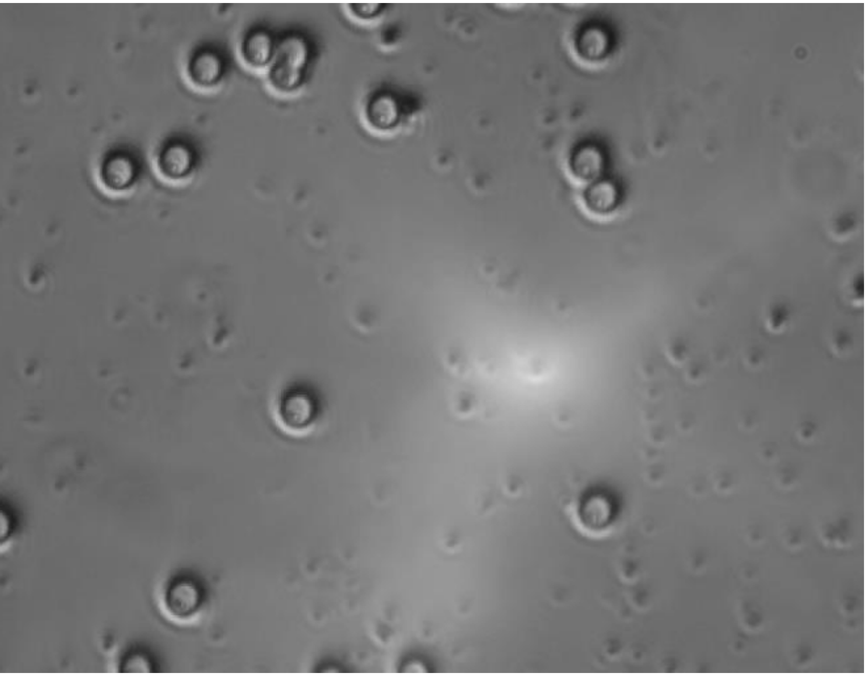
Reinventing the Introductory Physics Labs for Future Biologists

Wolfgang Losert
Department of Physics, University of Maryland

Director, UMD-NCI Partnership for Cancer Technology
Director, Biophysics Graduate Program



Kimberly A. Moore (PERG)

John Giannini (Biophys)

Kerstin Nordstrom (Phys)

NEXUS
NATIONAL EXPERIMENT in Undergraduate Science Education

UNIVERSITY OF MARYLAND 1856

HHMI

Biological Physics

- **Research –** Dynamics of Living Systems

- **Teaching –** with EF Redish and PERG

  new Intro Physics for Life Scientists Course & **Labs**

- **Integrating Teaching and Research**

  FIRE-299L

Dynamics of Living Systems Research Team

Julian Candia
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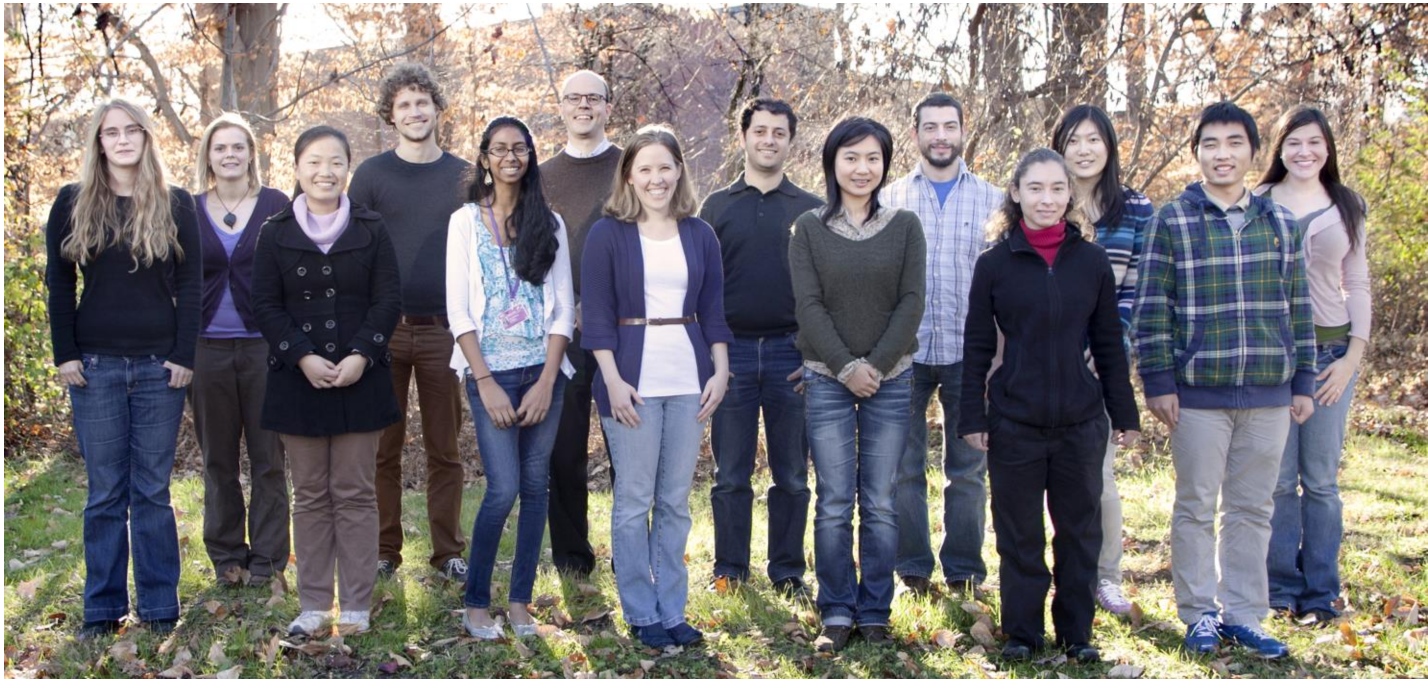
Matt Harrington
Deb. Hemingway
Rachel Lee
Kerstin Nordstrom
Eleanor Ory
Joshua Parker
Yang Shen
Xiaoyu Sun
Chenlu Wang



Undergraduates

Zeynep Karakas
Sima Koolaee
Michael Lin
Zeshan Tariq
Jaclyn Weisz

Collaborators

Carole Parent *(NCI)*
John Fourkas
Helim Aranda-Espinoza
Jayanth Banavar
Curt Civin *(Med School)*
Kan Cao
Anders Carlsson *(WashU)*
Joy Dunkers *(NIST)*
Michelle Girvan
SK Gupta
Josef Kaes *(Leipzig)*
Amos Maritan *(Padua)*
Stuart Martin *(Med School)*
Alex Morozov *(Rutgers)*
Bob Nussenblatt *(NIH)*
Ed Ott
Joe Redish
Kandice Tanner *(NCI)*

NSF
NATIONAL INSTITUTES OF HEALTH
NIST

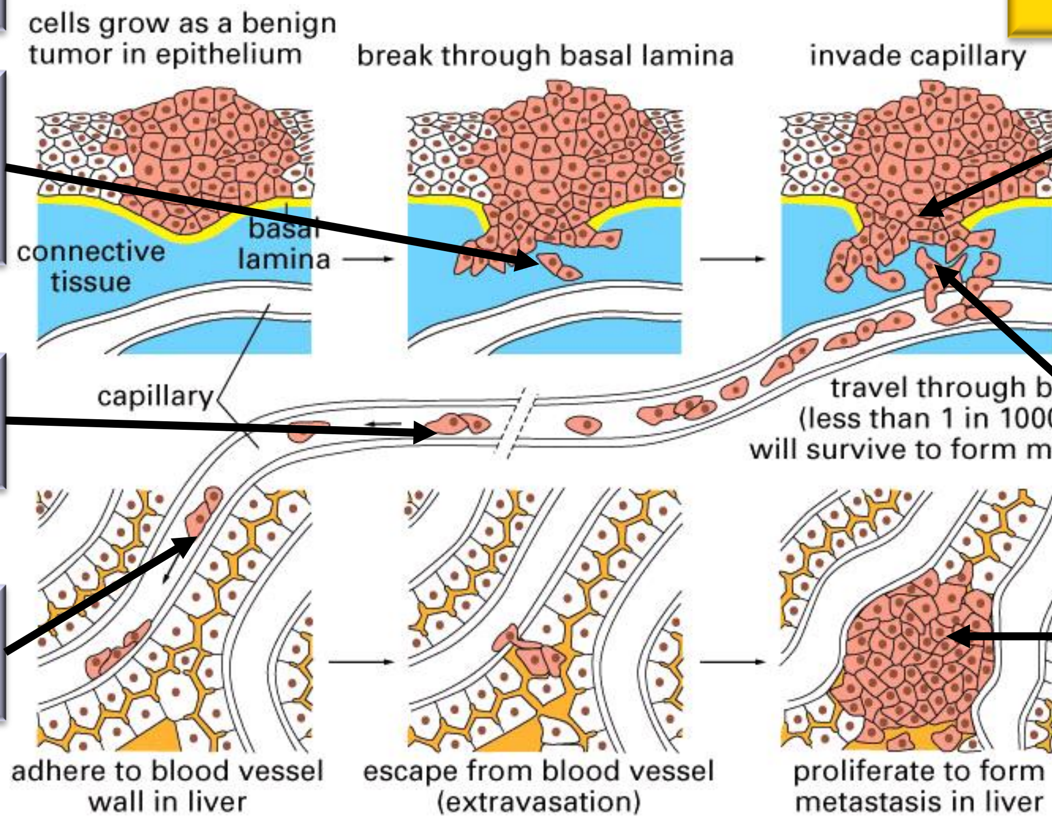
Physics of Cancer Metastasis

Physical Constraints on Metastasis

Cancer cells generate forces & migrate

Cells are deformed by fluid forces

Cells adhere to blood vessel walls



Using Physics Tools for Phenotyping

Characteristic Shapes

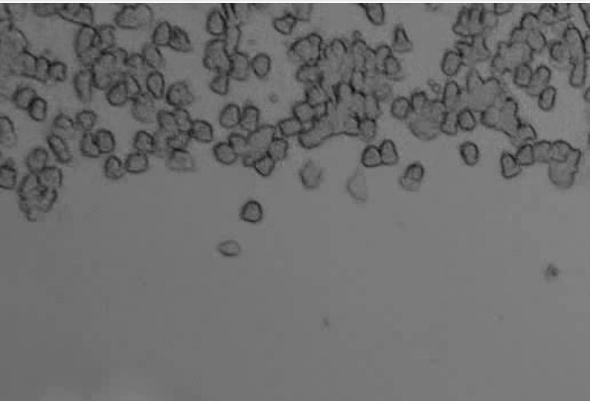
Characteristic Dynamics

Population Statistics

Alberts, B. et al. Molecular Biology of the Cell p. 1325 (2002)

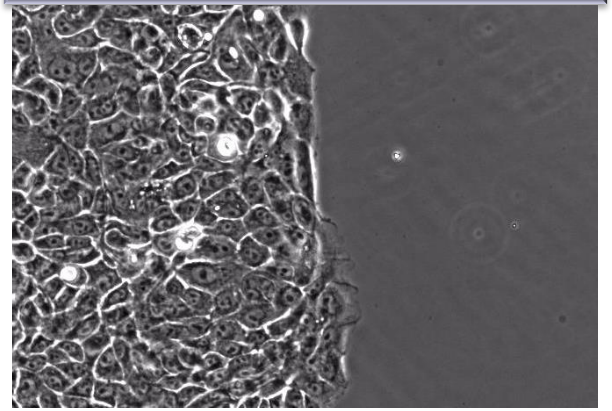
Our Focus: Cell Migration

Immune Response
(white blood cells)



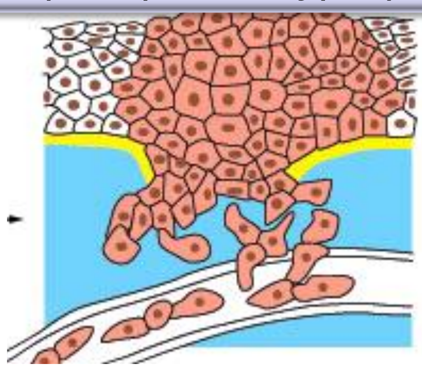
L. Liu, S. Das, W. Losert, & CA. Parent *Dev. Cell* (2010)

Wound Healing
(epithelial cells)



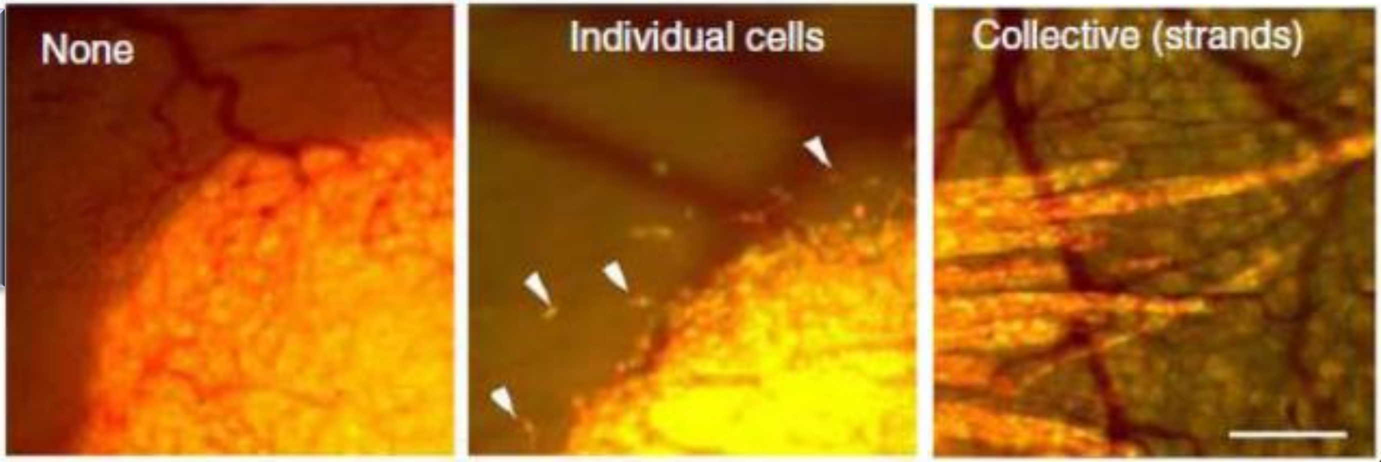
MC. Weiger, …W.Losert, & CA Parent, *PLOS ONE* (2013).

