The Adolph C. and Mary Sprague

Miller Institute
for Basic Research in Science

Newsletter
Winter 2018

Understanding biodiversification through the lens of herbivore/microbe interactions

Miller Fellow Focus: Rebecca Duncan

No organism lives in a vacuum – interactions between different species weave together to form the exquisite tapestry of life that connects all living things. This network of interactions shapes selective pressures faced by each species, influencing how it functions in its environment and its evolutionary trajectory. Species interactions happen at all scales, with the most intimate interactions occurring between multicellular hosts and symbiotic microorgansisms. Symbiotic microbes enable multicellular organisms to colonize novel environments by giving hosts access to their genetic toolkit. Mounting evidence suggests that host/microbe interactions are important for host evolution and even speciation, but how do these interactions influence large-scale patterns of biological diversification? My research as a Miller Fellow will help address this question.

I am working with my faculty hosts Noah Whiteman (Integrative Biology) and Steve Lindow (Plant & Microbial Biology) on the role of gut bacteria in the evolution of a plant-based diet (herbivory). Herbivory is a challenging life strategy underlying large-scale patterns of animal diversification, particularly in herbivorous insects, which make up 25% of all animals. Among the challenges of a plant-based diet is that plants produce toxic chemicals like nicotine, caffeine, morphine, and mustard oils. Some herbivores natively detoxify plant toxins, but gut bacteria may also metabolize these compounds. It has been proposed for decades that gut bacteria facilitate herbivory by breaking down host plant toxins, but only recently has the hypothesis been supported in scientific studies. Even so, the extent to which bacteria facilitate herbivory by degrading host plant toxins is an open question.

Even if gut bacteria break down host plant toxins, whether they enable an evolutionary shift from a non-herbivorous diet to a herbivorous diet has not been addressed. This initial shift and subsequent diversification to new host plants requires detoxification of new chemicals. Acquiring new gut bacteria with different metabolic capabilities would provide a relatively easy mechanism to evolve herbivory (or switch host plants). New gut bacteria could thus act as a bridge by enabling herbivores to break down toxins before they evolve their own detoxification mechanisms and other adaptations they may need to thrive on their host plant.

I am addressing the role of gut bacteria in the evolution of herbivory through host

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Inside this edition:

"My year as a Miller Professor was an incredible luxury. I had a chance to focus exclusively on my research. It was especially beneficial to think deeply about new research directions that I might pursue. I am now beginning two new projects; one at the interface between atmospheric chemistry and public health and another focused on the role of forests on the Nitrogen cycle. Along the way I recruited a postdoc to Berkeley who arrived as a Miller Postdoctoral Fellow last Fall."

- Ronald C. Cohen, *Miller Professor, Professor, Department of Chemistry, Professor, Department of Earth & Planetary Science, University of California, Berkeley*

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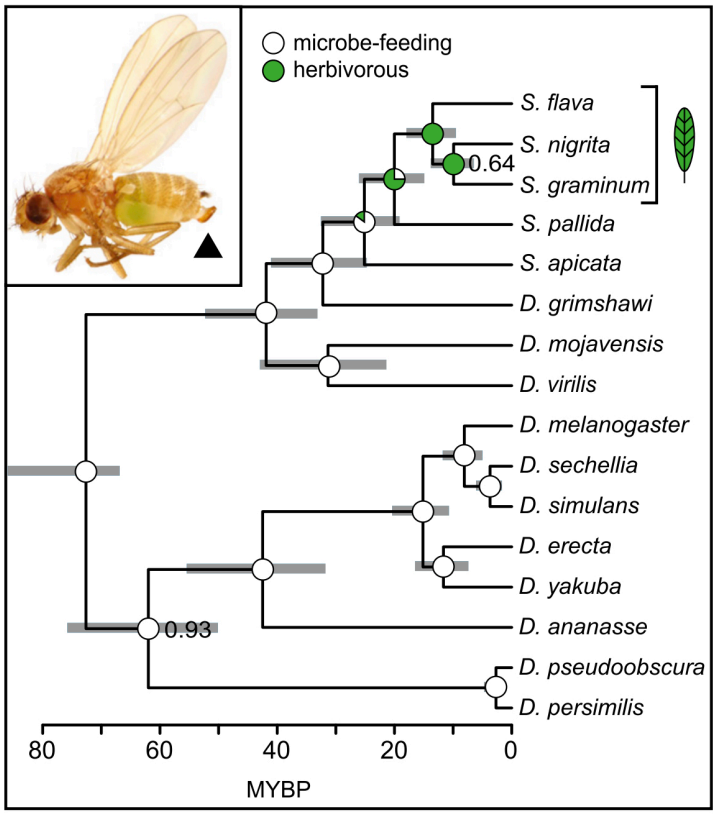

