



#### So how does the beetle push whilst climbing?

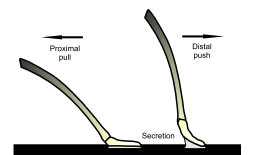
→ Each pad of the leg has evolved a different stiffness, giving the soft distal pad high adhesion and direction-dependence, but allowing the stiff proximal pad stability during pushing.



### Conclusions:

- Beetle attachment pads offer many important advantages over conventional synthetic adhesives.
- The hairs confer several functional properties and attach with impressive forces, however the pads are able to adhere dynamically, detaching quickly.

**Direction-dependence** may be explained by both area loss and a decrease in contact quality, allowing the pads to detach during running. However stiff, stable rear pads also allow pushing when climbing up or down.



When pushing - Area and stress may decrease due to individual hair design and increased fluid layer