Cancer Cell Migration
(multiple cell types)



Alberts, B. et al. (2002)

In-Situ Imaging of Tumor Growth and Spreading in a Living Mouse

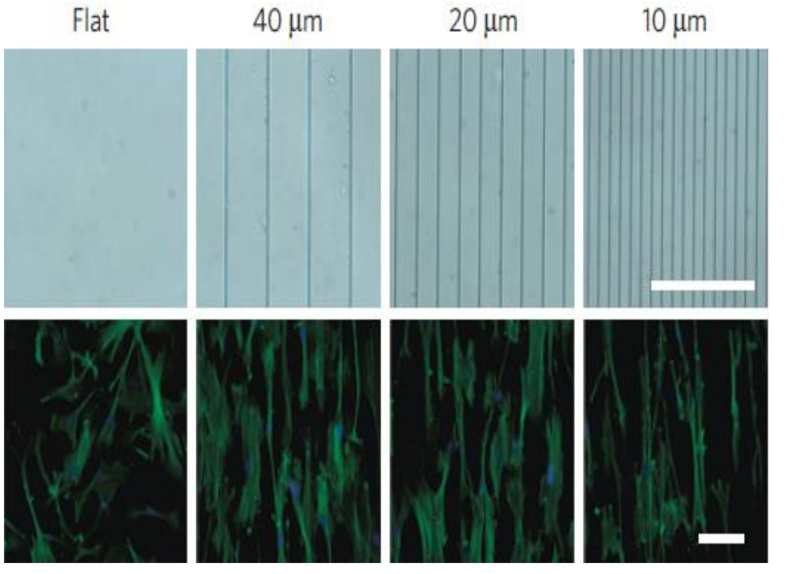


Alexander, Koehl, et al. Histochemistry and Cell Biology(2008).

Physical Context of Metastatic Migration Confinement and Topography

Confinement affects migration

Topography drives Reprogramming

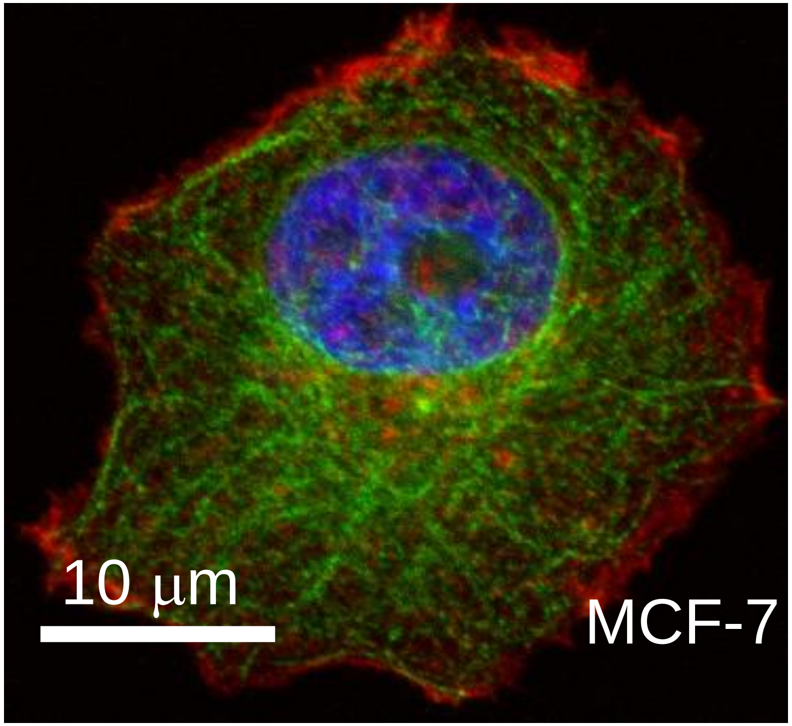


Downing et al, . Nature Materials (2013)

Peter Friedl).

How do cells sense their surrounding on scales much larger than proteins?

Structural Elements

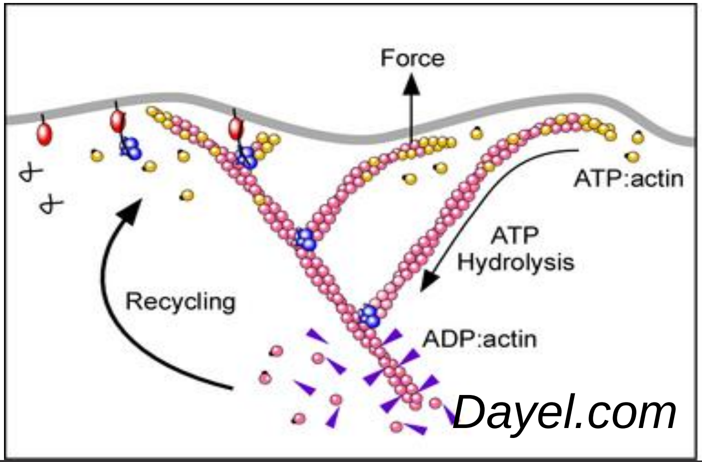


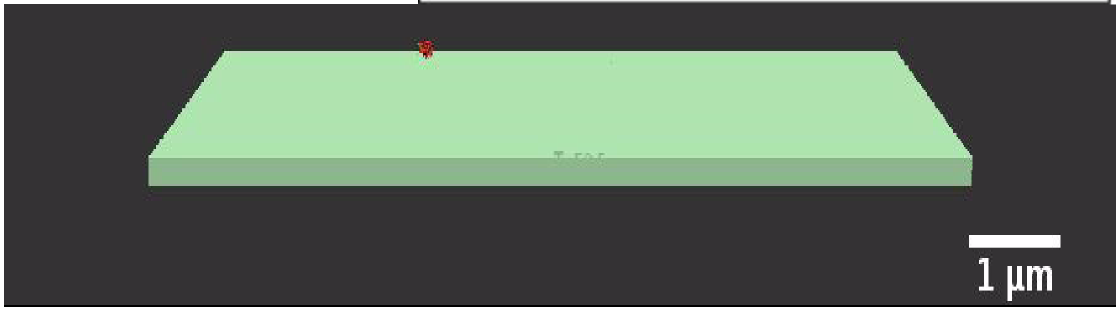
Scaffolding of

- **Actin,**
- **Microtubules,**
- Intermediate Filaments

Active Elements

Scaffolding **nucleates**, **grows**, and **dissolves**

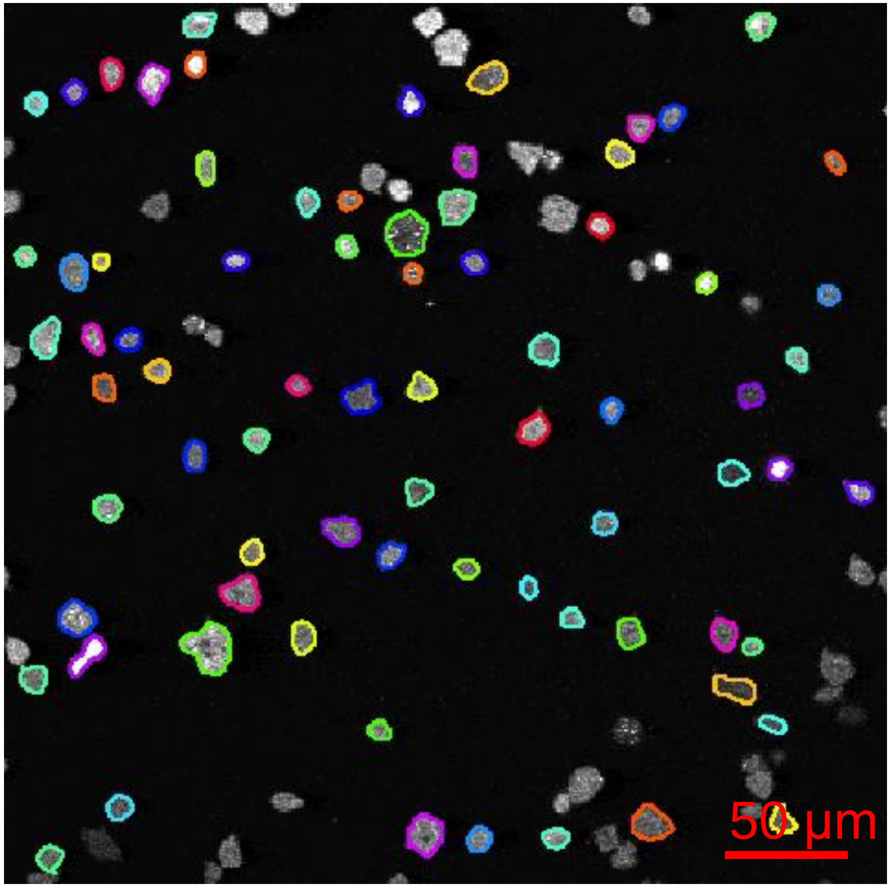


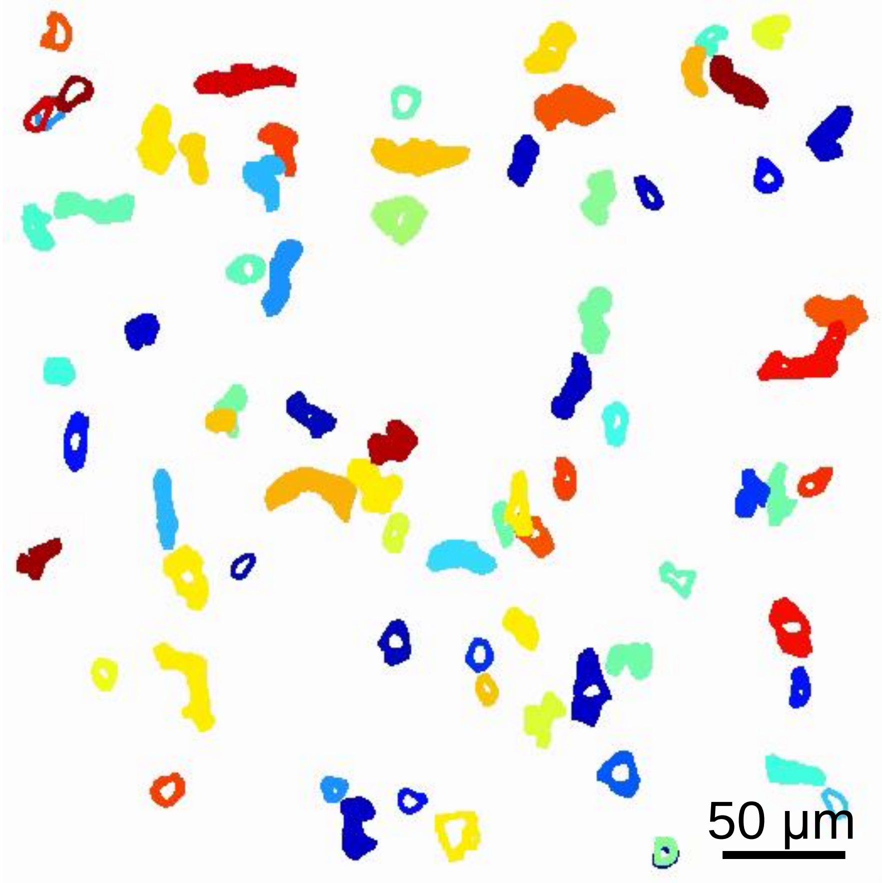


Simulations of Actin Waves w/
Anders Carlsson (WashU)

Joshua Parker

Systematic Analysis of Shape Dynamics





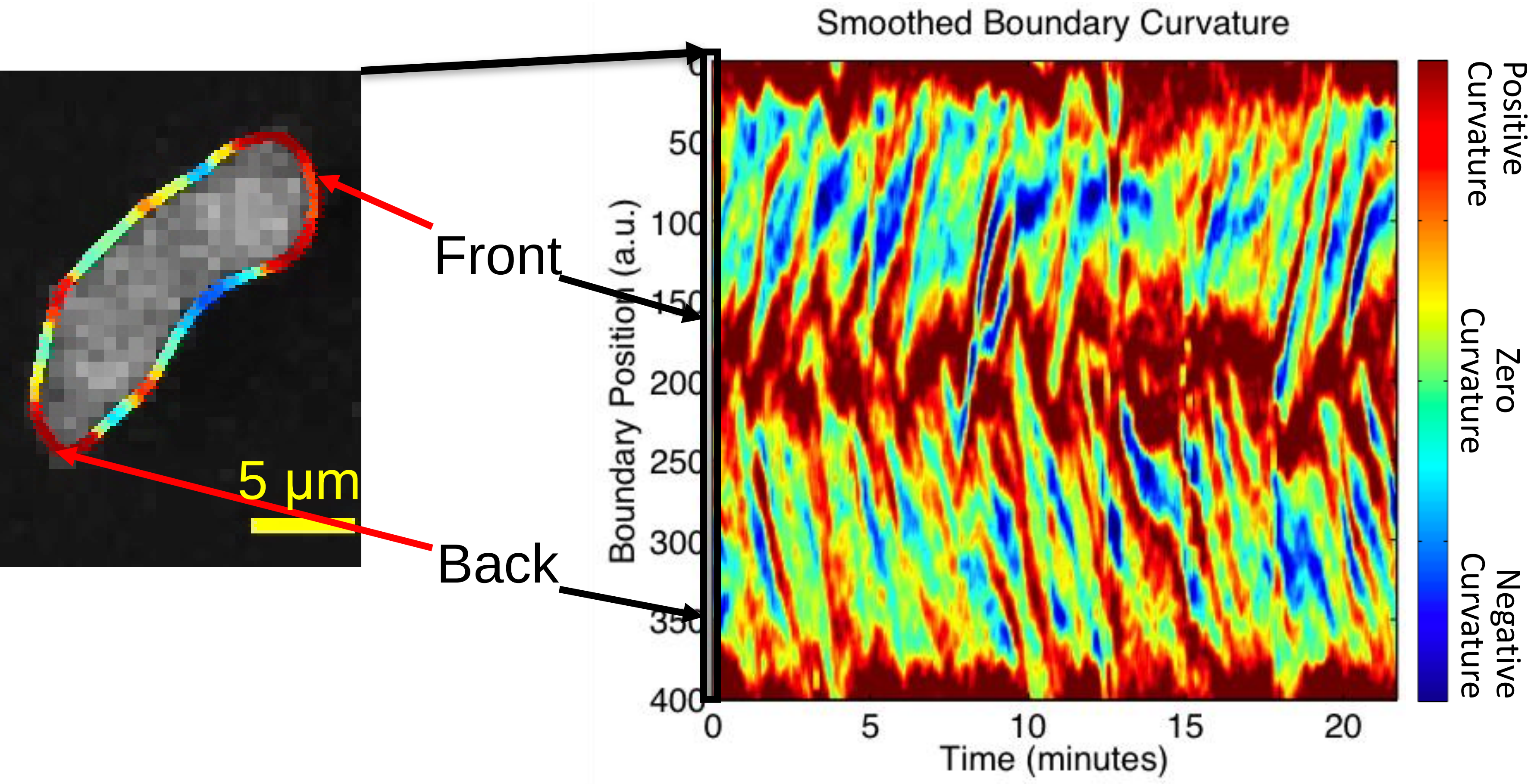
Meghan Driscoll

100 frames; 6.7 minutes

One Movie: 71,700 shapes in 922 tracks (1200 frames; 80 minutes)

