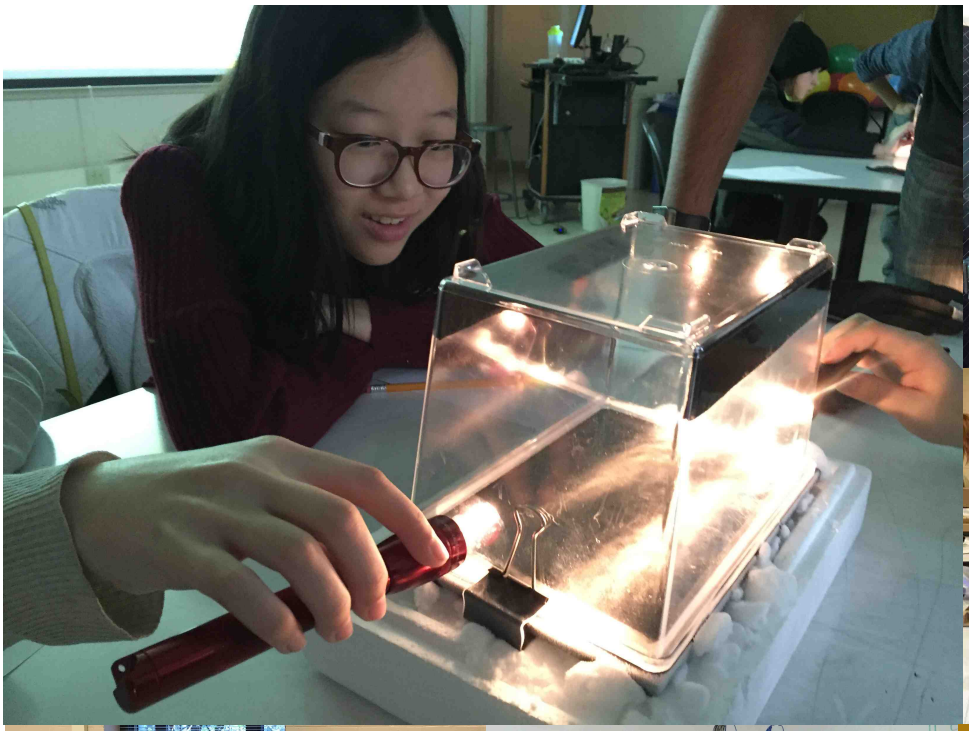
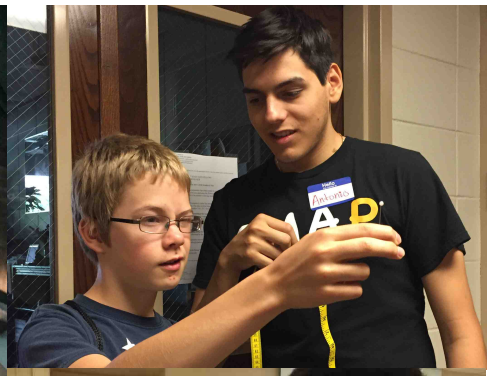
# Physics INTERACTIONS

A NEWSLETTER HIGHLIGHTING THE DEPARTMENT OF PHYSICS AND ASTRONOMY AT PURDUE UNIVERSITY

2017





**Saturday Morning Astrophysics at Purdue offers middle and high school students activities not often found in the classroom (page 10)**

## Inside

## Credits

Physics Interactions is published annually by the Department of Physics and Astronomy at Purdue University.

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*Front Cover Credit: David Sederberg*

# From the Head

Greetings Alums and friends of the department. We are progressing through another academic year and finals week is upon us as I write this. There have been some developments to report since we last talked that I would like to pass along. Reflection on where we are and where we would like to go seems natural as the Sun progresses towards its most southern extent and then, thankfully, begins to head north again.

We welcomed Assistant Professor Dan Milisavljevic at the beginning of the academic year after a thorough and comprehensive search. Dan comes to us from the High Energy Astrophysics division of the Smithsonian Astrophysical Observatory where he was a postdoctoral fellow. Dan was a postdoctoral associate at Harvard after completing his PhD studies at Dartmouth College. Dan's research interests are in the burgeoning field of Time Domain Astrophysics. He specializes in fundamental research concerning massive star evolution and death. We also had our fair share of departures as well. Prof. Tom Clark retired after 37 years of devoted service to the department. Tom was a theoretical high-energy theorist and was a fixture in our graduate curriculum. Prof. Yeong Kim also retired this past year after 50 years of service to the department. Yeong, a many-body nuclear theorist, also played a large role in our graduate curriculum over the years. Many of you probably have fond memories of their insightful teaching and concern for their students. They will be missed.

