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Looking Beyond the Surface – Thinking Like Geckskin®

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Video created and provided by Prof. Duncan Irschick
Biology, Digital Life, Center for Evolutionary Materials, UMass Amherst

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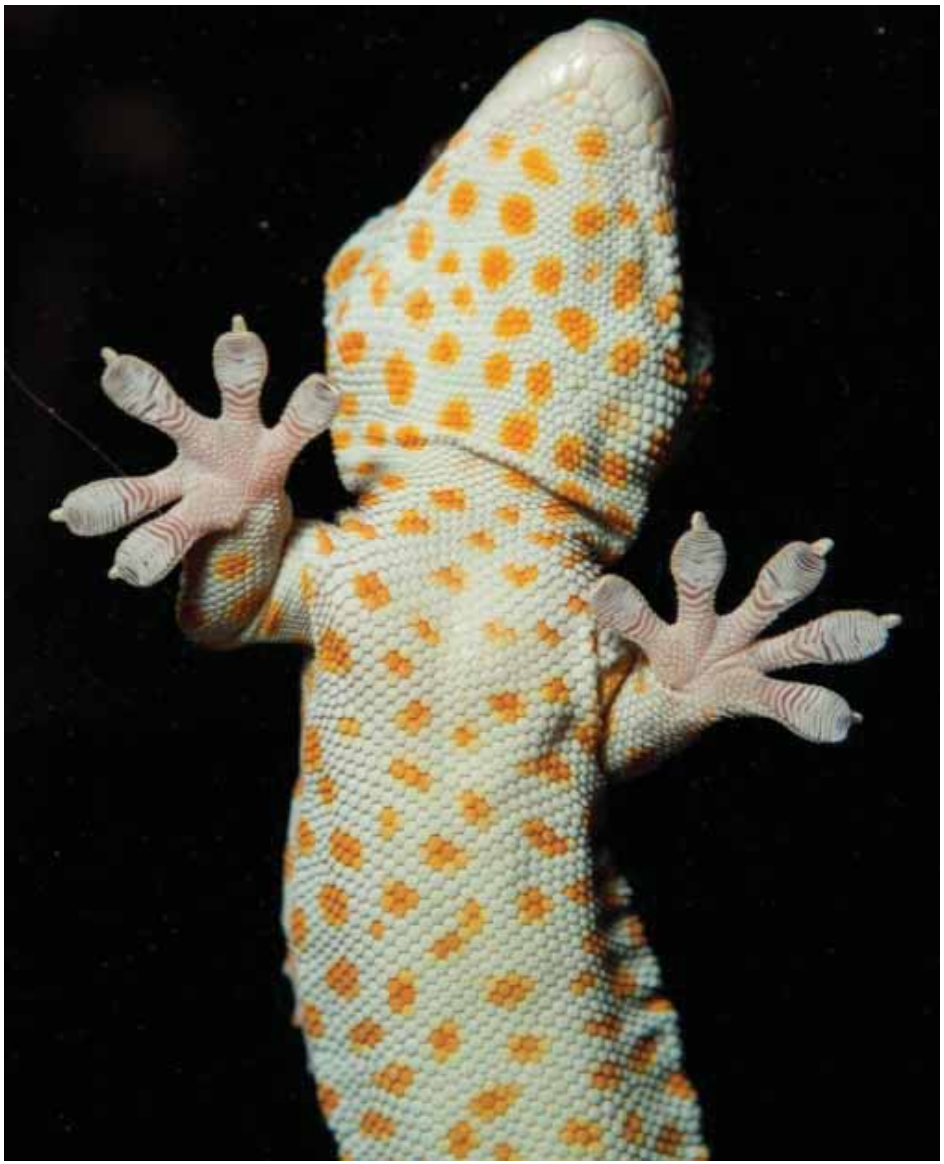
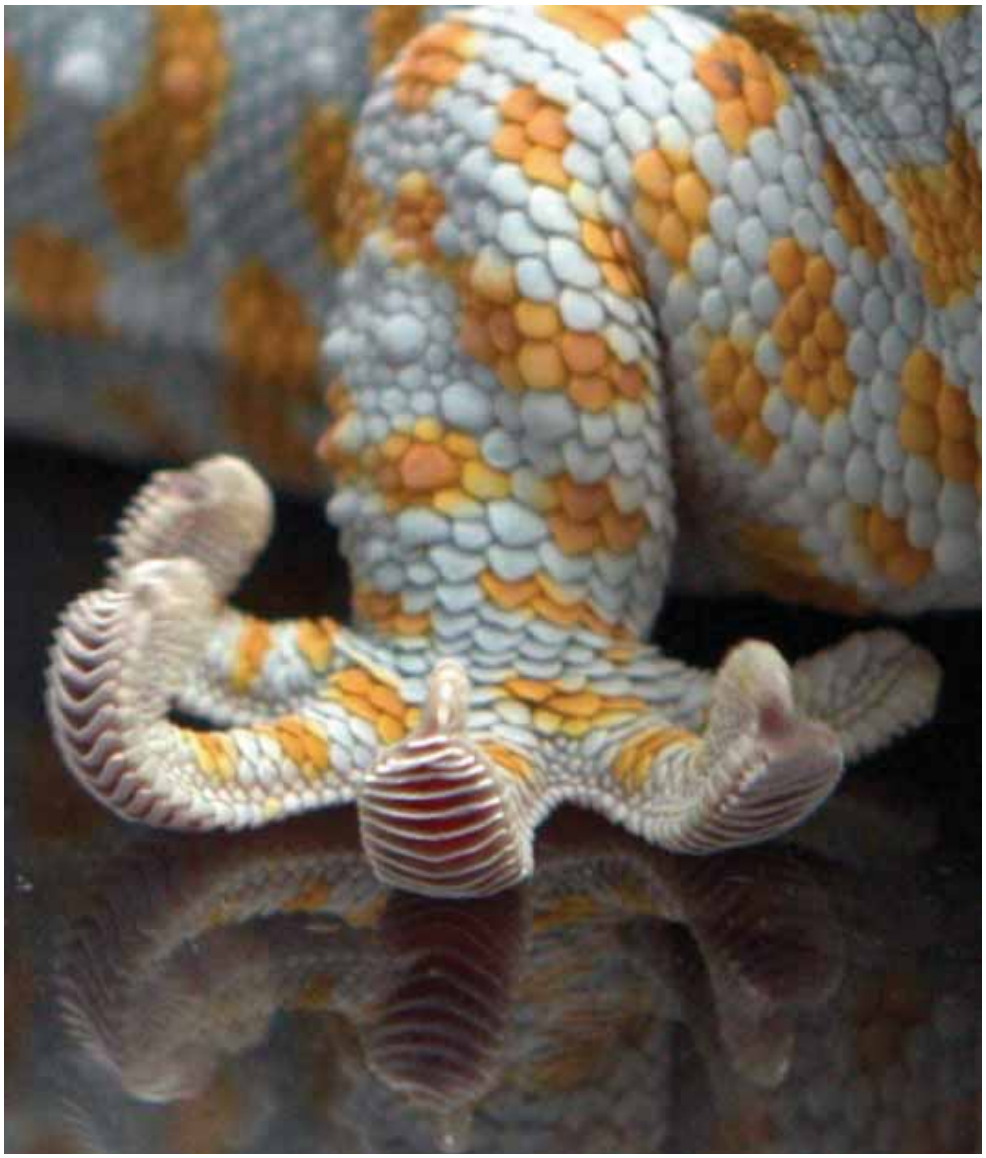
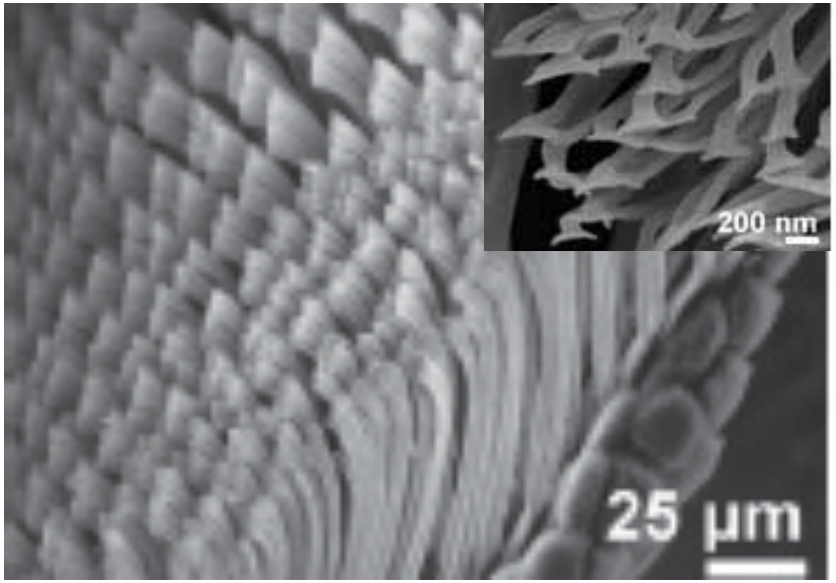
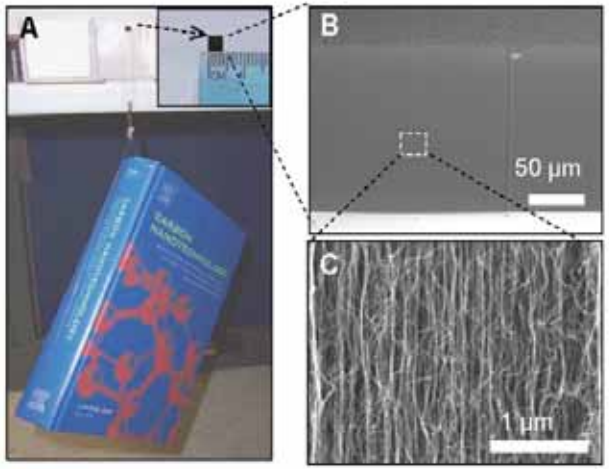
Gecko = evolutionary innovation