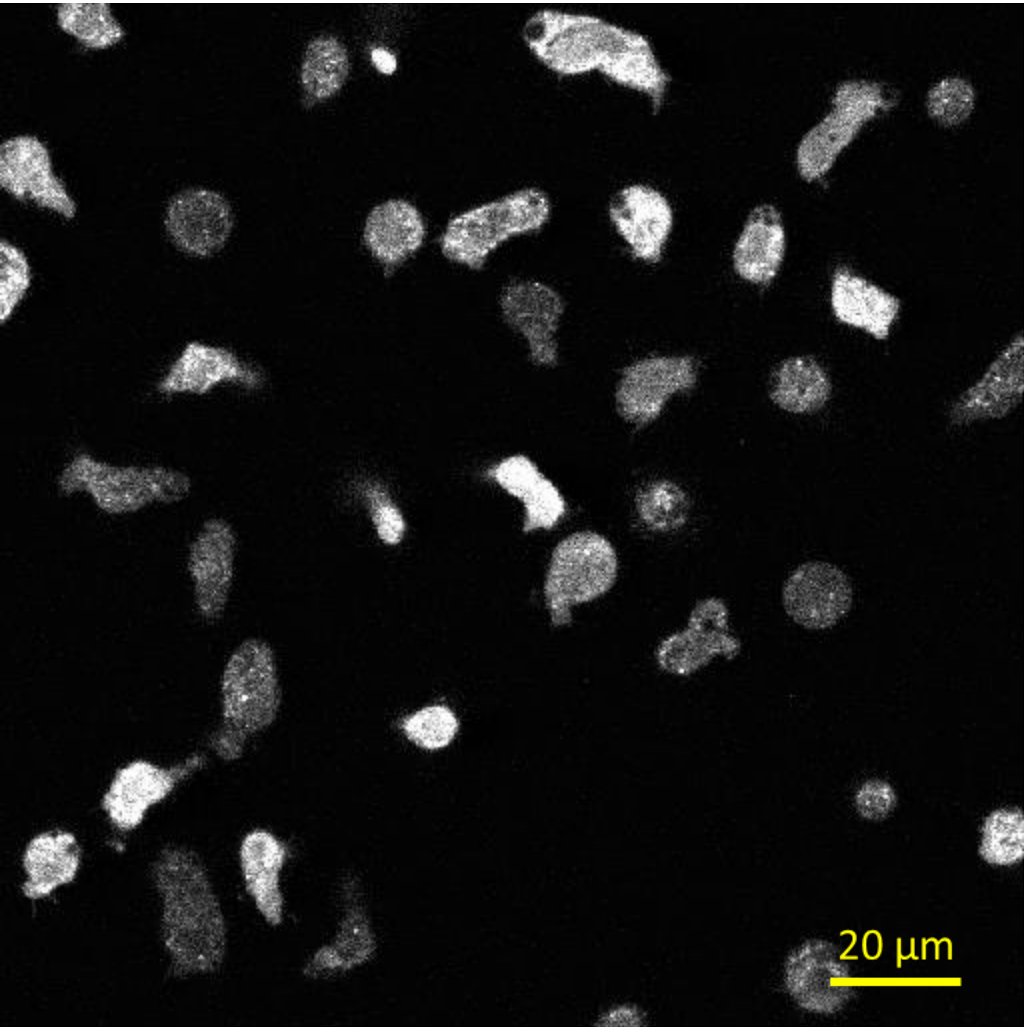
Driscoll et al., *PLOS Comp. Biol.* (2012)

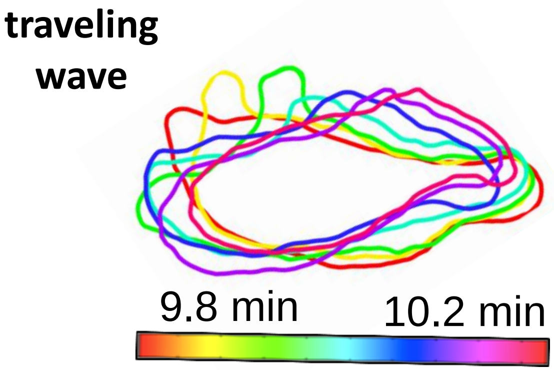
Local Shape Dynamics Reveal Shape Waves

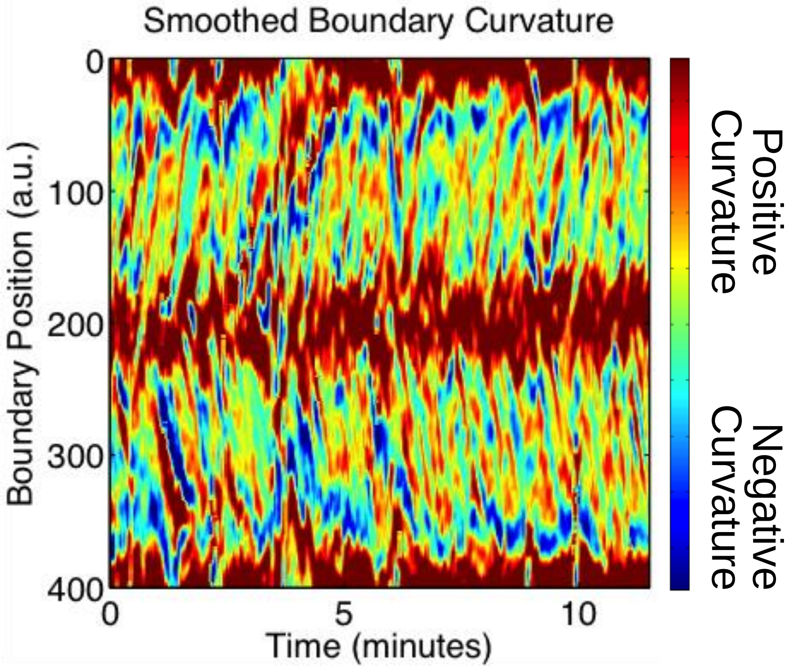


Driscoll, Fourkas and Losert, *Physical Biology* (2011)

Inhibiting Cell-Surface Adhesion Enhances Visibility of Shape Waves

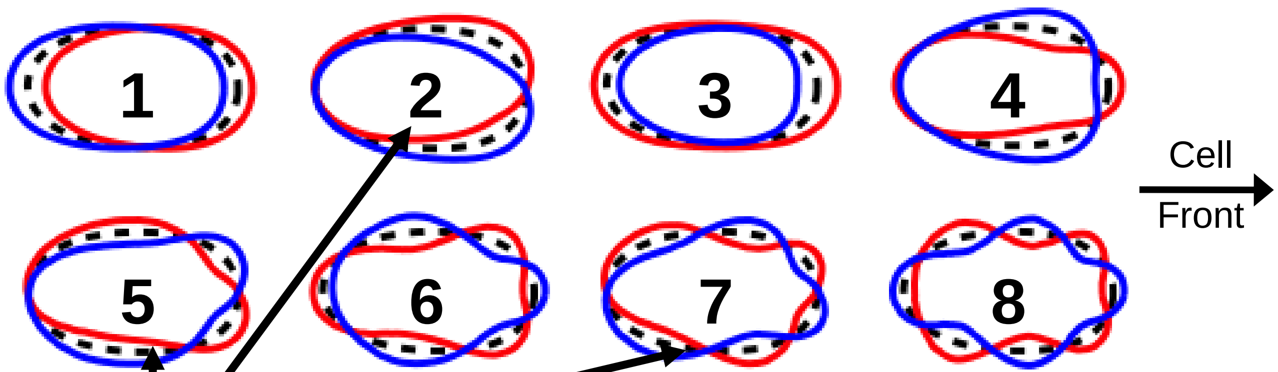




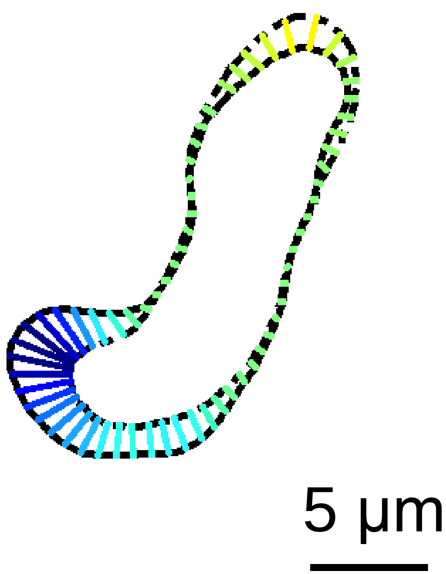


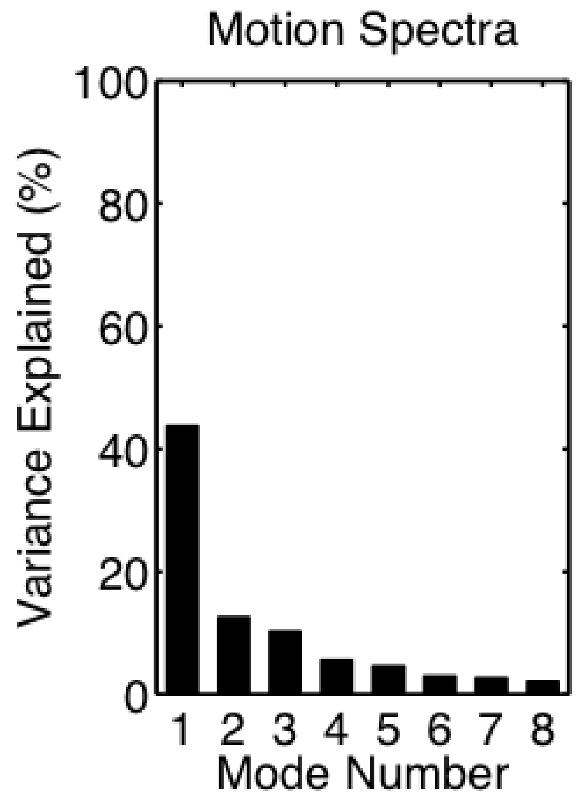
Driscoll et al *PLOS Comp Biol* (2012)