We also had some notable accolades dispensed upon our faculty. Prof. Erica Carlson was the recipient of the Charles Murphy Award for Outstanding Undergraduate Teaching. The Murphy Award is the highest teaching recognition that the University can bestow upon a faculty member and, in Erica's case, is much deserved. Prof. Chen-Lung Hung, an AMO experimentalist, was named an Air Force Research Office Young Investigator and Prof. Norbert Neumeister was once again named an LHC Physics Center Distinguished Researcher. We continue to excel in the profession and this incomplete list is only a sampling of the excellent personnel in our department. We also have excellent students, both graduate and undergraduate, and their accomplishments are recognized in this newsletter as well.

Very often, our recognitions are solely directed towards faculty and students but there is a whole support group behind us that make everything work. That is, of course, the excellent staff that do many of the tasks that allow the rest of us to be successful. Each year we award our staff in the department for their contributions to our overall mission of producing the next generation of science literate citizens that will shape this state's and this nation's future. Those recognitions are outlined inside as well.

We also honored you, our alumni, with awards for your contributions to society, to science, and to the Department of Physics and Astronomy. Last year's Outstanding Alums and Distinguished Alum were another truly deserving class and we have described their accomplishments within. I am always struck by the genuine affection that our alums show for the department. It is always humbling to interact with each of you. It reinforces for me that, as instructors and mentors, we do have an impact. As an educator, nothing is more satisfying. Here's hoping your new year is a bountiful one and that all your wishes come true!

# New Faculty

Assistant Professor **Dan Milisavljevic** specializes in astrophysics. His research interests include time-domain astronomy, 3-D reconstruction of supernovae, mass loss in massive stars, and the formation and destruction of dust and molecules in the universe. Prof. Milisavljevic comes to Purdue from the Smithsonian Astrophysical Observatory where he was a Postdoctoral Fellow. He holds a Bachelor of Arts & Science from McMaster University, a Master of Science from the London School of Economics, and a Ph.D. from Dartmouth College.

# Faculty Honors

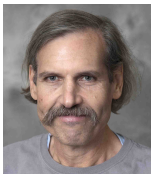
**Erica Carlson** received the Purdue University Outstanding Undergraduate Teaching Award in memory of Charles Murphy.

**Birgit Kaufmann** was named a University Faculty Scholar.

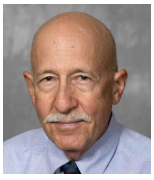
**Gabor Csathy** was named Associate Head.

**Matthew Lister** was named a University Faculty Scholar.

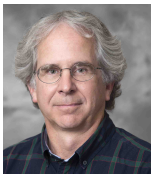
**Dan Elliott** was named an American Physical Society Outstanding Referee.



**Sherwin Love** received the Ruth and Joel Spira Award for Outstanding Graduate Teaching.



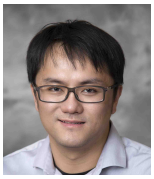
**Ephraim Fischbach** was named an American Physical Society Outstanding Referee.



**David Nolte** received a Purdue University Outstanding Commercialization Award.

**Mark Haugan** received the College of Science Graduate Student Mentoring Award.

**Yulia Pushkar** received the College of Science Research Award.

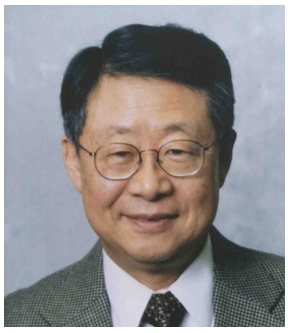


**Chen-Lung Hung** was named a 2017 Air Force Office of Scientific Research Young Investigator.

**Ken Ritchie** received the Ruth and Joel Spira Award for Outstanding Undergraduate Teaching.

# Farewells

**Thomas Clark**, Professor of Physics and Astronomy, retired in January 2017. Prof. Clark began his Purdue career in 1980 and conducted research in high energy theoretical physics, focusing quantum field theory and its application to elementary particle physics. He earned a B.S.from Rensselaer Polytechnic Institute and an M.S. and Ph.D. from New York University.