Answers Rarely Found on the Surface

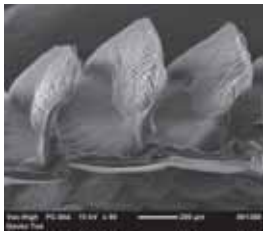
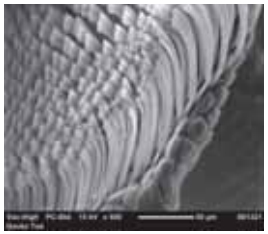


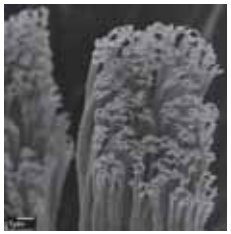


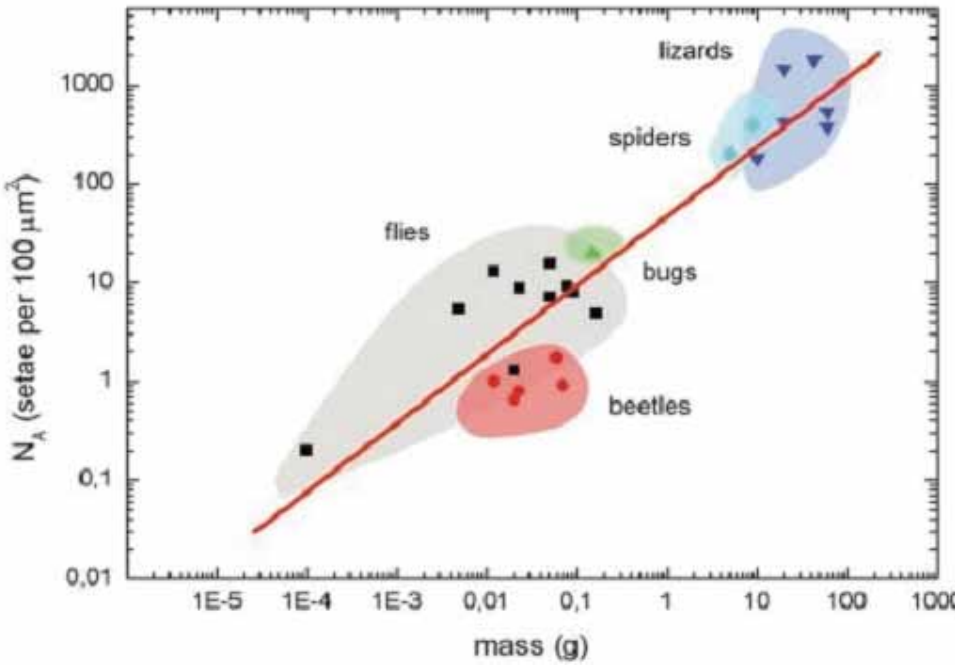
Qu,L. *et al., Science*, 2008, **322**.

- Micro- and Nano- scale fibrils partial solution for geckos and insects
- Direct mimicry did not lead to scalable engineering

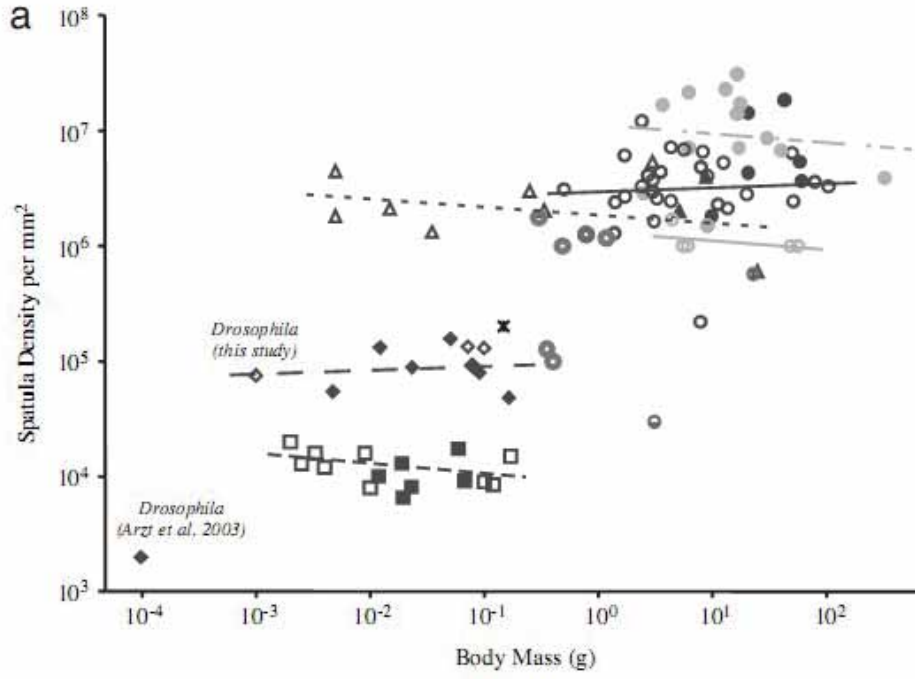
Setae are not the scaling parameter





Arzt, E., et al. PNAS, 100 (19) 2003.



Peattie, AM, et al. PNAS, 104 (47) 2007.

What is the *scaling parameter* to guide adhesion force control on all length scales?

Scaling adhesion to large sizes?

Math Not Mimicry

- Developed **theory** to hypothesize what controls **force capacity** (F_c) for reversible adhesives used for biological locomotion.