Figure 1. Herbivory evolved recently in *Scaptomyza*. Time-calibrated Bayesian phylogeny of select *Scaptomyza* and *Drosophila* representatives. Herbivory is mapped onto species with a leaf and probability of ancestral diet (green: herbivory; white: microbe-feeding) is mapped onto internal nodes. Node labels represent support for the relationships reflected at each node in the form of posterior probability (PP). Unlabeled nodes have PP=1. Scale at bottom represents time in million years before present (MYBP). Error bars represent 95% highest posterior density interval. Inset: *Scaptomyza flava* female. Arrowhead points to the ovipositor which plays the dual role of laying eggs and cutting a hole in the leaf where she inserts the egg. Figure from Goldman-Huertas et al. 2015. PNAS. 112(10):3026-3031.

plant detoxification using an emerging model mustard-feeding fly called *Scaptomyza flava* (**Fig. 1**). Several herbivorous insects are models for studying the role of symbiotic bacteria in the evolution of herbivory, but they are limited in their ability to address the evolutionary shift to herbivory because either they lack genetic tools for both host and symbiont or their symbionts are unculturable. Vertebrate models are also less tractable than insect models because vertebrate gut communities tend to be diverse, while insect communities often consist of a small handful of bacterial species. *S. flava* has a culturable gut community, lending itself to genetic manipulation and gut community manipulation. *S. flava* is also closely related to the model fly *Drosophila melanogaster*, benefiting from all the genetic tools and genomic resources developed for *Drosophila* species. Additionally, work is ongoing in the Whiteman Lab to make mutant *S. flava* lines using CRISPR. Another benefit of *S. flava* is that one of its natural host plants is the genetic model plant *Arabidopsis thaliana*, and I can use its genetic tools to manipulate levels of defensive compounds. Further, herbivory evolved recently in *Scaptomyza* (~20 MYA) (**Fig. 1**), so it may represent a herbivore in the early stages of adapting to its host plants. Lastly, *S. flava* and related mustard-feeding species can be found right here on campus, in watercress and other mustards growing in and around Strawberry Creek (**Fig. 2**). These features make *S. flava* an ideal model for studying the role of gut bacteria in the evolution of herbivory here at Cal.

Figure 2. Patch of watercress in Strawberry Creek outside of the Life Sciences Annex (UC Berkeley campus), where *S. flava* and relatives have been collected.

To survive on a diet of mustards, *S. flava* must overcome mustard chemical defenses. Mustards are defended by the glucosinolate/myrosinase system. Mustards produce non-toxic glucosinolates. Upon tissue disruption, glucosinolates come into contact with plant-derived enzymes called myrosinases that break down glucosinolates into toxic mustard oils, the compounds responsible for the bitter and spicy taste of cruciferous vegetables (**Fig. 3**). *S. flava* natively detoxify mustard oils to a certain extent using conserved and newly evolved enzymes called Glutathione S-Transferases (GSTs). The newly evolved GSTs are much more efficient at breaking down mustard oils in vitro than the conserved GSTs, so it is unclear if the ancestral ability of Scaptomyza to break down mustard oils was sufficient to facilitate the shift to feeding on mustards. Teasing apart the relative roles of gut bacteria and native fly detoxification mechanisms will require genetic manipulations of each player.

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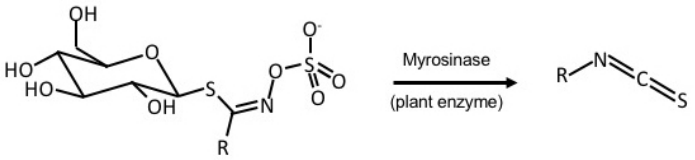

Figure 3. The glucosinoalte/myrosinase defense system of plants in the mustard family. Mustards produce non-toxic compounds called glucosinolates and enzymes called myrosinases that can break down glucosinoltes, but these two molecules are compartmentalized in intact cells. Upon tissue damage by a chewing herbivore, myrosinase contacts glucosinolates and breaks them down. One of the products of this chemical reaction are toxins called isothiocyanates, also known as mustard oils.