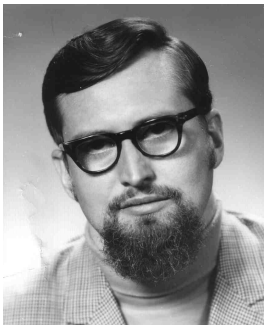
**Yeong Kim**, Professor of Physics and Astronomy, joined the faculty in 1967 and retired in June 2017 after 50 years of service. His research focused on theoretical nuclear physics, specifically in the area of many-body theory. During his time at Purdue, Prof. Kim served as Director of the Purdue Center for Sensing Science and Technology and Director of the Division of Sponsored Program Development for the Purdue Research Foundation. Prof. Kim holds a B.S. from Lincoln Memorial University and a Ph.D. from the University of California.

**Chen Yang**, Associate Professor of Chemistry and Associate Professor of Physics and Astronomy, began as an Assistant Professor at Purdue in 2007 in the area of experimental condensed matter. She was promoted to Associate Professor in 2013. She accepted a position at Boston University in July 2017.

# Faculty Memorials

**Art Garfinkel**
1934 - 2017

**Zbig Grabowski**
1931 - 2017



**Jim Mullen**
1933 - 2017

# Staff Recognitions

**College of Science Customer Service Award**
Anna Bauer
Carol Buuck
Mark Linvill
Bruce Poer

**College of Science Engagement Award**
David Sederberg

**College of Science Professional Achievement Award**
Tom Woodruff

**College of Science Team Award**
Emjai Gregory
Marsha Grider
Kasey Howe
Carla Redding
Keith Schmitter
Mark Smith

*Staff Awardees (from left to right): Tom Woodruff, David Sederberg, Carol Buuck, Bruce Poer, Mark Linvill, Mark Smith, Keith Schmitter, Kasey Howe, Marsha Grider, Emjai Gregory, Anna Bauer, Department Head John Finley, Dean Craig Svensson.*

# Staff Retirements

**Linda Paquay,** Condensed Matter Secretary, Years of Service 1983-2017
**V.K. Saxena**, Coordinator of Computerized Instruction, Years of Service 1987 - 2017
**Nancy Schnepp**, Condensed Matter Secretary, Years of Service 1975-2017
**Randy Schnepp**, Lecture Demonstration Assistant, Years of Service 1983-2017

**Did You Know?**

The department welcomed 32 incoming graduate students and 70 incoming undergraduate students this fall.

# Graduate Student Awards

**Akeley-Mandler Award for Teaching Excellence**
Kelsie Niffenegger

**Bilsland Dissertation Fellowship**
Yifei He
Julian Varennes

**Charlotte Ida Litman-Tubis Writing Award**
Dustin Hemphill

**Class of 1922 Outstanding Innovation in Helping Students Learn Award**
David Blasing

**Dr. Warner L. Black Award**
Jacques Pienaar

**Edward S. Akeley Award**
Sean Fancher

**Gabriele F. Giuliani Award**
John Daniel

**George W. Tautfest Award**
Jian Sun

**H.Y. Fan Award**
Katherine Schreiber

**Karl Lark-Horovitz Award**
Katherine Schreiber

**Lijuan Wang Award**
Cassie Reuter

**Teaching Academy Graduate Teaching Award**
Peter Anderson
Darryl Masson

# Undergraduate Student Awards

**Arthur N. Pozner Scholarship**
Alaina Glidden

**Frederik J. Belinfante Scholarship**
Nathan Glotzbach
Edwina Sunny

**College of Science Outstanding Student Award**
Andrew Santos (Fr)
Oscar Dilman (So)
Joshua Leeman (Jr)
Zachary Schroeder (Sr)

**David G. Seiler Physics Scholarship**
Diana Forbes

**Judith Peters Humnicky Memorial Award**
Annaliese Bankson

**Kenneth S. and Paula D. Krane Scholarship**
Joshua Leeman
Zhengjia Tong

**Lijuan Wang Award**
Elizabeth Spiers

**Margie and Don Bottorff Physics Scholarship**
Nathaniel Essington
Charles Guinn
Tristan Schefke

**Richard W. King Award**
Colin Burke (Jr)
Bruce Edelman (Sr)

**Shalim and Paul Sargis Memorial Scholarship**
Rachel Lee
Joshua Leeman

**Spira Summer Research Award**
Joshua Leeman

# Physics of Collective Cell Sensing

Andrew Mugler

Cells are remarkably precise chemical sensors. A single amoeba can detect a difference of about 60 molecules between the two halves of its cell volume [1]. When cells work together, their sensory precision can be even higher. A group of neurons can detect a difference of less than 1 molecule across a cell volume [1]. This precision is not just remarkable, it also approaches the limit of what is physically possible.