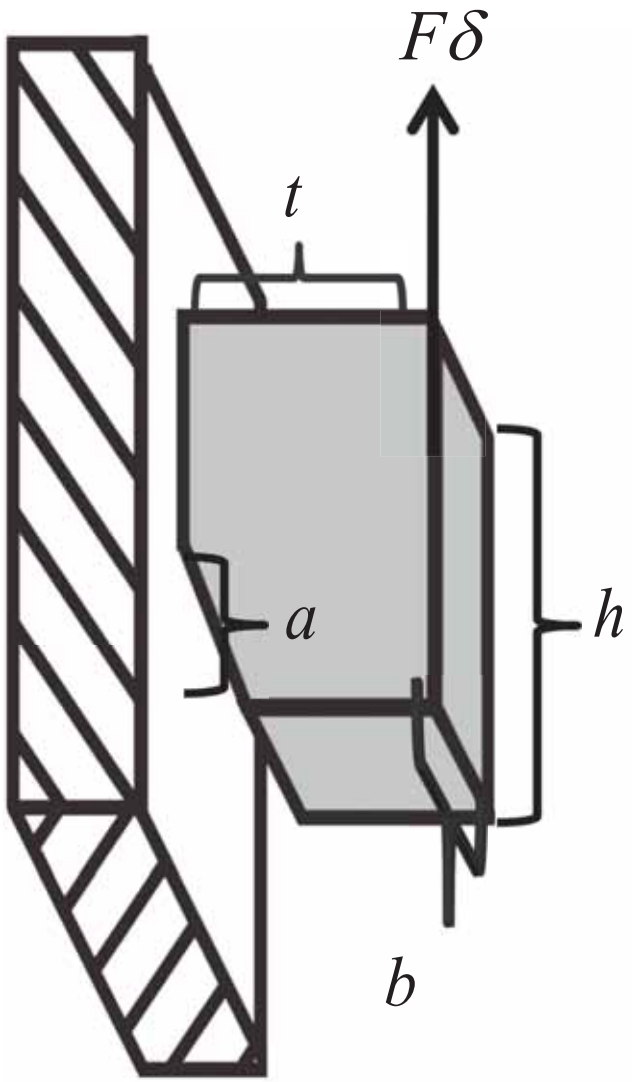
- Assumptions:
  - **Forces balance (equilibrium)**
  - **Energy in = Energy Out**
    - Contrary to current adhesives!!!
    - Organisms that climb with adhesion don't want to lose energy!
  - **Nature designs around instability**

Andrew Croll
Post-doc (2009-2010)

Mike Bartlett
Ph.D. Student ('08-13)

$$\text{Force Capacity} = [\text{van der Waals}]\left[\frac{Area}{Compliance}\right]$$

Simple Scaling



Can we define a problem to give general guidance:

$$U_{Total} = U_{Elastic} + U_{Work} + U_{Interface}$$

1. Assume equilibrium $\dfrac{\partial U}{\partial A} = 0$

2. Assume unstable failure when maximum load is achieved $\dfrac{\partial^2 U}{\partial A^2} \leq 0$

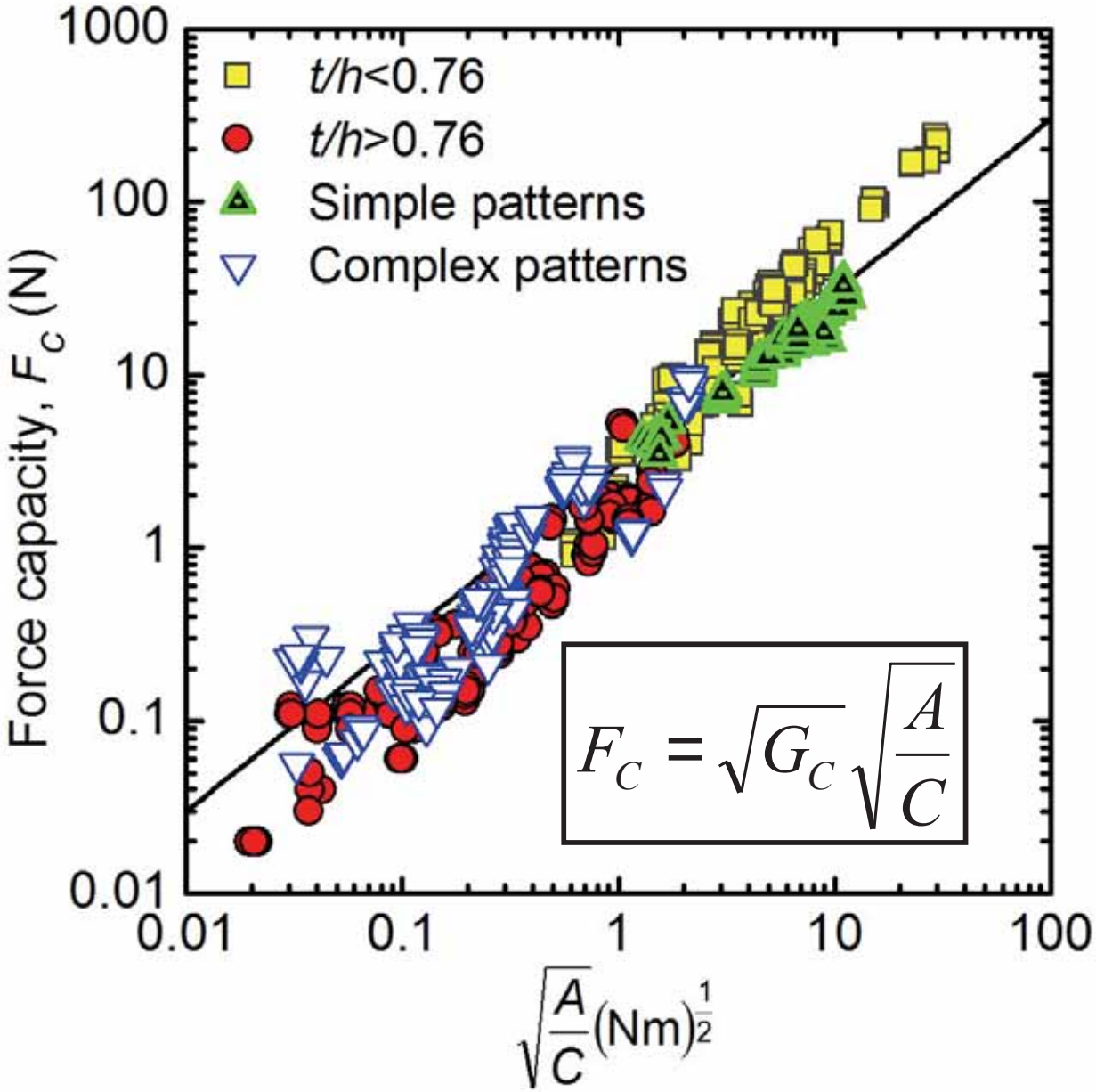
3. Consider systems that want stored energy to be recoverable, $\Delta U = U_{final} - U_{initial} = 0$

$$F_C = \sqrt{G_C}\sqrt{\frac{A}{C}}$$

F_c: Maximum sustainable force
G_c: Adhesion Energy
A: Interfacial area
C: Compliance in direction of loading

Bartlett, Croll, King, Paret, Irschick, Crosby, *Advanced Materials* **2012**.