My preliminary research found that *S. flava* have gut bacteria that are resistant to mustard oils at high concentrations, consistent with the ability to break them down. I am collaborating with Hans Carlson, a biochemist at the Lawrence Berkeley National Laboratory, to confirm that *S. flava* gut bacteria break down mustard oils using a high-throughput spectrophotometric assay. From there, I will use a forward genetic screen to create mutant lines of bacteria that can break down mustard oils to find the genetic basis of mustard oil metabolism. Once I have found the gene(s) responsible and verified that they are necessary and sufficient for mustard oil detoxification, I will conduct a series of experiments in which I introduce mutant and wild-type bacteria into antibiotic-treated flies and measure their fitness on a panel of mutant and wild-type host plants that vary in their glucosinolate production. To approximate the fly's ancestral detoxification abilities, I will use CRISPR to knock out newly evolved GSTs that most efficiently break down mustard oils. As a complementary experiment, I also plan to introduce *S. flava* gut bacteria into sterile *D. melanogaster* and measure their fitness on media containing mustard oils. These experiments should help to uncover the importance of gut bacteria in facilitating the evolution of herbivory in *Scaptomyza*, advancing our understanding of the mechanisms by which bacterial partners promote the evolution of life on Earth.

Rebecca Duncan grew up in Atlanta, GA in a family of artists and craftsmen (and women). Despite the strong draw to follow in her family's footsteps, she decided to major in Biology after learning about evolution and reading Stephen Jay Gould as a freshman at Lewis & Clark College (Portland, OR). She went to graduate school at the University of Miami (Miami, FL) where she studied the molecular and functional evolution of amino acid transporters that mediate symbiotic interactions between sap-feeding insects called aphids and their intracellular bacterial symbionts. She still enjoys crafting, and also cooking, biking, and spending time with her husband, Michael, and two-year- old son, Arlo.

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Fall Reception 2017

Miller Fellows Farnaz Niroui and Sarah Slotznick, Executive Director Marla Feller, Miller Fellows Rebecca Duncan and Grant Remmen

Former Miller Professor Peter Yu and Gloria Yu, former Miller Professor Joel Moore, Miller Senior Fellow Raymond Jeanloz and former Miller Professor Ron Cohen

Chancellor Carol Christ, former Miller Professor Arash Komeili, Executive Director Marla Feller and Miller Fellow Christopher Lemon

Former Miller Fellows Greg Crutsinger, Brooke Gardner and Amy Shyer

In the News

(see more past & current Miller Institute News: miller.berkeley.edu/news)

Barbara Meyer (Miller Senior Fellow 2013 - 2018) to receive the **Francis Amory Prize of the American Academy of Arts and Sciences** for *"distinguished achievement in the area of reproductive medicine and physiology."*

Grant Remmen (Miller Fellow 2017 - 2020) won the **2018 J.J. and Noriko Sakurai Dissertation Award in Theoretical Particle Physics** from the the American Physical Society *"for his contributions to understanding the structure and self-consistency of gravity and effective field theories using ideas from quantum field theory and holography."*

Jeremy Thorner (Miller Professor 1984 - 1985, 1999 - 2000) was named an **American Society for Cell Biology Fellow** for his lifetime achievements in advancing cell biology.

Two Miller members are among the **2017 AAAS** Fellows:

- **Ron Cohen** (Miller Professor 2015 - 2016) honored for insights into how chemistry affects the composition of the Earth's atmosphere, especially the chemistry of nitrogen oxides and the isotopes of water.
- **Marla Feller** (Miller Fellow 1994 - 1996) credited for her outstanding, influential, original discoveries in neuroscience, particularly mechanisms and development roles for activity waves, gap junctions and motion detection in the retina.

Richard Henderson (Visiting Miller Professor 1993) shared the **Nobel Prize in Chemistry in 2017** with Jacques Dubochet and Joachim Frank for developing cryo-electron microscopy for the high-resolution structure determination of biomolecules in solution.

Lucy Pao (Visiting Miller Professor 2008) won major scientific awards this year: **2017 Control Engineering Practice Award** from the American Automatic Control Council and the **European Academy of Wind Energy Scientific Award 2017.**

Eve Ostriker (Visiting Miller Professor 2009) recognized by the Simons Foundation with the **2017 Simons Investigator Award** for her *"major contributions to our understanding of the role of the interstellar medium in star formation and galactic structure and evolution, with a focus on the role of turbulence and on the effects of energy returned by massive stars to the interstellar medium."*

Louise Glass (Miller Professor 2011 - 2012) was recognized as an outstanding mycologist by being **named Fellow of Mycological Society of America**.