The physics of cell sensing was first studied forty years ago by biophysicist Howard Berg and Nobel Prize-winning physicist (and Purdue graduate) Edward Purcell [2]. Berg and Purcell realized that the precision of cell sensing was limited by the physics of diffusion. Specifically, they asked how precisely a cell could measure a uniform concentration of mean value c (Figure 1A). Modeling the cell as a sphere of radius $a$ that is permeable to the chemical, they reasoned that the average number of molecules inside the cell is $\mu \sim ca^3$, but that this number fluctuates due to molecular diffusion. Because diffusion is a Poisson process, the variance of this number is equal to its mean. However, they argued that the cell could reduce this variance by taking more than one measurement. In a time $T$, a cell could make about $T/(a^2/D)$ independent measurements, where $a^2/D$ is the typical time for diffusion with coefficient $D$ to refresh the molecules in the cell. This results in a reduced variance of $\sigma^2 \sim ca^3/[T/(a^2/D)]$, or a fractional error of $\sigma/\mu \sim 1/(acDT)^{1/2}$. Intuitively, the error decreases with the size ($a$) and the measurement time ($T$) of the cell, and with the amount ($c$) and the diffusivity ($D$) of the chemical.

Berg and Purcell showed that these simple arguments set a bound on the performance of an *Escherichia coli* bacterium (Figure 1B) as it searches for molecular nutrients [2]. Amazingly, not only do bacteria obey this bound, but they approach the maximum precision to within a factor of two. Bacterial sensory precision thus

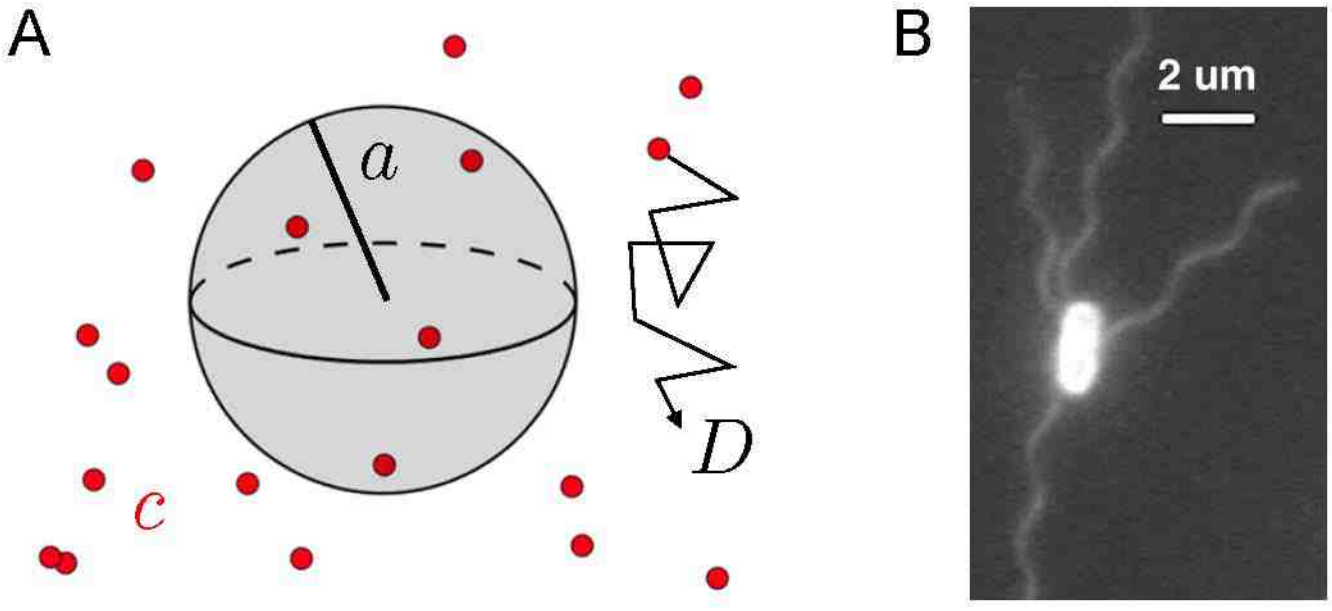



**Figure 1**. Molecular diffusion limits the precision of cellular sensing. (A) A molecule with uniform concentration $c$ and diffusion coefficient $D$ is sensed by a spherical cell with radius a that is permeable to the molecule. Adapted from [1]. (B) Image of an *E. coli* bacterial cell from Howard Berg's group [3].

approaches the limit of what is possible given the physics of diffusion. In more recent years, it has been shown that amoebae and mammalian cells also approach similar sensory bounds [1].