Principal Component Analysis of Protrusions



Turning Modes

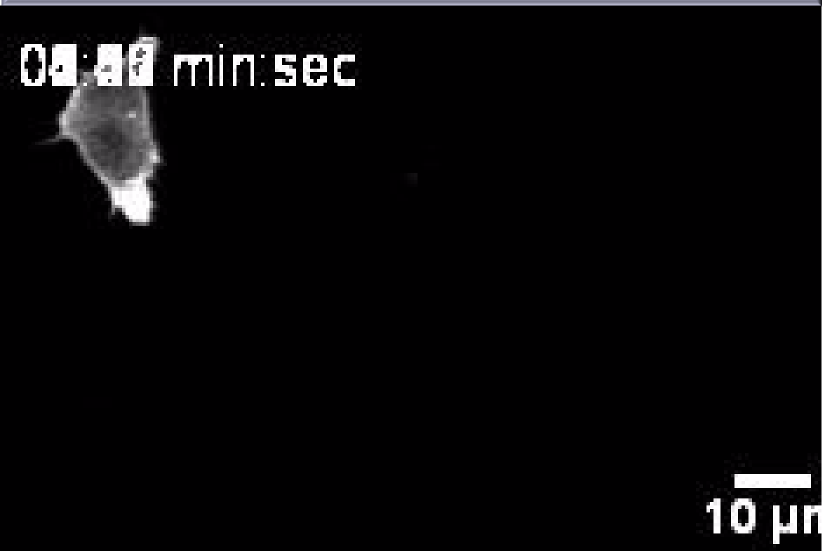


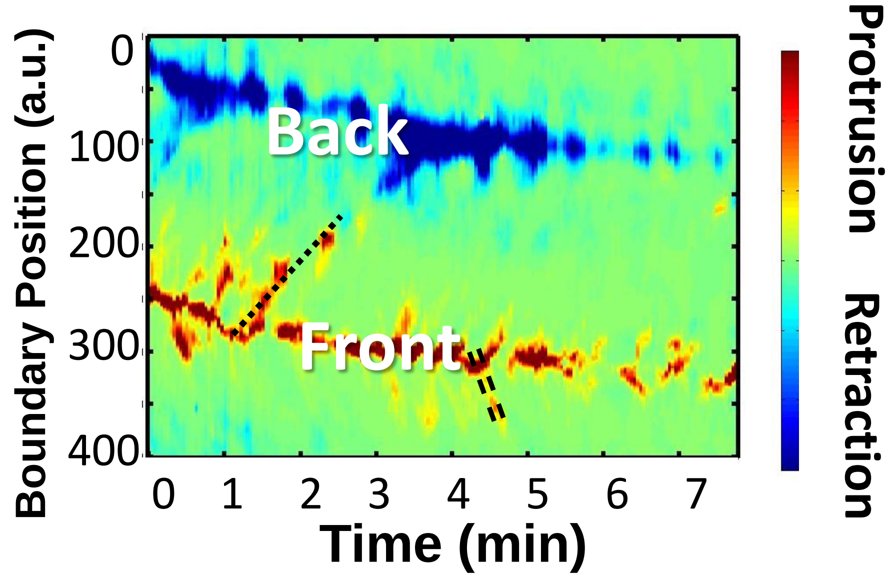


M. Driscoll et al, *ACS Nano (2014)*

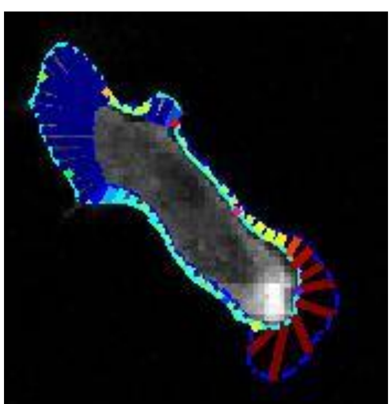
Protrusions Correlate with Actin Waves

Actin Waves

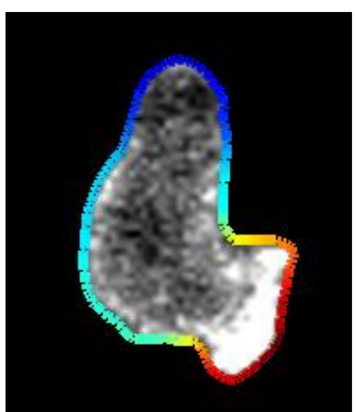


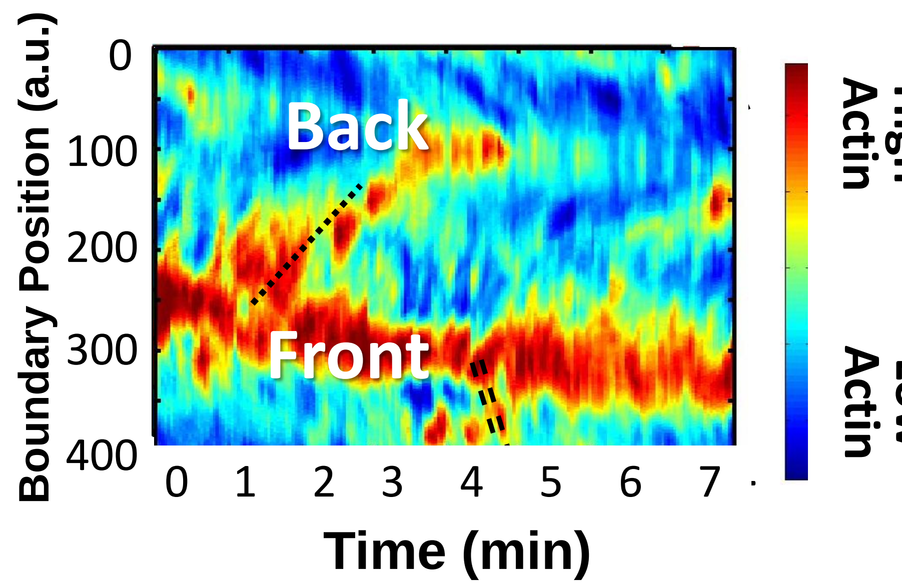


Protrusions



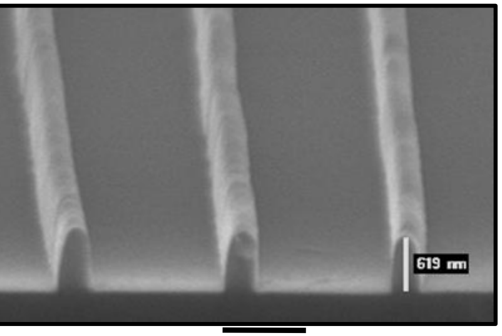
Actin

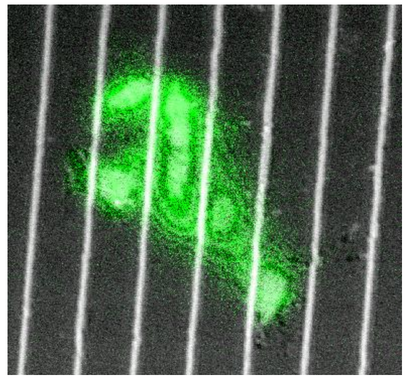


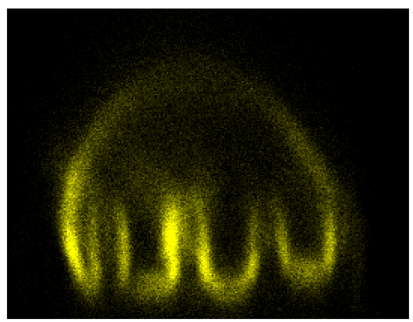


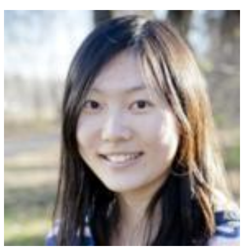
Dictyostelium Cells Guided by Bioinspired Nanotopography