Force capacity follows scaling



M.D. Bartlett *et al*. *Adv. Funct. Mater. 22, 4085-4092* **(2012)**

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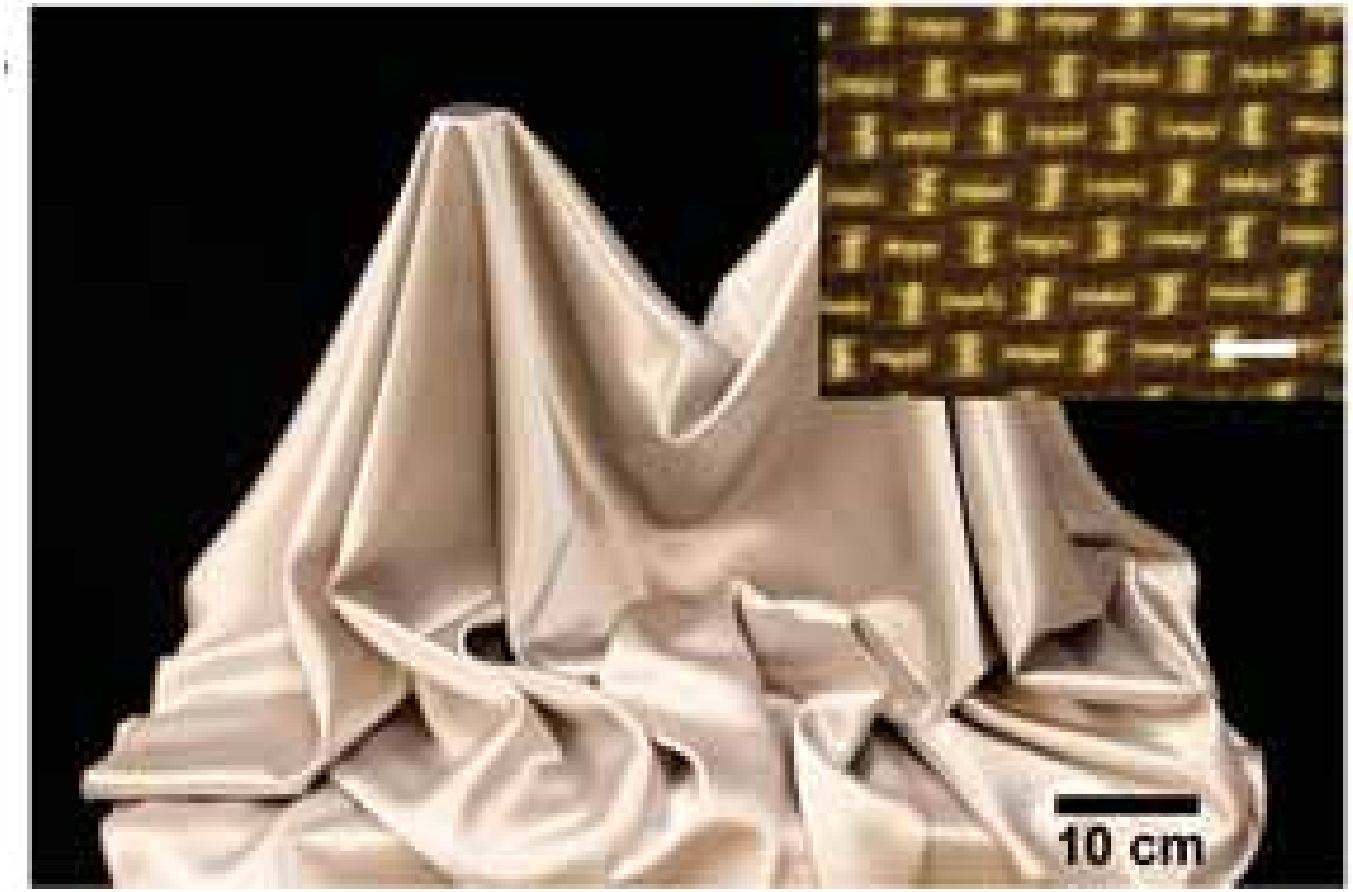
How do take advantage?

$$F_c = \sqrt{G_c}\sqrt{\frac{A}{C}}$$



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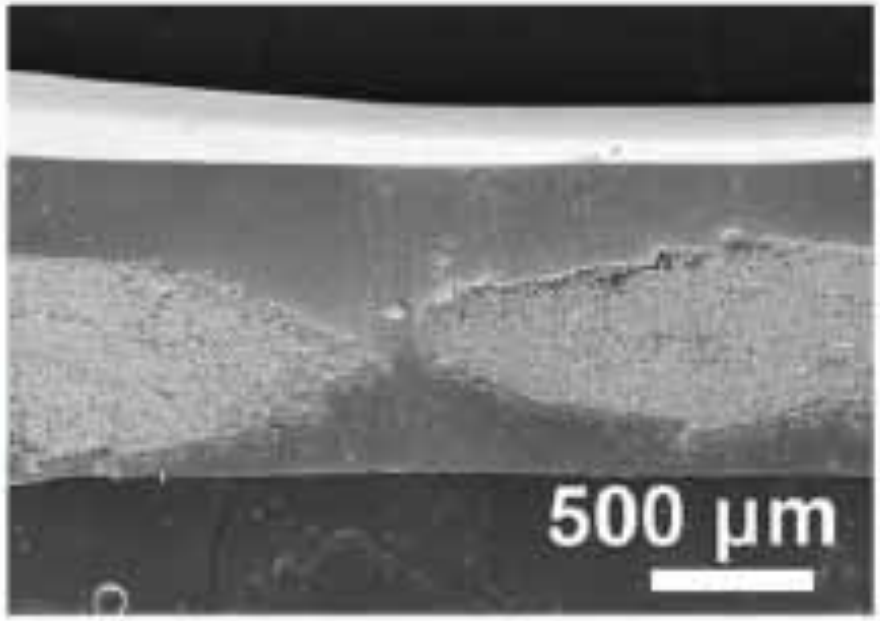
Draping with High Stiffness Fabrics



Mike Bartlett, Ph.D. student

Dan King, Ph.D. student

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Conform to Reality

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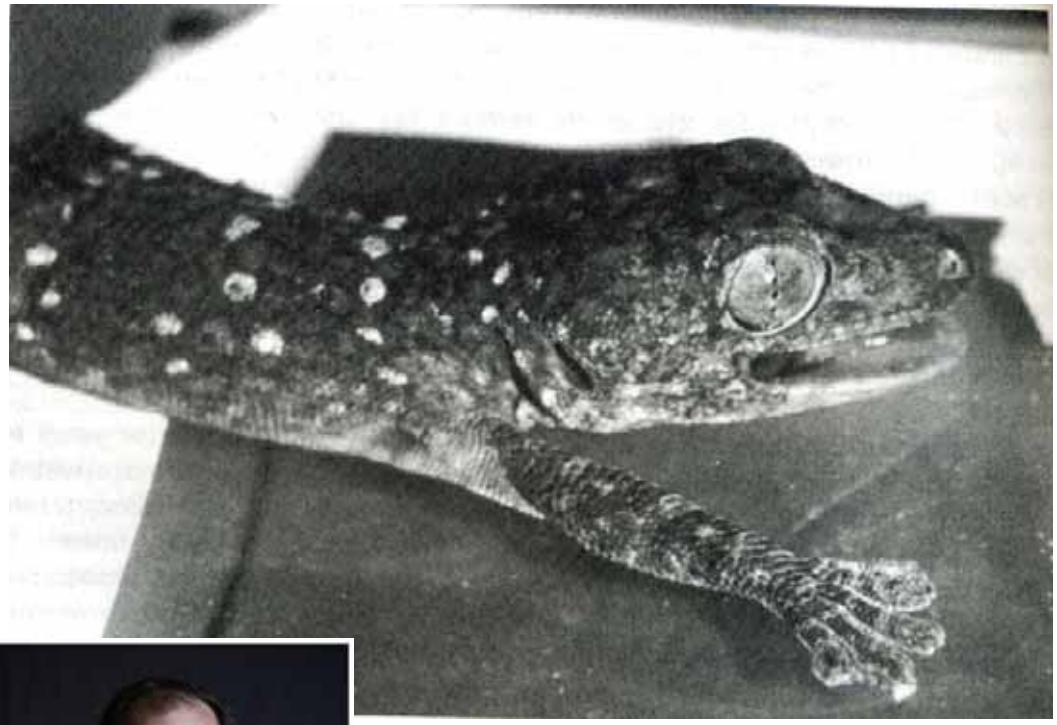
Geckskin on Everything

Does this scaling work for biology?