Two Miller Members were elected to the **National Academy of Medicine:**

- **Arup K. Chakraborty (Miller Professor 2000) -** for his work on bringing together immunology and the physical and engineering sciences. He is one of a small number of individuals who are members of all three branches of the US National Academies.
- **Nicholas Jewell** (Miller Professor 2004) - for his research in biostatistics and statistics related to infectious diseases, including AIDS, as well as in epidemiological data analysis, in survival analysis and stochastic processes, and in genomics.

Omar Yaghi (Visiting Miller Professor 2009) received the **2017 Albert Einstein World Award of Science Prize** for his ground-breaking scientific contributions in making materials by stitching organic and inorganic units through strong bonds into robust, porous crystalline metal-organic frameworks (MOFs) and covalent organic frameworks (COFs), and for establishing a new field of chemistry - Reticular Chemistry.

Steven Poe (Miller Fellow 2000-2002) has discovered two new species of *Anolis* in Costa Rica and Panama. He has honored Miller Institute Chief Administrative Officer, Kathryn Day, by naming one of the discoveries ***Anolis kathydayae***, citing her contributions *"to the professional and personal development of scientists and the advancement of basic science through her position running the Miller Institute".*

Adrian Bejan (Miller Fellow 1976 - 1978) to receive the **Benjamin Franklin Medal for 2018** for *"his pioneering interdisciplinary contributions in thermodynamics and convection heat transfer that have improved the performance of engineering systems, and for constructal theory, which predicts natural design and its evolution in engineering, scientific, and social systems."*

Jennifer Doudna (Miller Senior Fellow 2017) who co-invented CRISPR-Cas9 gene editing, shared the **2017 Albany Medical Center Prize in Medicine and Biomedical Research** for groundbreaking work leading to current medical advances.

Alexander Levitzki (Visiting Miller Professor 2008) shared the **EMET Life Sciences award** for his protein kinases inhibitors in cancer research. Also, he was elected as **foreign associate of the National Academy of Sciences.**

Paul Alivisatos (Miller Professor 2001 - 2002) has been chosen to serve as **UC Berkeley's new Executive Vice Chancellor and Provost** because of his demonstrated abilities in strategic planning, organization and leadership as well as his deep administrative experience.

Miller Research Competitions: Awards

The Advisory Board

On December 4, 2017, the Advisory Board of the Miller Institute met to select next year's Professorship awards. The Board is comprised of four advisors external to UCB: Steven Block (Physics, Stanford University), Luis Caffarelli (Mathematics, University of Texas, Austin), Feryal Özel (Astronomy & Physics, University of Arizona) and Tim Stearns (Biology, Stanford University); and four internal Executive Committee members: Executive Director Marla Feller (Molecular & Cell Biology), Stephen Leone (Chemistry/Physics), Roland Bürgmann (Earth & Planetary Science) and Yun Song (EECS/Statistics/IB). The Board is chaired by Chancellor Carol Christ.

The Miller Institute is proud to announce the awards for Professorship terms during the Academic Year 2018-2019. These outstanding scientists pursue their research, following promising leads as they develop. The Visiting Miller Professors join faculty hosts on the Berkeley campus for collaborative research interactions.

Miller Professorship Awards

Alan Hammond

Mathematics

Nicole King

Molecular and Cell Biology

Dan Stamper-Kurn

Physics

Umesh Vazirani

Electrical Engineering & Computer Science

Emeritus Miller Institute Members!

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Visiting Miller Professorship Awards