Bioinspired Nanotopograph



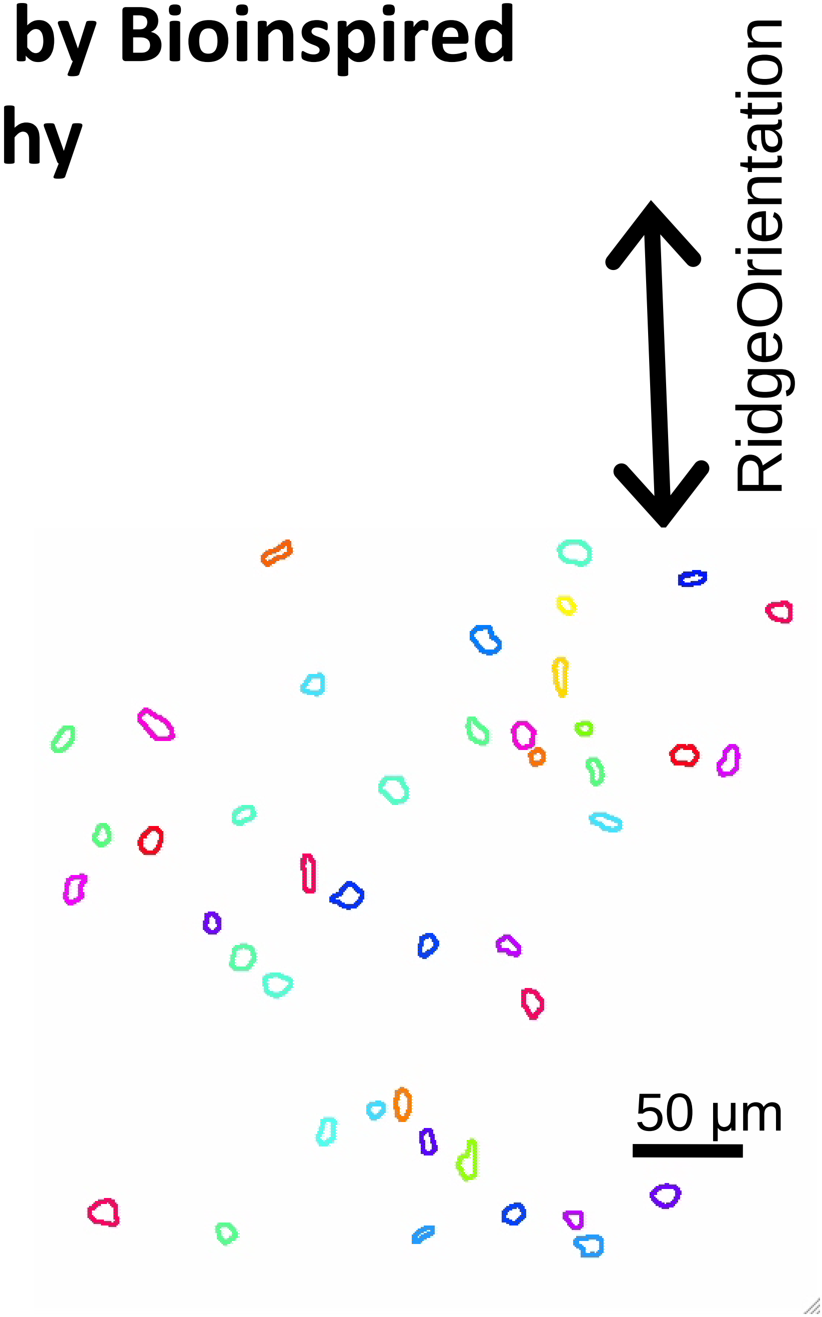






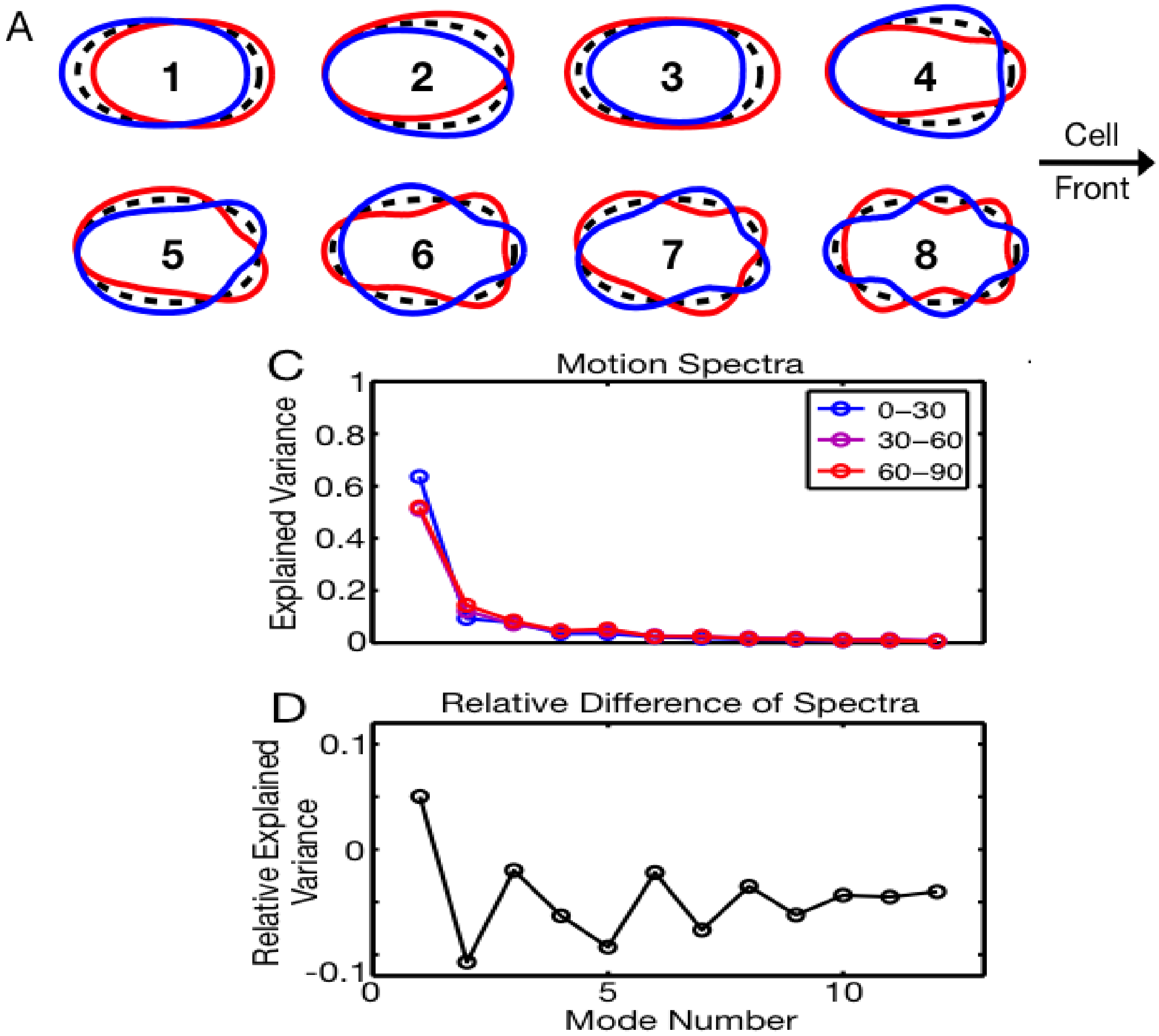
Xiaoyu Sun

Meghan Driscoll



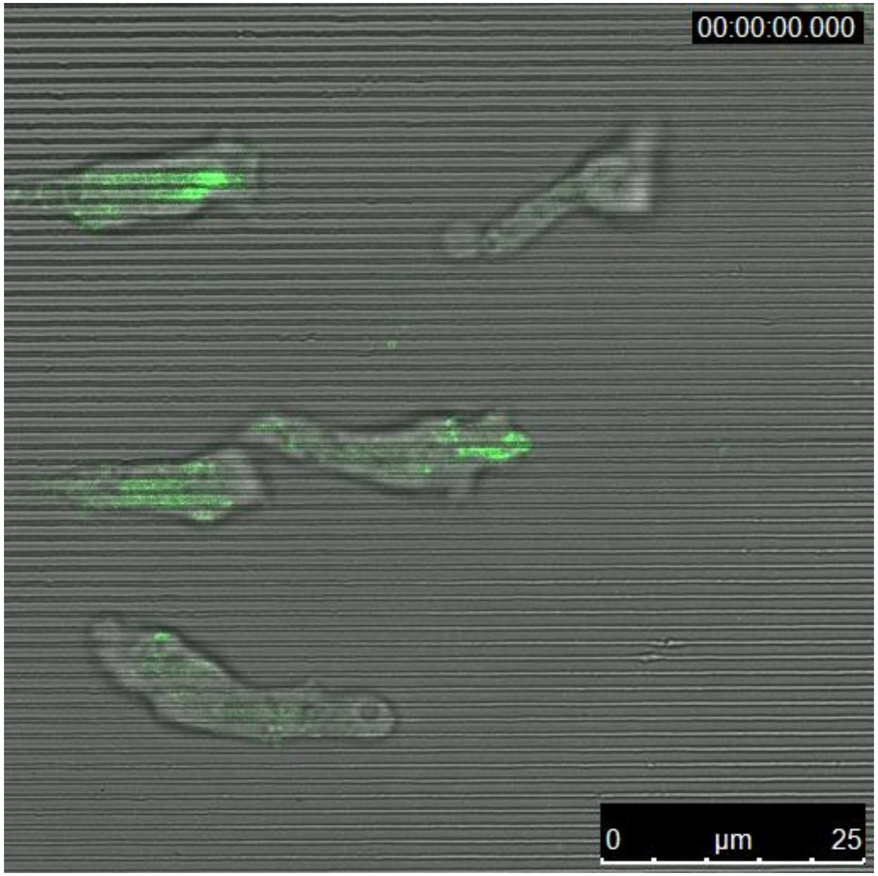
M. Driscoll et al, *ACS Nano (2014)*

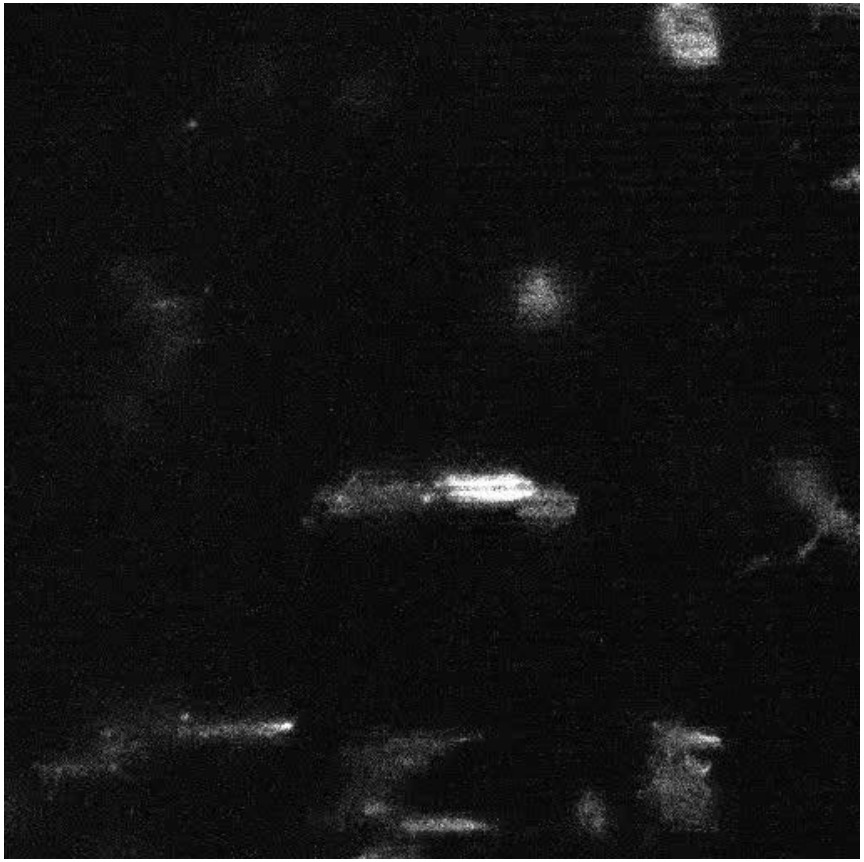
Principal Component Analysis on Ridges



M. Driscoll et al, *ACS Nano (2014)*

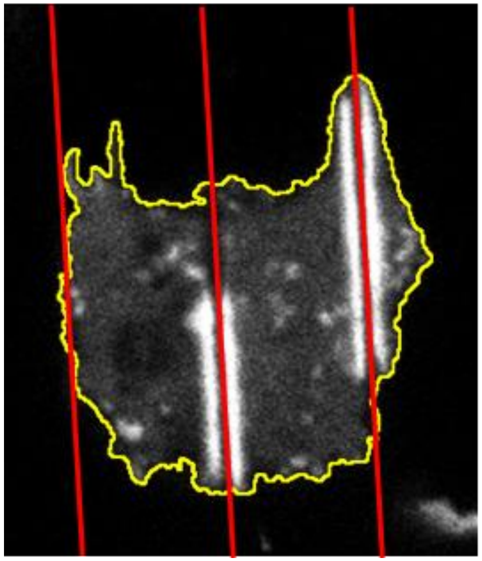
Actin Waves Travel Along Ridges



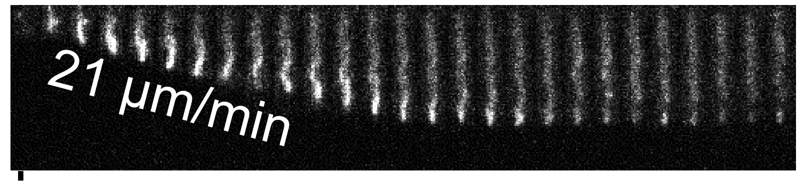


Quantifying Waves of Actin Polymerization

5 µm ridges

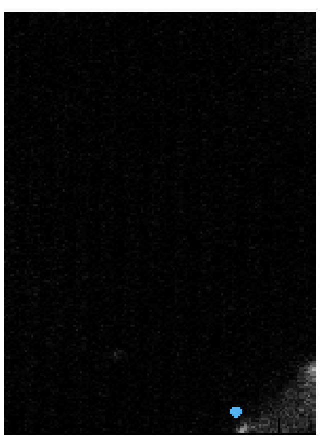


kymograph – actin waves
(vertical scale 16.3 µm)

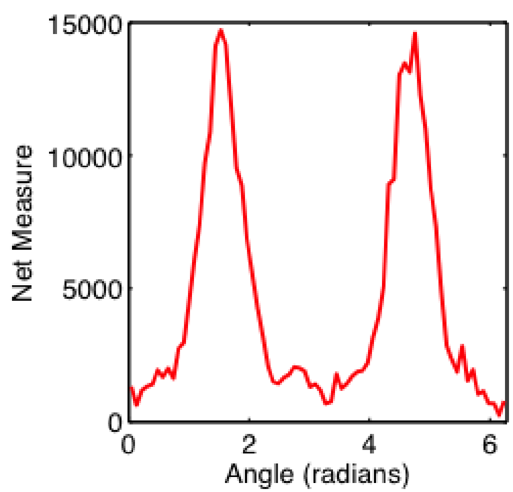


time →

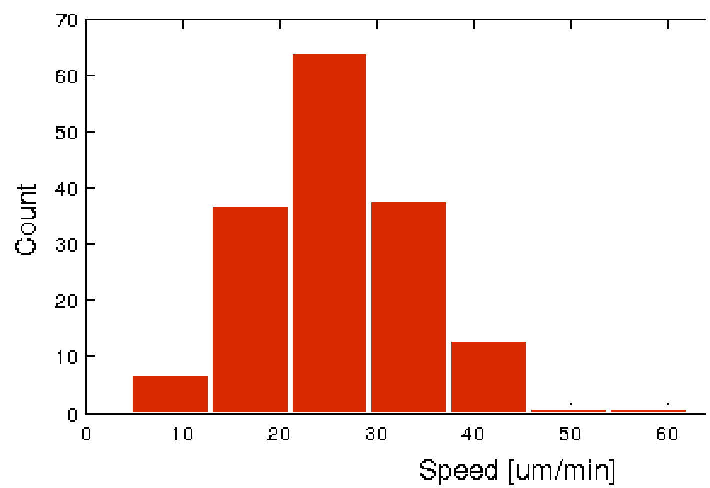
Tracking Waves



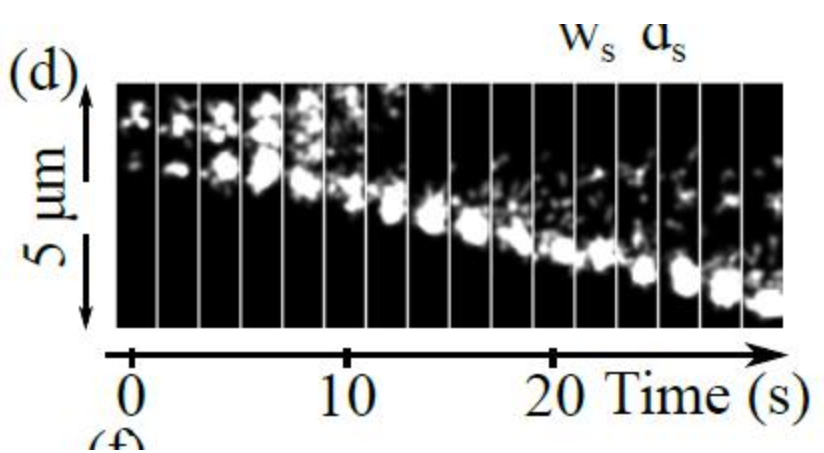
Wave Direction

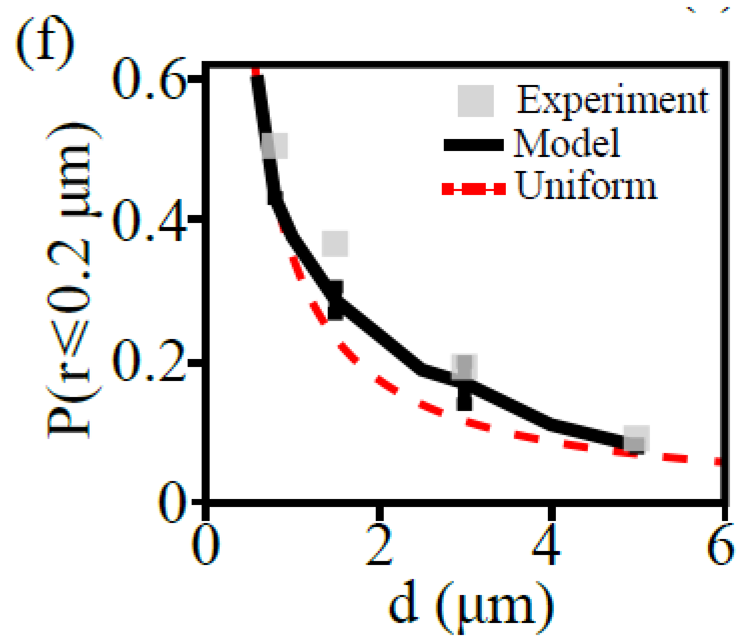


Wave Speed



Simulating Actin Dynamics





C. Guven et al, *to be submitted (2014)*

Biological Physics

- **Research –** Dynamics of Living Systems

- **Teaching –** with EF Redish and PERG

  new Intro Physics for Life Scientists Course & **Labs**

- **Integrating Teaching and Research**

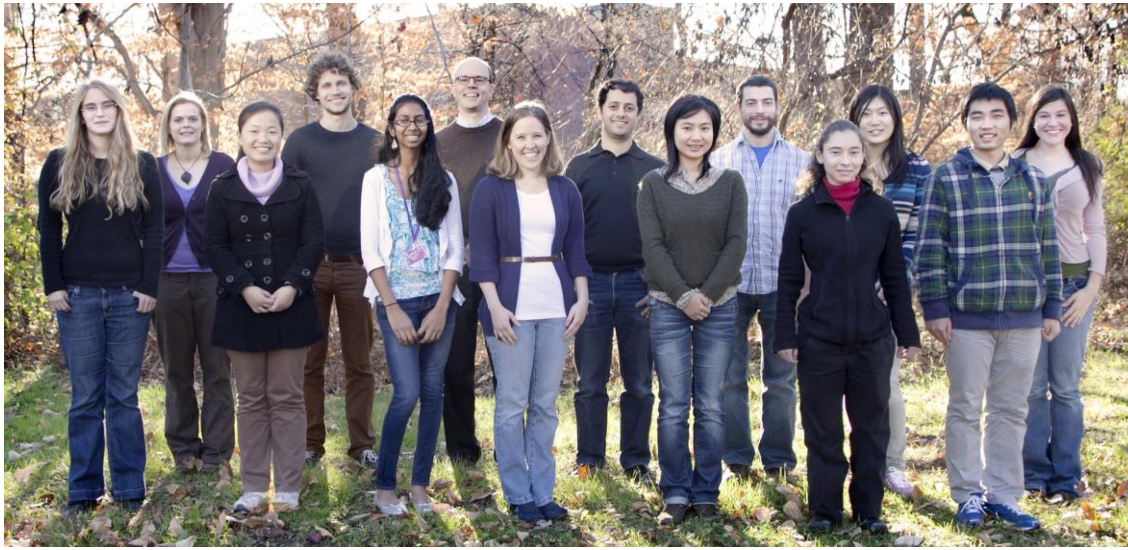
  FIRE-299L

Reinventing the Introductory Physics Labs (& Course) for Future Biologists

Physics Education

Joe Redish
Todd Cooke
Karen Carleton
Ben Dreyfus
Ben Geller
Julia Gouvea
Kim Moore
Vashti Sawtelle

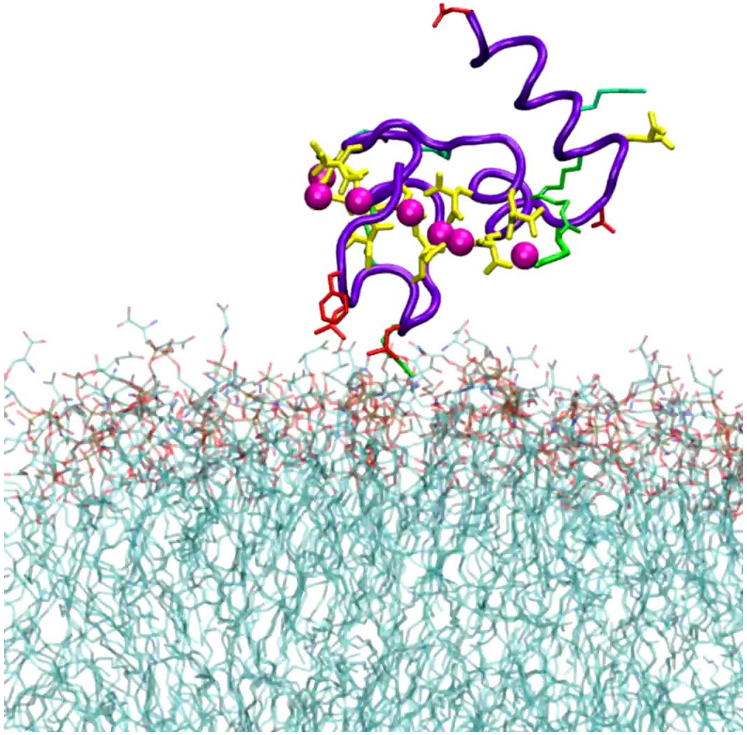
Biodynamics Research Lab



Joshua Parker – TA in 2011/2012
John Giannini – Lab Development 3 semesters
Kim Moore – Lab Development/ TA 2012-2014
Kerstin Nordstrom – Lab Refinements 2014

NEW in the Lab (and Course): (1) Topical Shift

Physics @ Biological Scales: Example: Forces and motion



Blood Clotting Protein on Membrane, Molecular Dynamics Simulation
Ohkubo & Tajkhorshid, *Structure* 2008.

NEW in the Lab (Course): (2) Pedagogy Shift

Pedagogy Encourages Student Sensemaking

- Flipped classes with wiki pre-reading.
- Community-style labs.
- Interdisciplinary Dialogue.
  - Can you gain biological insights by measuring speed or another physical quantity?
  - Are Newton’s laws useful to understand proteins, membranes, and cells?