The two feet of a 50 g tokay gecko can produce about 20 N of adhesive force ~ a bag of 20 apples

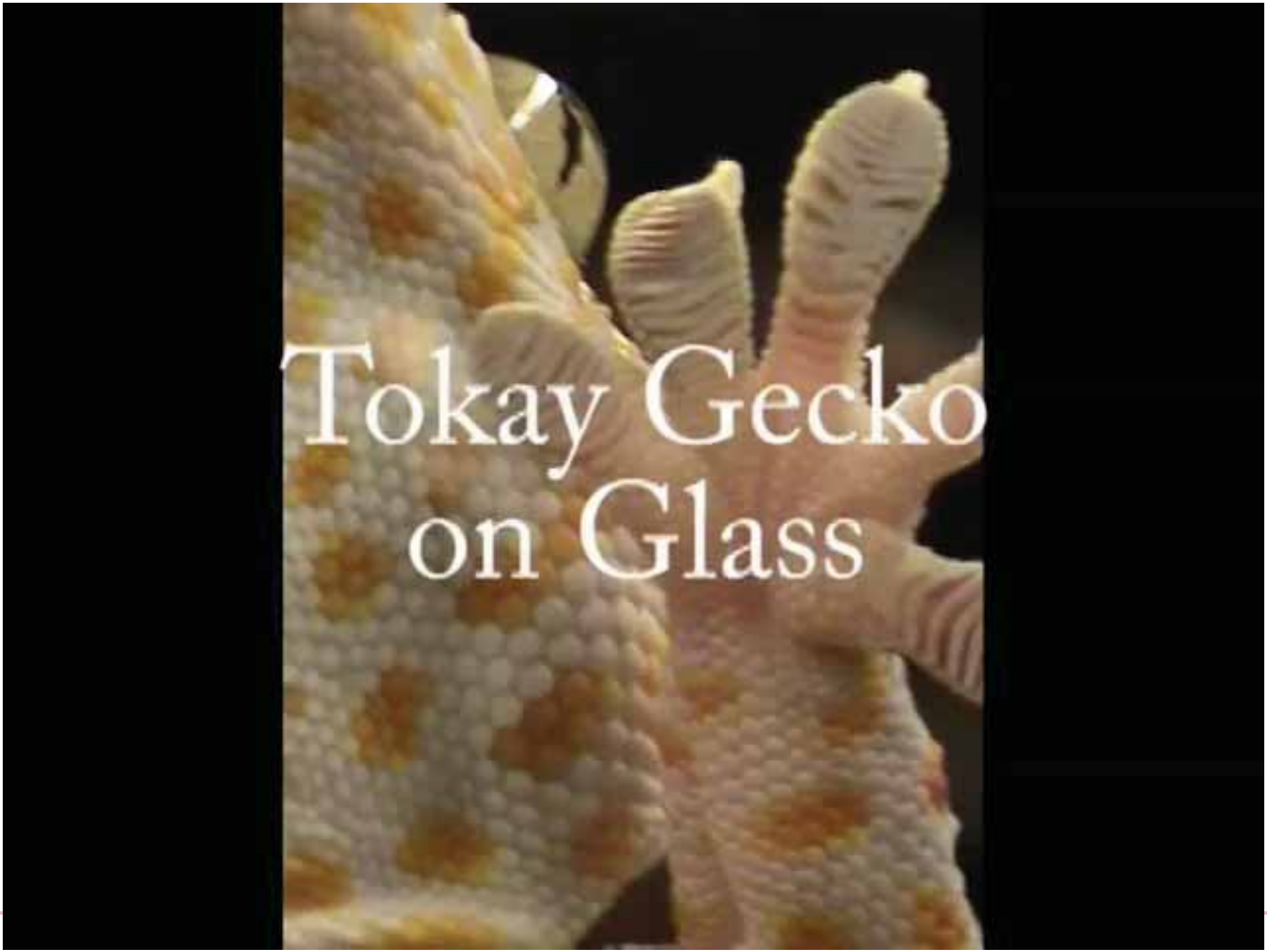


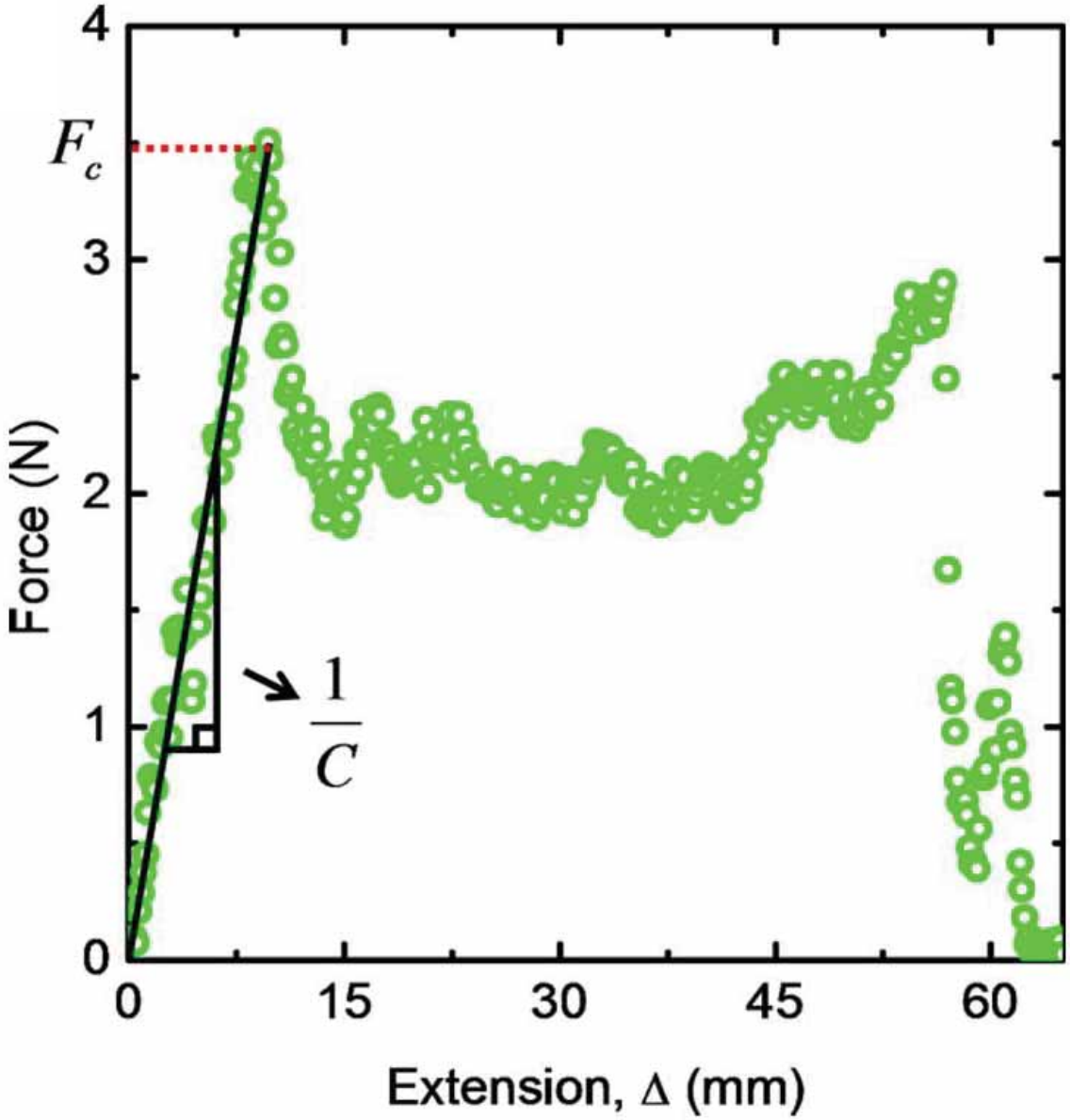
Irschick et al. 1996. Biol. J. Linn. Soc

??