Bernd Abel

Chemistry

Host: Daniel Neumark

Home Institution: Leibniz Institute of Surface Modification

Uri Banin

Chemistry

Host: Eran Rabani

Home Institution: Hebrew University of Jerusalem

Jens Bruning

Helen Wills Neuroscience Institute

Host: Andrew Dillin

Home Institution: Max Planck Institute for Metabolism

Jean-Michel Coron

Mathematics

Host: Craig Evans

Home Institution: University Pierre et Marie Curie

Stephan Fueglistaler

Earth & Planetary Science

Host: David Romps

Home Institution: Princeton University

Jan Koenderink

EECS

Host: Alexei Efros

Home Institution: KU Leuven

Manos Mavrikakis

Chemistry

Host: Gabor Somorjai

Home Institution: University of Wisconsin

Natalia Requena

Plant & Microbial Biology

Host: Louise Glass

Home Institution: Karlsruhe Institute of Technology

William Schafer

Molecular & Cell Biology

Host: Diana Bautista

Home Institution: MRC Laboratory of Molecular Biology

Anne Socquet

Earth & Planetary Science

Host: Roland Bürgmann

Home Institution: University of Grenoble - Alpes

Thomas Surrey

Molecular & Cell Biology

Host: Rebecca Heald

Home Institution: Francis Crick Institute

Manik Varma

Astronomy

Host: Josh Bloom

Home Institution: Microsoft Research India

Fall Dinner 2017

Executive Director Marla Feller and guest speaker John P. Holdren, President Obama's Science Advisor and Director of the White House OSTP

Miller Fellows Grant Remmen, Peter Walters, Ryan Dalton and Alex Turner

Miller Fellows Christopher Lemon, Jessica Ray and Kelly Nguyen

Miller Fellows Rachel Zucker, Shirshendu Ganguly and Lian Xue

Miller Fellow Farnaz Niroui and Miller Professor Naomi Ginsberg

Miller Fellows Thibault de Poyferre and Louis Kang

Monica Li, Miller Fellows Sarah Slotznick, Cara Brook, Amy Goldberg and Visiting Miller Professor Mohamed Noor

Executive Director Marla Feller and Chief Administrative Officer Kathryn Day

Guest speaker John P. Holdren chatting with Miller Senior Fellow Gabor Somorjai

Gifts to the Miller Institute

The Miller Institute gratefully acknowledges the following contributors to the Miller Institute programs in 2017. These generous donations help support the Miller Research Fellowship program, the general programs of the Institute, and the Gabor A. and Judith K. Somorjai Visiting Miller Professorship Award (SVMP). (*= 5 years of giving)

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miller.berkeley.edu/gift

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Anonymous - in memory of Edward A. Steinhaus

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*Randy Schekman
*Jeremy Thorner
*Fausta Segre Walsby

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Roland Bürgmann
*Craig Evans
*John Hunter III
**Ronald Johnson
Andrew Ogg
Gabor Somorjai
*Jesse Thaler
*Patricia Zambryski

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Jiaxing Huang - in honor of Peidong Yang
*Tom Juenger
Henk Keers
Eric King
*Judith Klinman
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Xanthippi Markenscoff
Dustin & Kate Rubenstein
Daniel Tataru

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(2017 Gifts received after January 1 will be acknowledged in a later issue.)

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Miller Institute News : Winter 2018
Please send address corrections to:
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Where in the World Is Your Fleece?

Please share a photo of you wearing your Miller Institute fleece at places around the world. We will post these photos on our website sharing the world wide reach of the Miller Institute!

Miller Fellows Alex Turner, Thibault de Poyferre, Cara Brook and Sarah Slotznick don their Miller gear at Yosemite!

Online Newsletter

The Miller Institute invites you to enjoy our previous e-newsletters by visiting: http://miller.berkeley.edu/news/newsletters

Birth Announcements

Alex Engstrom (Miller Fellow 2009-2012) announced the birth of daughter, Emma Isabella Eva Engstrom born April 2017.

Phil Chang (Miller Fellow 2005-2008) & his wife Morgan Jones welcomed Xander Anise Chang into their family, born July 2017.

Greg Engel (Miller Fellow 2005-2008) & his wife Kelly Plummer announced the arrival of daughter, Madeleine Elizabeth Engel, born September 2017.

Chang Liu (Miller Fellow 2009-2012) & and his wife Shira welcomed Noa Matilda Liu, born September 2017.

Maryam Modjaz (Miller Fellow 2007-2010) & her husband Tom Velez announced the birth of son, Benjamin born September 2017.

Claude-André Faucher-Giguère (Miller Fellow 2010-2013) & Jeanine Baqai announced the birth of their son, Luca Baqai Giguère, born October 2017.

Reimundo Heluani (Miller Fellow 2006-2009) & and his wife Mariana Guardia Claps welcomed Tomás Heluani, born October 2017.

The Miller Institute is dedicated to the encouragement of creative thought and the conduct of research and investigation in the field of pure science and investigation in the field of applied science in so far as such research and investigation are deemed by the Advisory Board to offer a promising approach to fundamental problems.