Aims of Lab Development

- Build on Successful Community Lab Concept
  - Provide hands-on experience with relevant physics concepts
    - *Focus on Sensemaking*
  - Develop student research skills
    - *Focus on Experimental Design*

<u>Additional Goals of our Labs:</u>

- Convey a modern view of physics
- Foster interdisciplinary transfer
  - *"What biology do you learn from a physical measurement?"*
- Help students toward their career goals

Can we achieve these additional goals without sacrificing the success of the Community Labs?

Modern Instruments & Analysis Tools

Inverted Microscope (2K$)

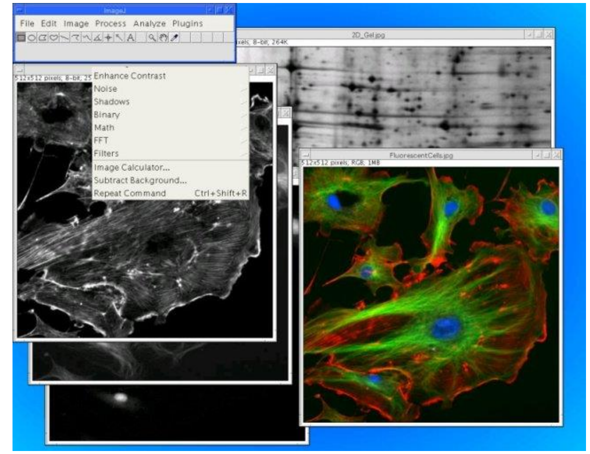
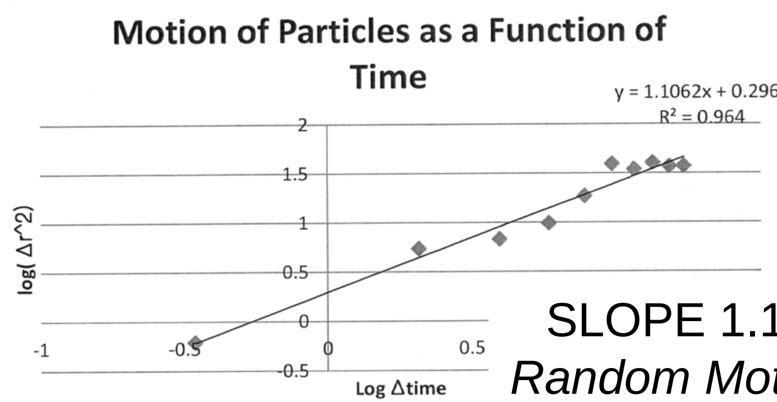


Image J (free)

Spectrometer (1.3K$)



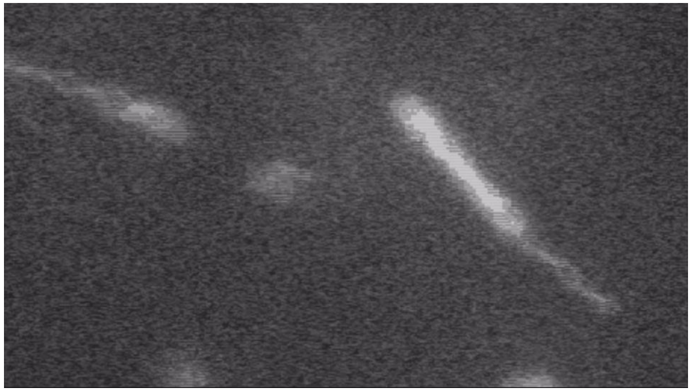
SLOPE 1.1

Random Motion

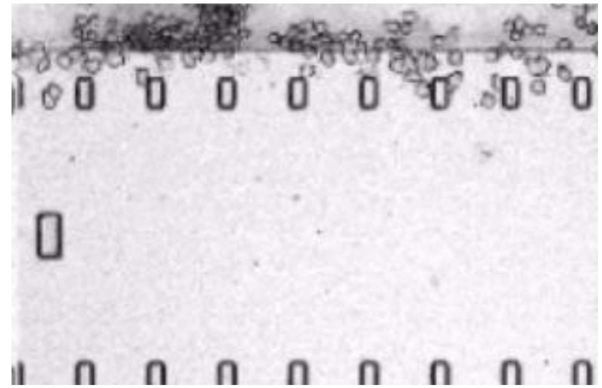
Modern Representations: Log-log plot

First Lab

Quantifying motion from Images and Videos (2 weeks)

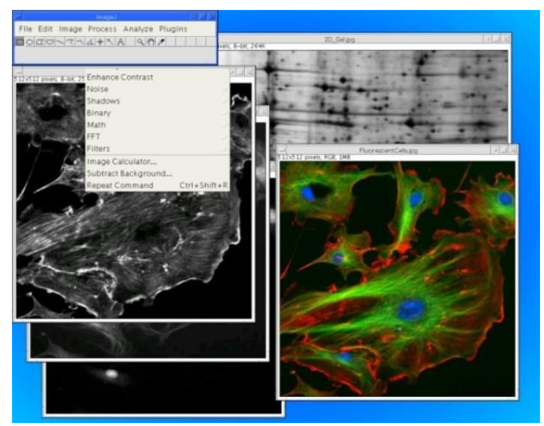


Bacteria



White blood cells

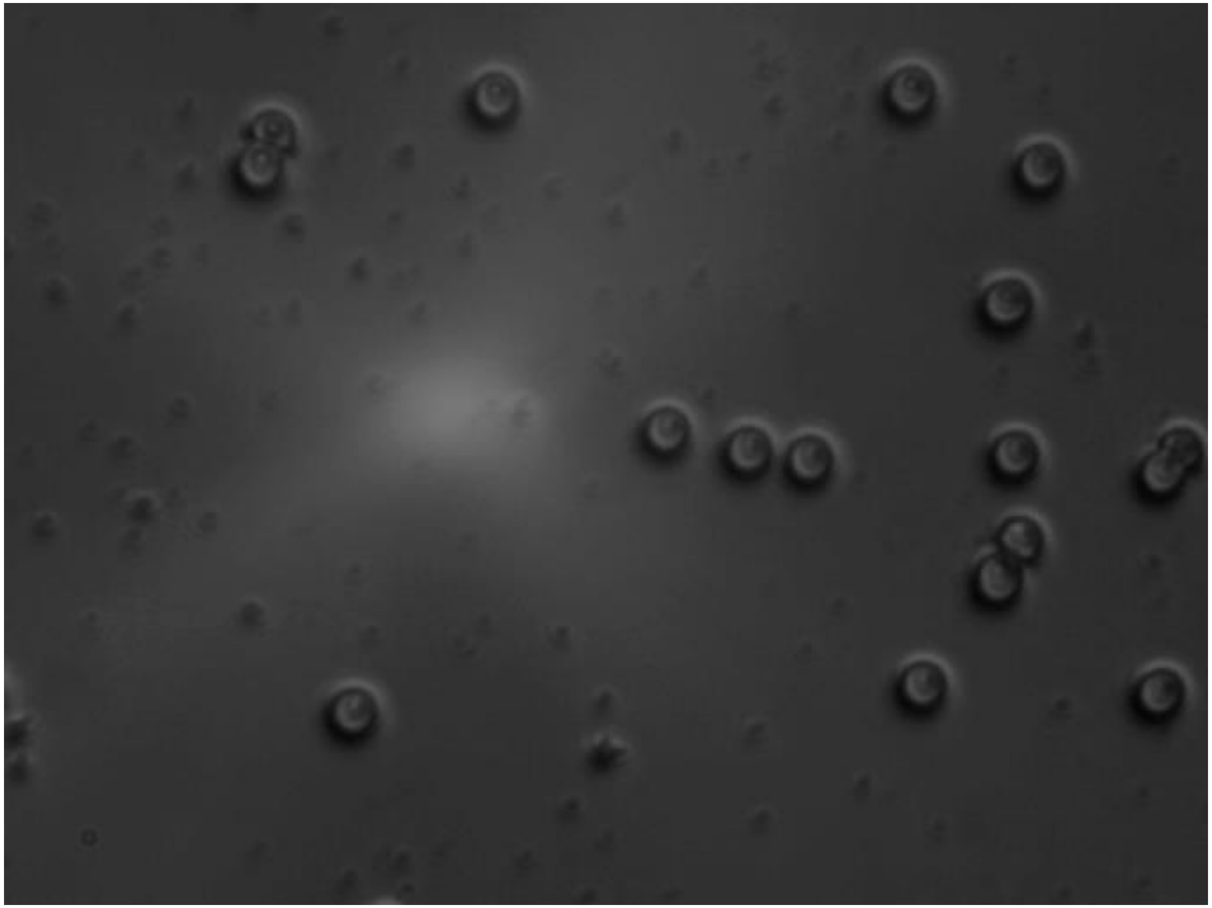
- *Analysis of cell motion*
  *using Excel and **ImageJ**.*



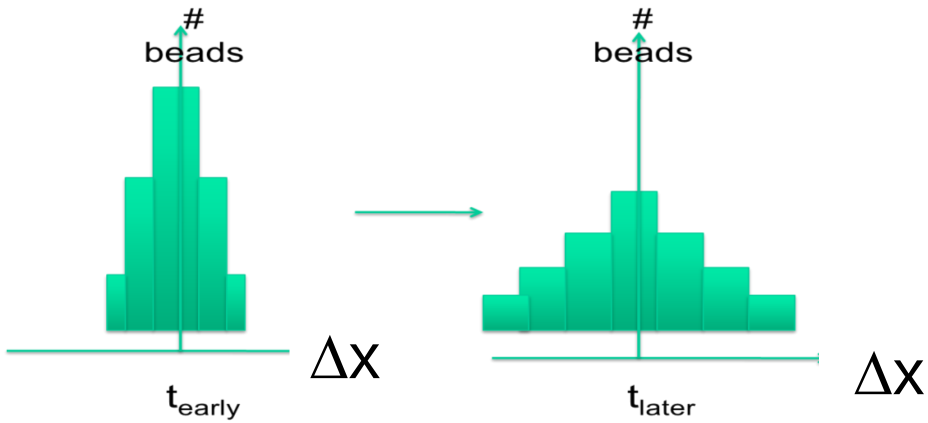
- *Fostering Interdisciplinary Transfer:*
  Can you learn any biology from physical measurements?

EXAMPLE:
Brownian Motion

Inspired by laboratories developed by Mark Reeves (GW)
Mix of 1 and 5 micron beads, observed under the microscope

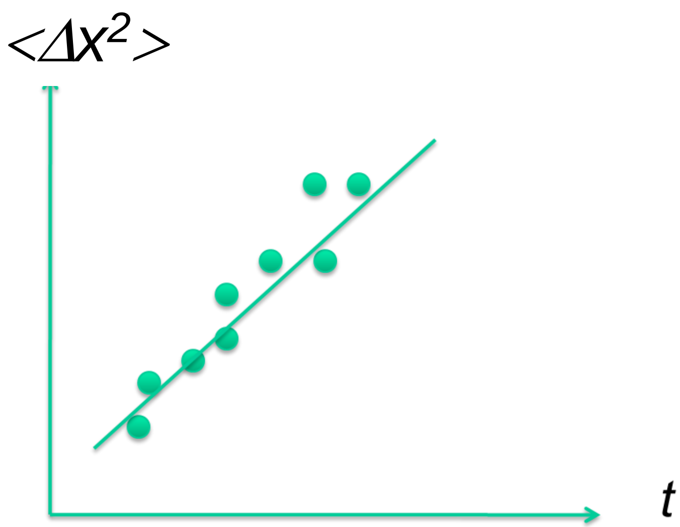


Measuring Brownian Motion



$\langle \Delta x \rangle = 0$

$\langle \Delta x \rangle = 0$



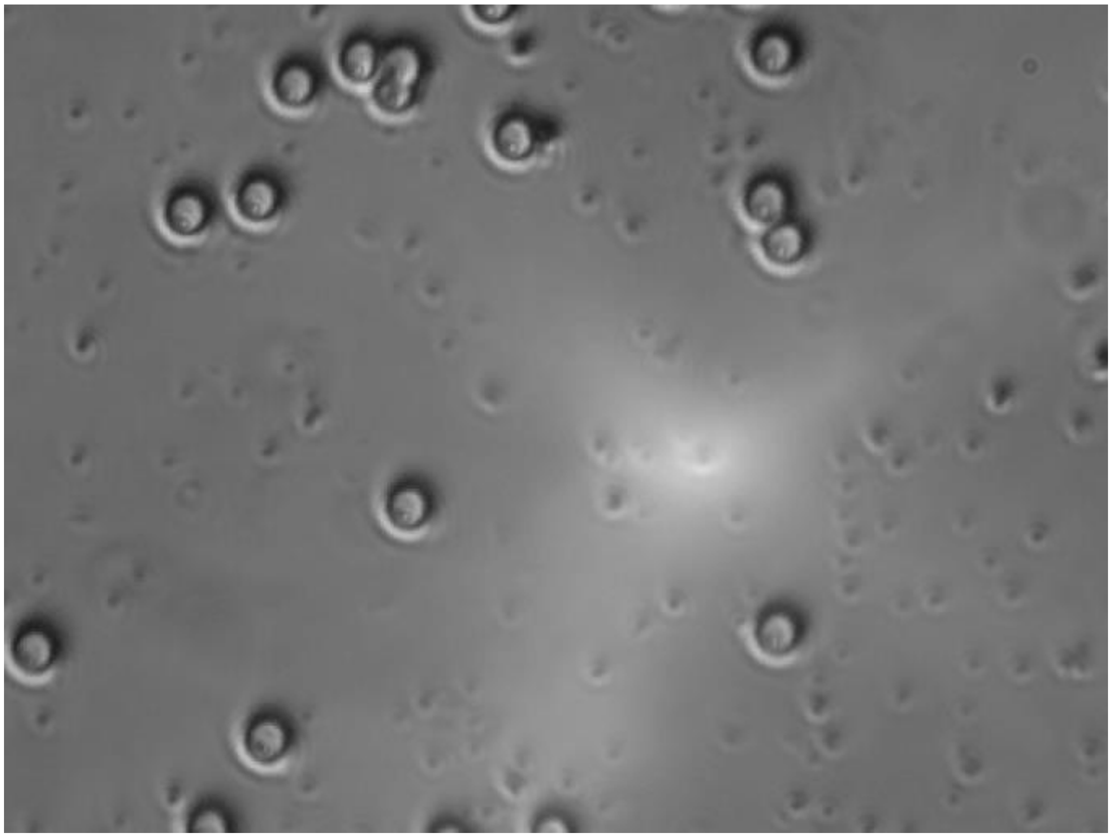
$$\langle \Delta x^2 \rangle = 4Dt$$

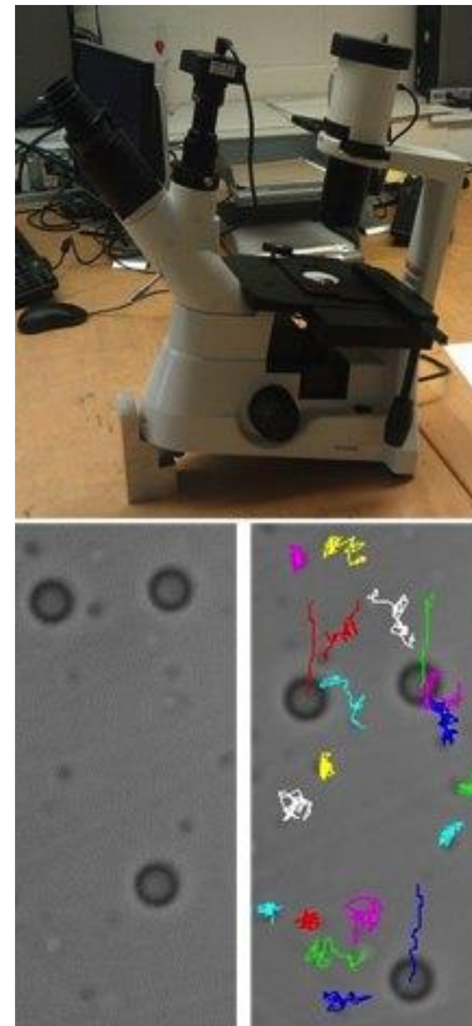
$$D = kT/6\pi\eta a$$

How does viscosity, bead size, mass, affect diffusion?