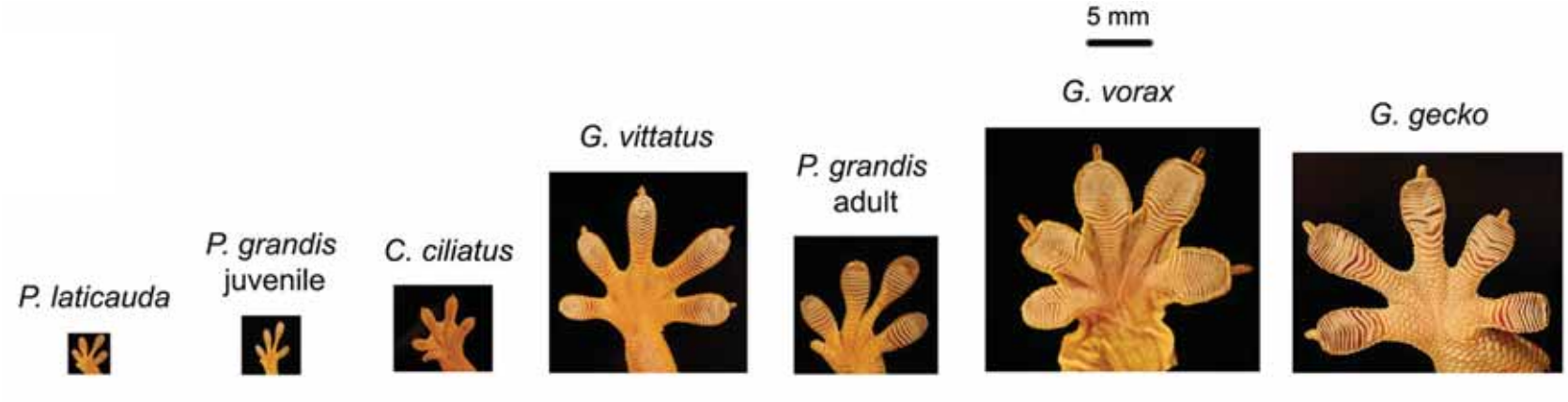
$$F_C = \sqrt{G_C}\sqrt{\frac{A}{C}}$$

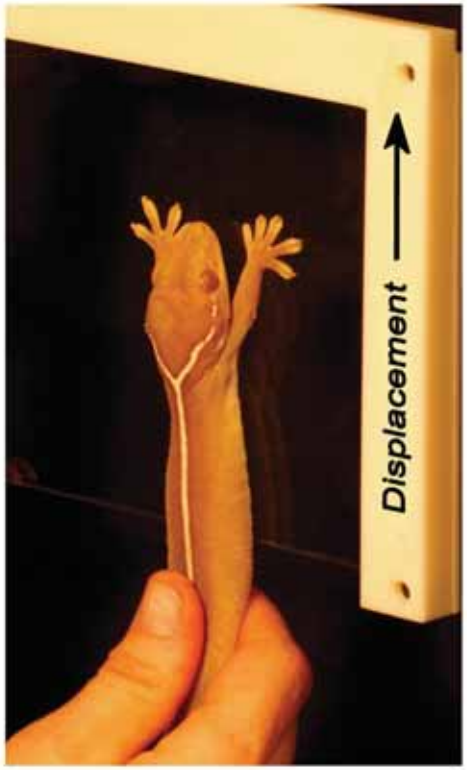
Stretching

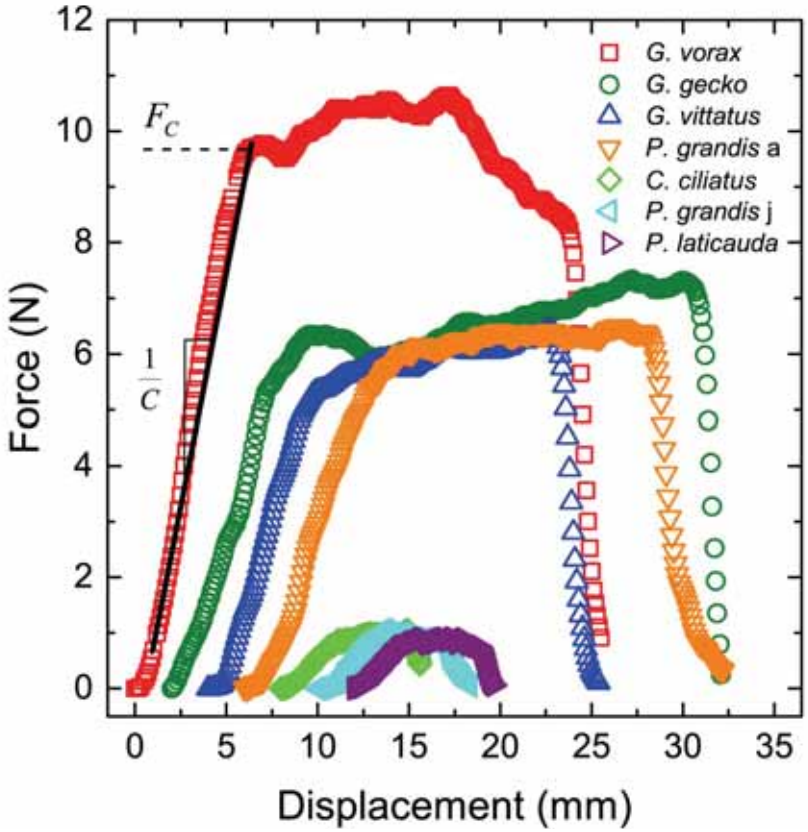



4
3
2
1
0
F_c
$\frac{1}{C}$
Force (N)
0
15
30
45
60
Extension, Δ (mm)