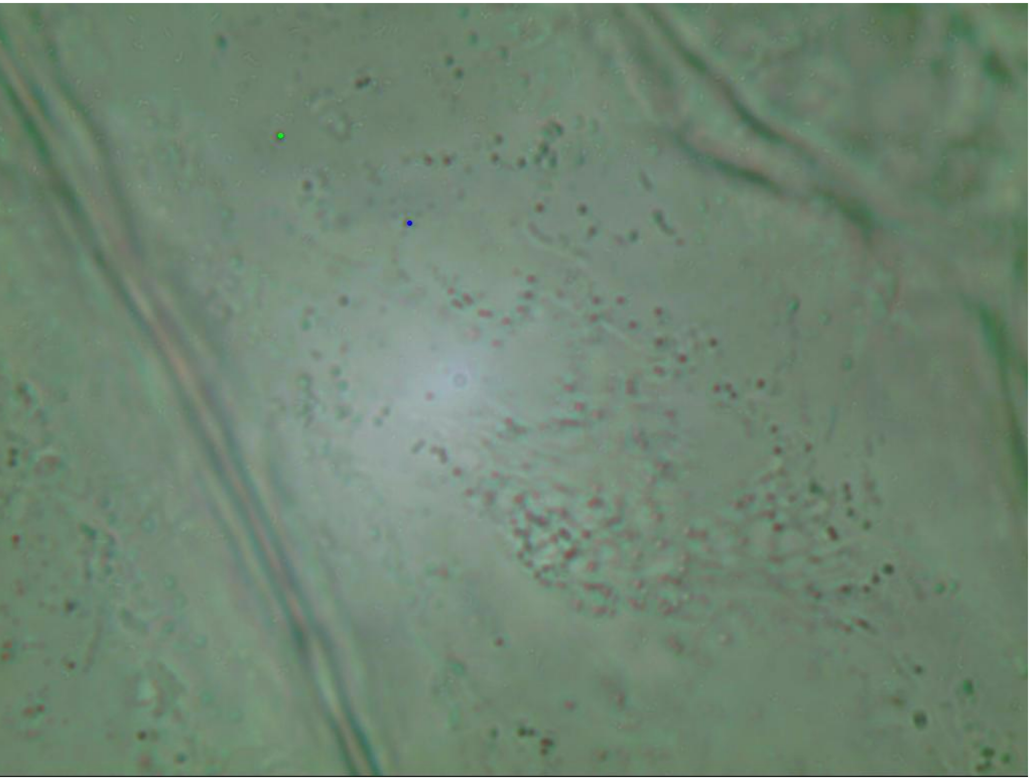
What is going on here?

A challenge suggested by Biophysics Colleague S. Sukharev

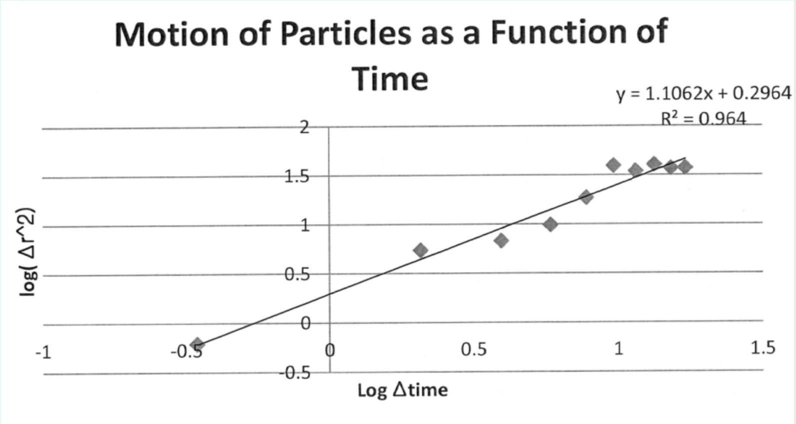




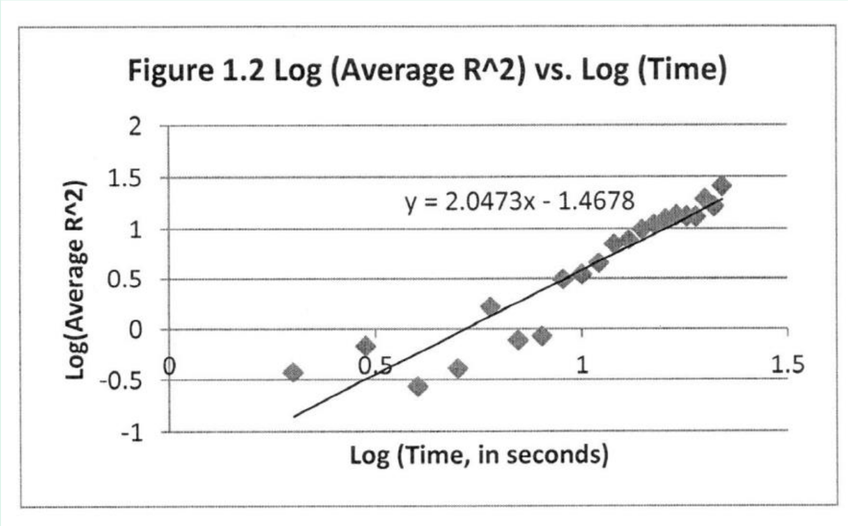
Interdisciplinary Transfer:
What Biology can we learn from a Physics Measurement?



Student Measurement Results



SLOPE 1.1 *Random Motion*



SLOPE 2.05 *Directed Motion*

Semester 1

Lab1: Quantifying motion from Images and Videos (2 weeks)

- Can you learn any biology from physical measurements?
- *Analysis of cell motion using Excel and ImageJ.*

Lab 2: Inferring force characteristics from motion analysis (2 weeks)

- How can information about forces be derived from a video?
- *Introduction to Video Capture & Analysis of Directed Motion and Resistive Forces.*

Lab 3: Observing Brownian motion at a microscopic scale (3 weeks)

- What does ‘Random’ motion look like? (inspired by M. Reeves)
- *Describing Diffusion & Random Motion.*

Lab 4: The competition between Brownian motion and directed forces

- How large a force is needed to transition from random to directed motion?
- *Distinguishing Random vs. Directed Motion*

Lab 5: Motion and Work in living systems (2 weeks)

- How much work is involved in Active Transport?
- *Classifying Motion and Examining Work in Onion Cells.*

MAKEUP LAB

Semester 2

Lab 6: Modeling fluid flow

- *Exploring Fluid Dynamics and the Hagen-Poiseuille (H-P) Equation.*

Lab 7: Analyzing electric forces in a fluid

- *Electrophoresis and Charge Screening in Fluids.*

Lab 8: Modeling electrical signal transmission along nerve axons

- *Testing Models of Signal Transmission.*
  (Adapted from labs by L. Cui UMBC & C. Crouch, Swarthmore)

Lab 9: Introducing geometric optics through experimental observations

- *Exploring Light and Lenses. (motivated by C. Crouch, Swarthmore)*

Lab 10: Analyzing light spectra and exploring implications for living systems.

- *Spectroscopy—Exploring Emission, Absorption & Evolutionary Adaptation.*
  (with K. Carleton, Biology)

Lab 11: Exploring complex absorption and emission in molecules. [1 week]

- *Spectroscopy & Fluorescence in Chlorophyll. (with K. Carleton, Biology)*

MAKEUP LAB

Data Comparison

- Comparing to ISLE (2005) data from E. Etkina & S. Murthy, "Design labs: Students' expectations and reality," *AIP Conf. Proc.*, 818 (2006), N = 187

- Since Fall 2012, 397 students have taken the Labs
- Students (largest N=209) were asked two questions:
  - **How important is each goal FOR YOU?**
  - **How successful were the labs in terms of achieving each goal?**
- **Goals:**
  - Learn to interpret experimental data
  - Learn to design your own experiment
  - Learn to work with other people
  - Learn to communicate ideas in different ways
  - Understand concepts better
  - Prepare for your future professional career

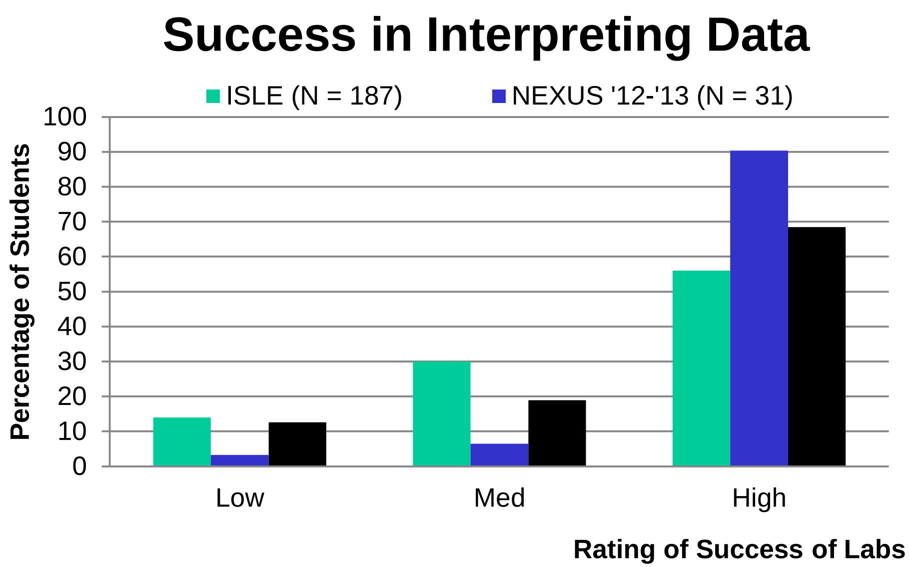
Transitioning from small test classes to a large enrollment environment—What has changed?

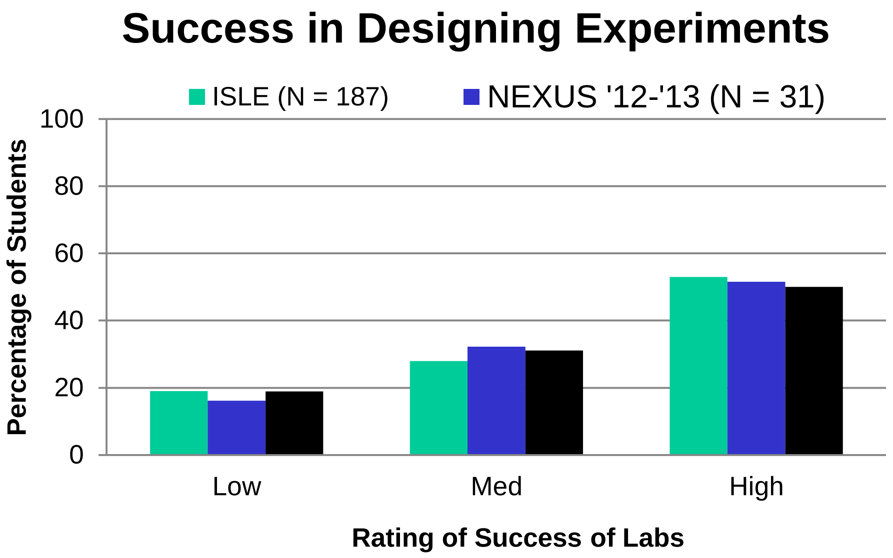
Fall 2012 to Spring 2013: 33 self-selected students in two lectures, labs run with both GTA curriculum designers & 1 LA per lab

Fall 2013: 235 mandatory students in two lectures, same two professors, one returning GTA,
5 GTAs new to the labs & 1-2 LAs per lab