Measuring Performance Variation

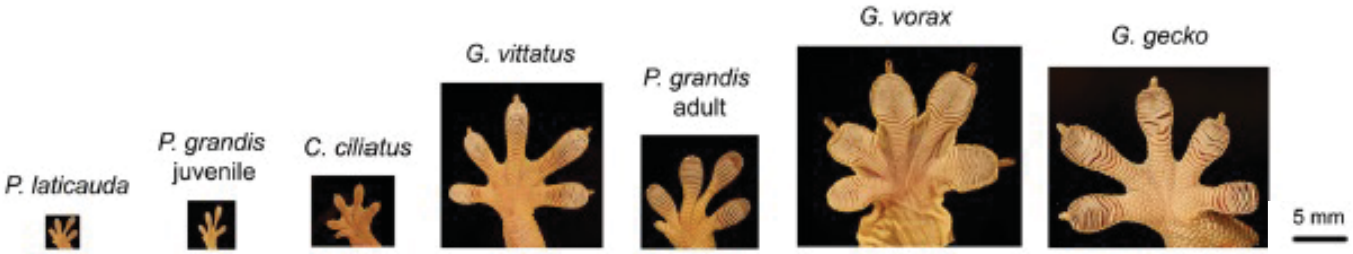


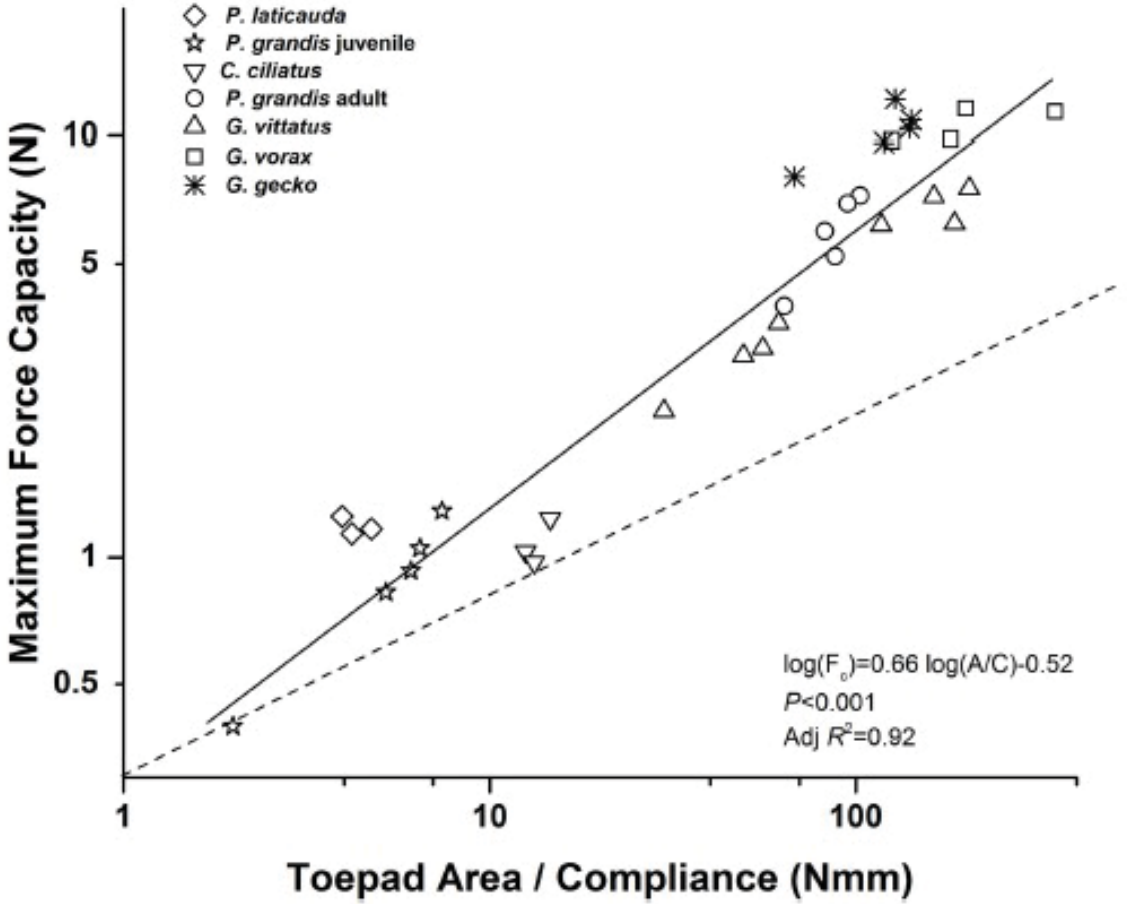


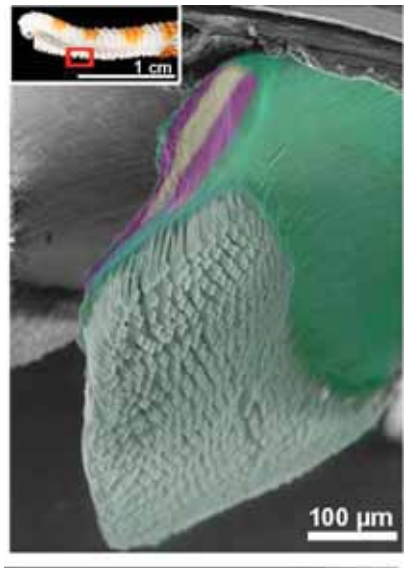


Gilman CA, Imburgia MJ, Bartlett MD, King DR, Crosby AJ, Irschick DJ *PLoS ONE*. 2015:10(9).

Scaling Across Species







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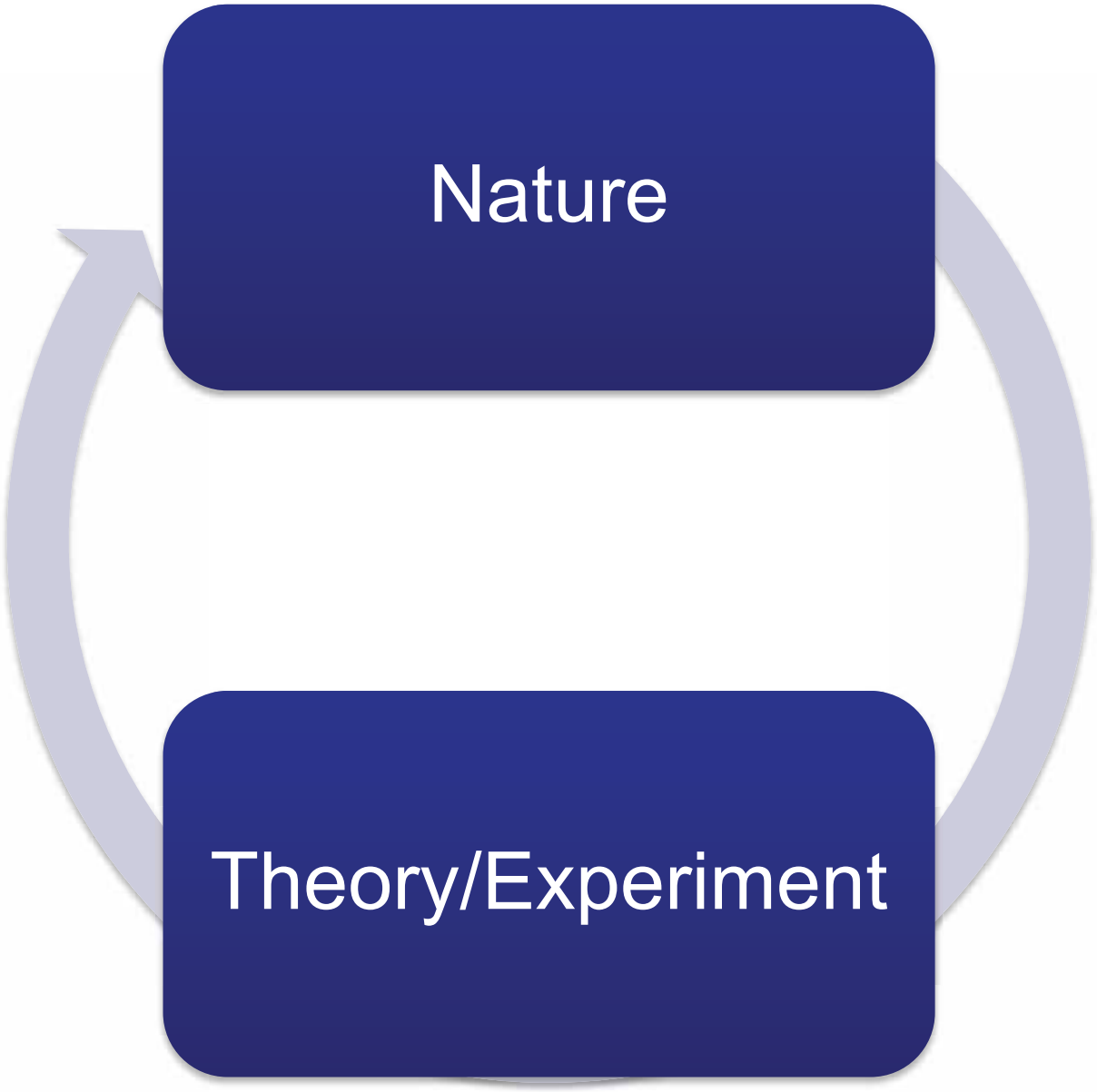
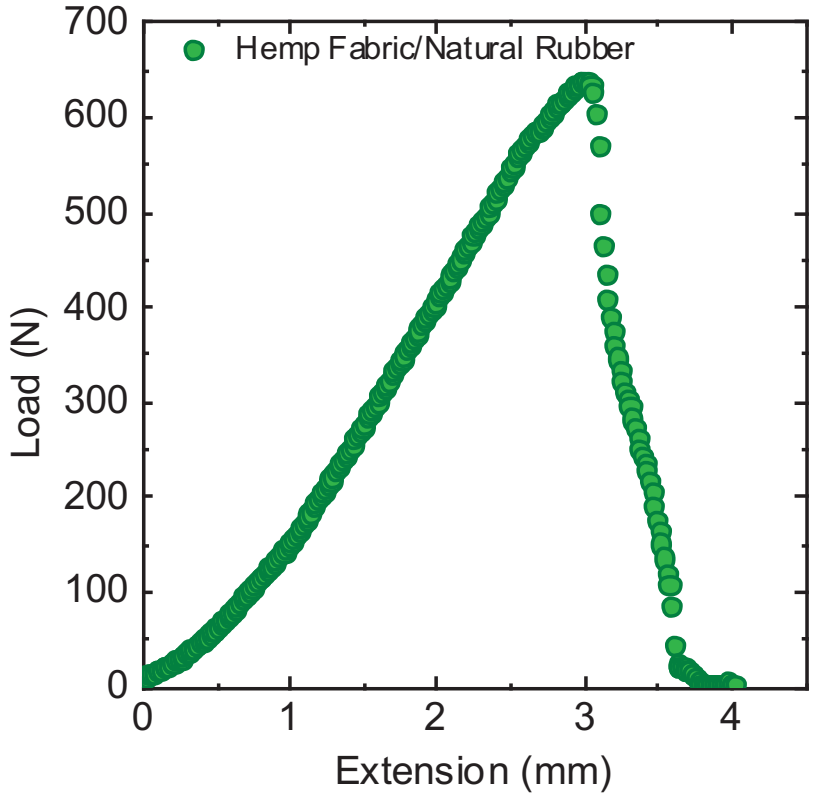
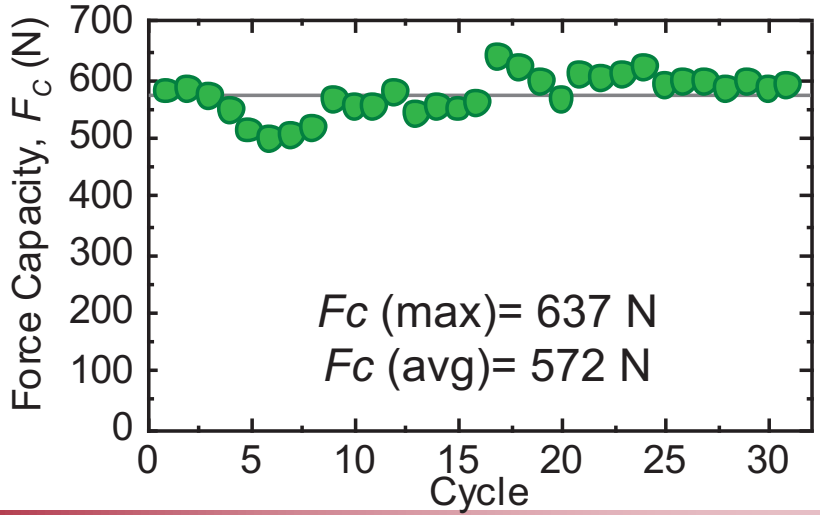

Nature
Theory/Experiment

Renewable Materials

Hemp

Natural Rubber



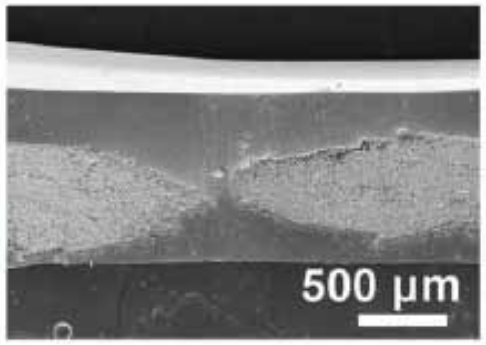


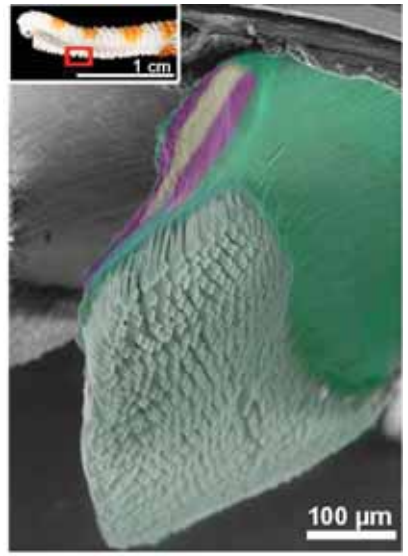
M.D. Bartlett, A.J. Crosby *Advanced Materials, 2014*

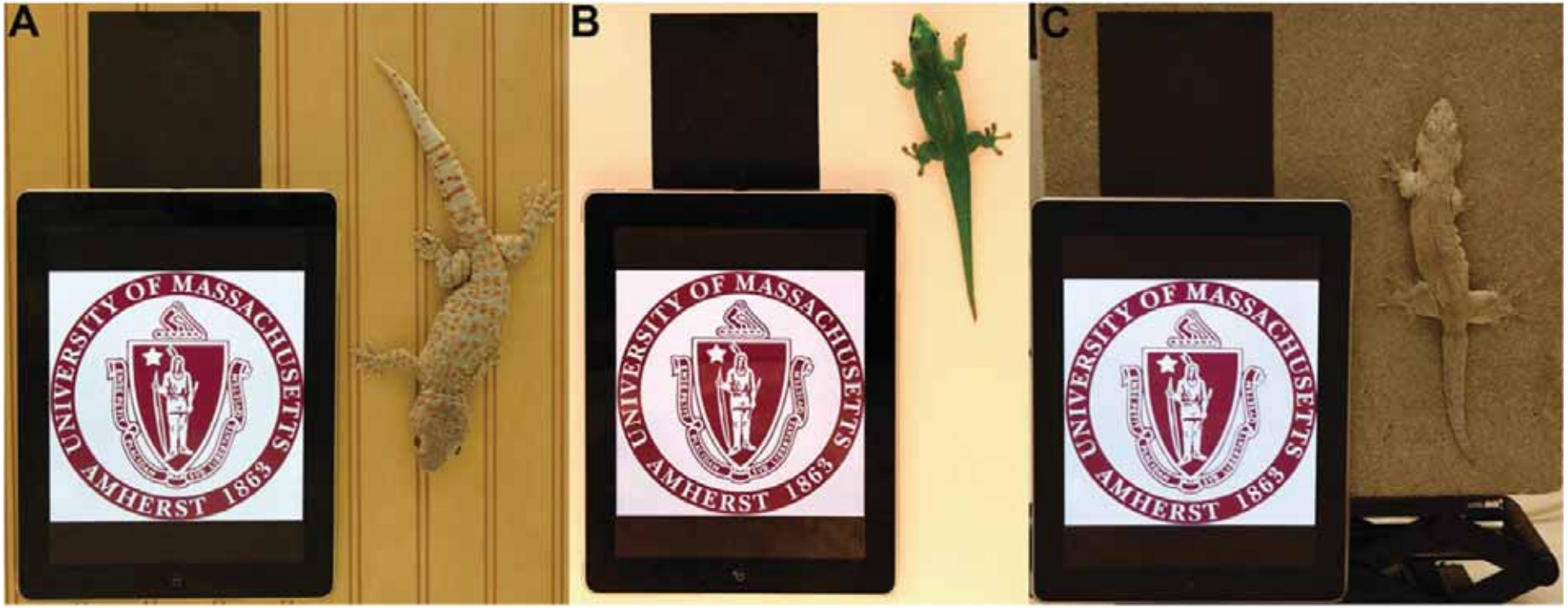
Final Thoughts on Bioinspiration

~ -1.50 x 10^8 years ~ -2.5 x 10^3 ~ -5 x 10^2 Today

Geckskin and Geckos







D.R. King et al *Advanced Materials*, 2014.

Acknowledgements

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DARPA

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Center for UMass Industry Research on Polymers

Felsuma, LLC was founded in April 2013 as a private entity to commercialize Geckskin™. Professor Crosby and Professor Irschick have a financial interest in Felsuma, LLC. A conflict of interest committee at the University of Massachusetts is established to manage potential conflicts.

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Duncan Irschick **Andrew Croll** **Mike Bartlett** **Dan King** **Mike Imburgia** **Beth Paret** **Satyan Choudhary**