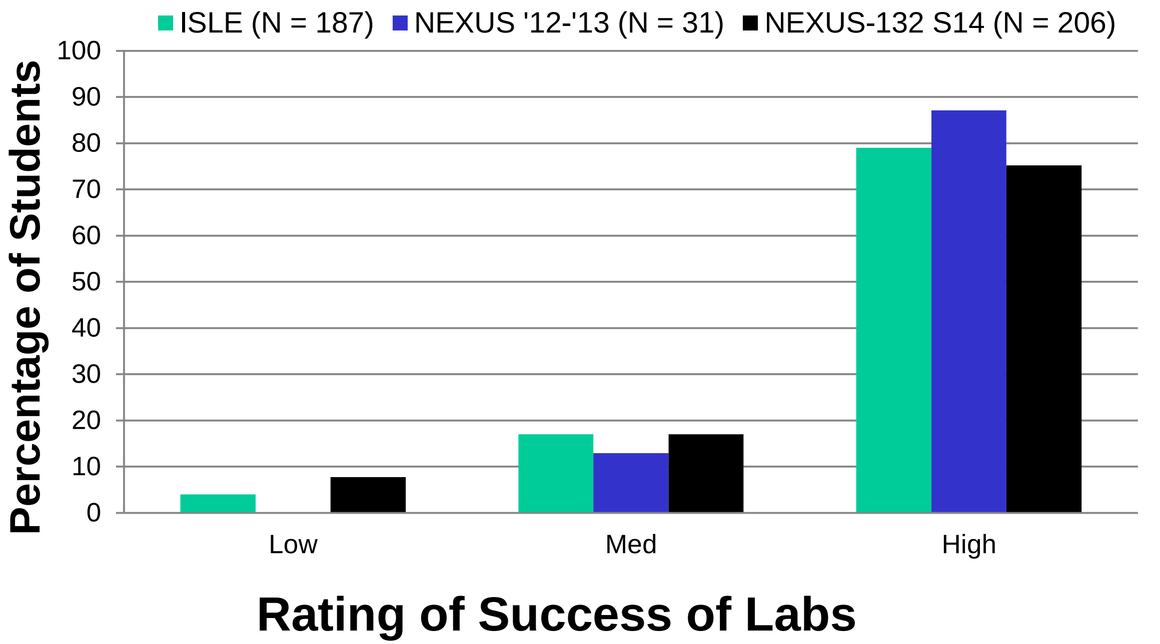
Spring 2014: 210 students in (2nd semester) 124 students (1st)
four new profs., 3 cont. GTAs, 5 new GTAs
(no curriculum designers as GTAs or Profs)

Lab Evaluations I
Interpret Data and Design Experiments



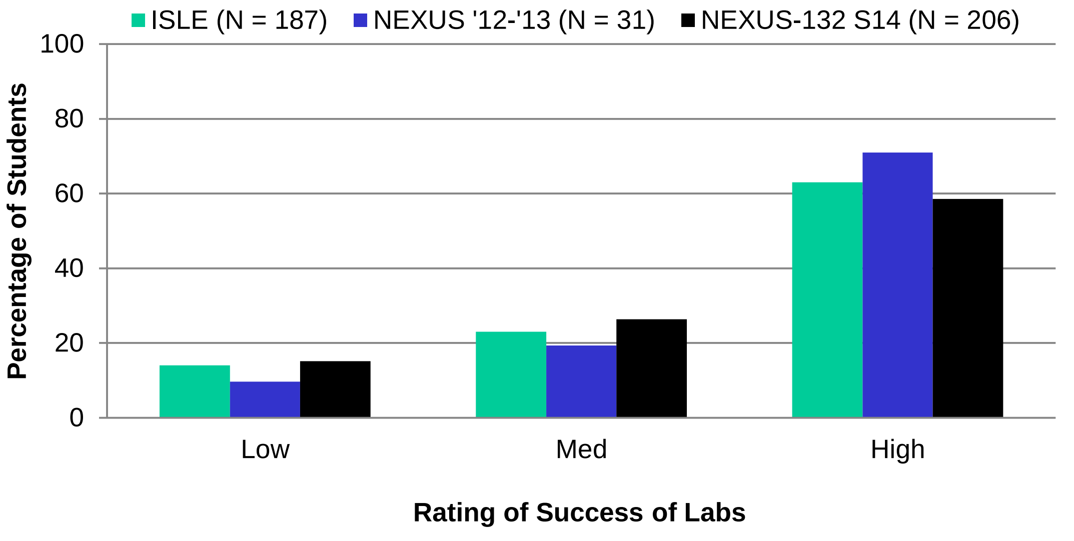


Lab Evaluations II
Work in Groups



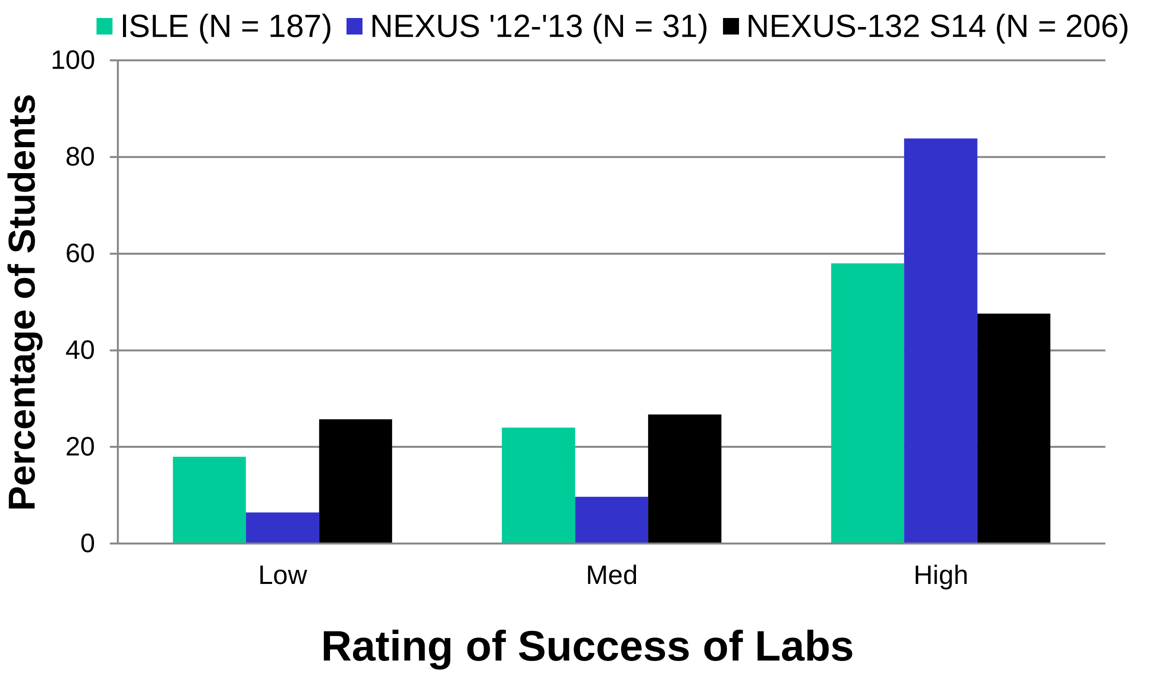
"There is more group work in this lab than in other labs that I have taken (I am mostly comparing to Chemistry labs). I think I benefit from this more because if there is ever anything that I don't understand, chances are one of my group members does."

Lab Evaluations III
Communicate Ideas



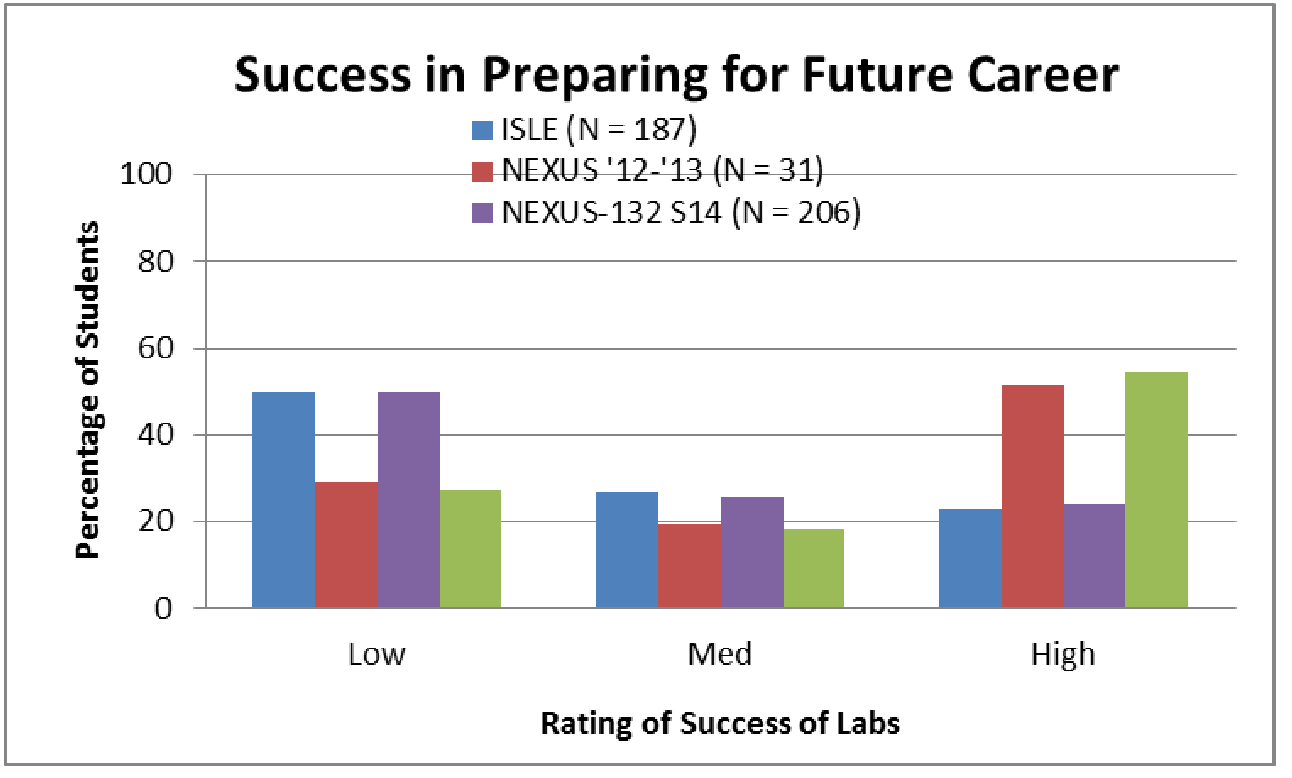
"I also like the reports, which are less data-filled than the chemistry labs. You don't just say what data you got from the lab, you actually discuss what it means and how it supports or doesn't support what was expected. That helps me to understand the concepts and their importance."

Lab Evaluations IV
Concepts



"I like the labs that we do. They allow me to better understand what we are learning in class. This enables me to remember what I learned and apply it to situations that I have not encountered in

Lab Evaluations V
Relevance



Conclusions

- Built on Successful Community Lab Concept
  - Provide hands-on experience with relevant physics concepts
    - *Focus on Sensemaking*
  - Develop student research skills
    - *Focus on Experimental design*

<u>In addition our labs</u>

- Convey a modern view of physics
  - Modern equipment, analysis and data representation tools
- Foster interdisciplinary transfer explicitly
  - *“What biology do you learn from a physical measurement?”*
- Help students toward their career goals

Biological Physics

- **Research –** Dynamics of Living Systems

- **Teaching –** with EF Redish and PERG

  new Intro Physics for Life Scientists Course & **Labs**

- **Integrating Teaching and Research**

  FIRE-299L

UMD-NCI Pilot
Spring 2014

Team based learning

Integrated Assessment

Connecting Research and Education

See POSTER

Extended Undergraduate Research Experiences in Quantitative Biology and Biophysics

This partnership between the University of Maryland and the National Institute of Health pairs postdoctoral mentors with teams of undergraduates to:

- address challenging authentic research problems
- collaborate in interdisciplinary teams to develop effective research designs
- take risks and come to see failure as part of the innovation process
- monitor progress toward short-term goals relative to larger project objectives

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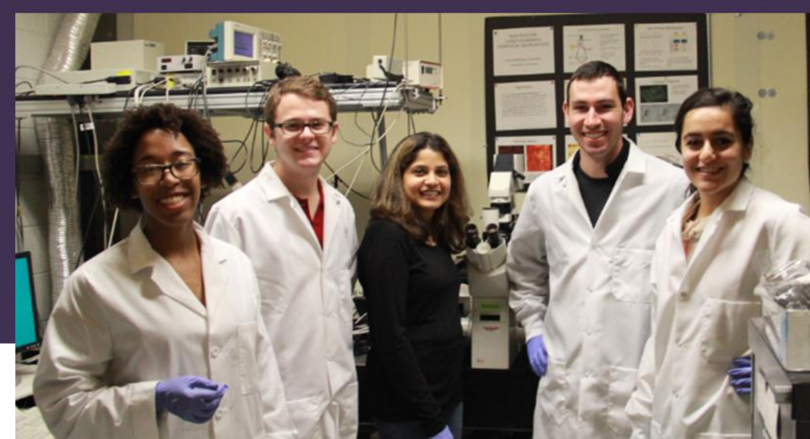


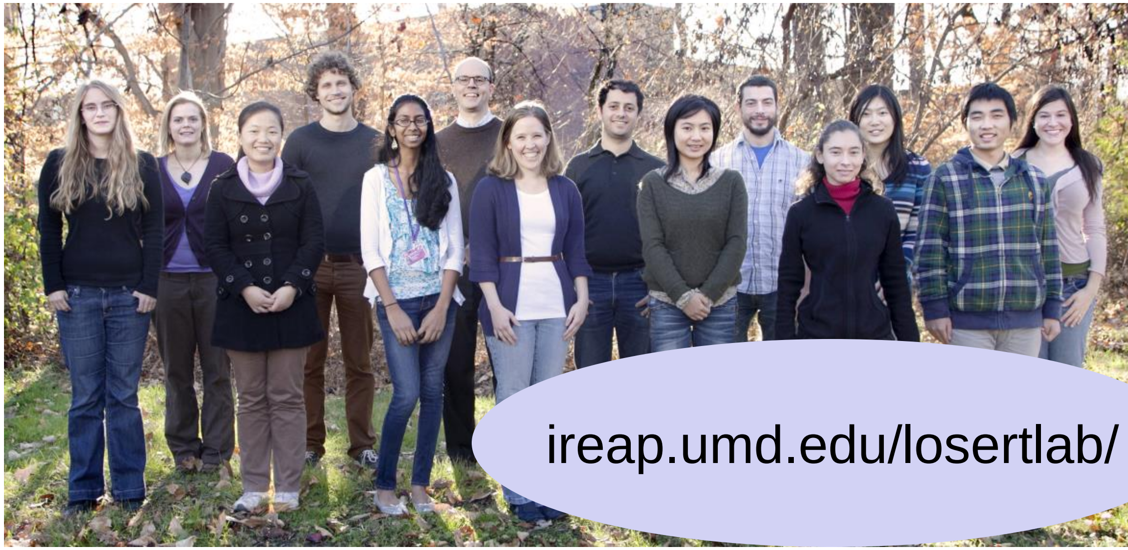
For more information please contact Dr. Wolfgang Losert at wlosert@umd.edu
Or visit: http://fire.umd.edu/streams-QBB.html

Reinventing the Introductory Physics Labs (& Course) for Future Biologists

Physics Education

Joe Redish
Todd Cooke
Karen Carleton
Ben Dreyfus
Ben Geller
Julia Gouvea
Kim Moore
Vashti Sawtelle

Biodynamics Research Lab



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