How do groups of cells beat the single-cell bound? The answer is that they communicate. Cells communicate in many ways, most of which involve exchanging molecules. Molecule exchange can occur over short distances, via junctions that connect cell membranes; or over long distances, via one cell secreting diffusible molecules that are detected by another (or the same) cell (Figure 2A). Recently, my group has investigated which of these two communication mechanisms provides the larger improvement in sensory precision [4]. Surprisingly, we found that even though communication is weaker in the long-range mechanism than in the short-range mechanism, the sensory error falls off more steeply with the number of cells (Figure 2B). The reason is that long-range communication allows cells to spread out, which in turn allows their measurements of the sensed chemical to be more independent from one another. The results help explain why bacteria, and even some tumor cells, spread out when performing sensory tasks [4].

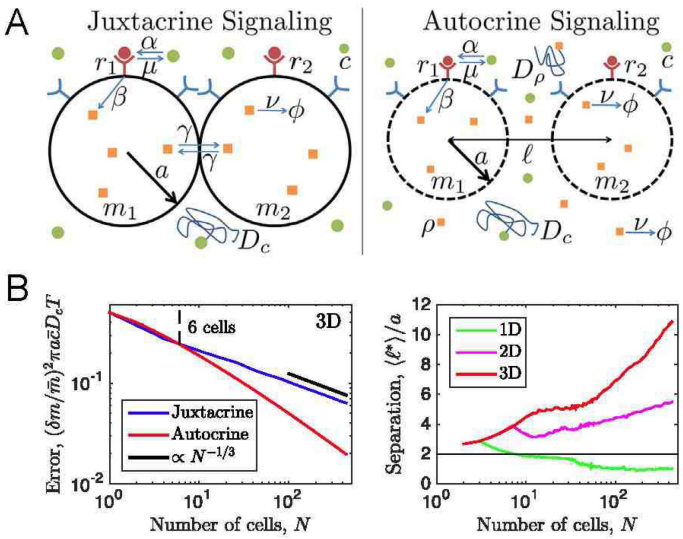



**Figure 2**. Long-range communication leads to more precise sensing than short-range comunication. (A) Schematics of cells using short-range, or juxtacrine, communication (left) and long-range, or autocrine, communication (right). (B) With long-range communication, sensory error falls off more steeply with the number of cells (left), and cell-cell separation grows with the number of cells (right, '3D'). From [4].

Groups of cells not only sense their environment, they also respond to the information that they sense. A common response is migration. Indeed, migration is often guided by a chemical cue such as a concentration gradient, a process termed chemotaxis. Do groups of cells sense the gradient individually and then migrate collectively (individual-based chemotaxis), or do they also sense the gradient collectively (emergent chemotaxis)? My group investigated whether these two stratgies resulted in different migratory precision (Figure 3A). We found that for one-dimensional cell chains and two-dimensional cell sheets, but not three-dimensional cell clusters, the sensory error falls off more steeply with the number of cells in the emergent strategy than in the individual-based strategy (Figure 3B), due to the geometry-dependent way that errors cancel out [5]. This finding helps explain why emergent chemotaxis has been observed in a variety of biological processes, including embryonic development, morphogenesis, and cancer metastasis [5].

What questions about collective cell sensing remain to be answered? The phenomena described thus far rely on linear processes, where the communication or migration strength is linearly proportional to the sensed concentration. Yet, cells possess complex molecular networks that can nonlinearly amplify the signals that they receive. These networks often contain transition points (e.g., bifurcations) that are reminiscent of crtitical points in many-body physical systems. Currently, my group is investigating these networks to determine whether they endow communicating cell populations with some of the same features as critical systems, such as long-range order, which could facilitate environmental sensing.

Nonlinear amplification can also lead to interesting dynamics in cell populations. It was recently discovered that bacterial populations communicate by passing ions from cell to cell, resulting in electrical signaling similar to that in neurons [6]. This form of communication allows cells on the edge of the bacterial population to transmit information to cells in the center about nutrients in the environment. My group is working with the experimental group that made this discovery, to investigate this communication at the single-cell level. We are finding that this type of communication has important advantages, such as the fact that not all cells need to participate in the signaling in order for the sensory information to be faithfully transmitted across the population.

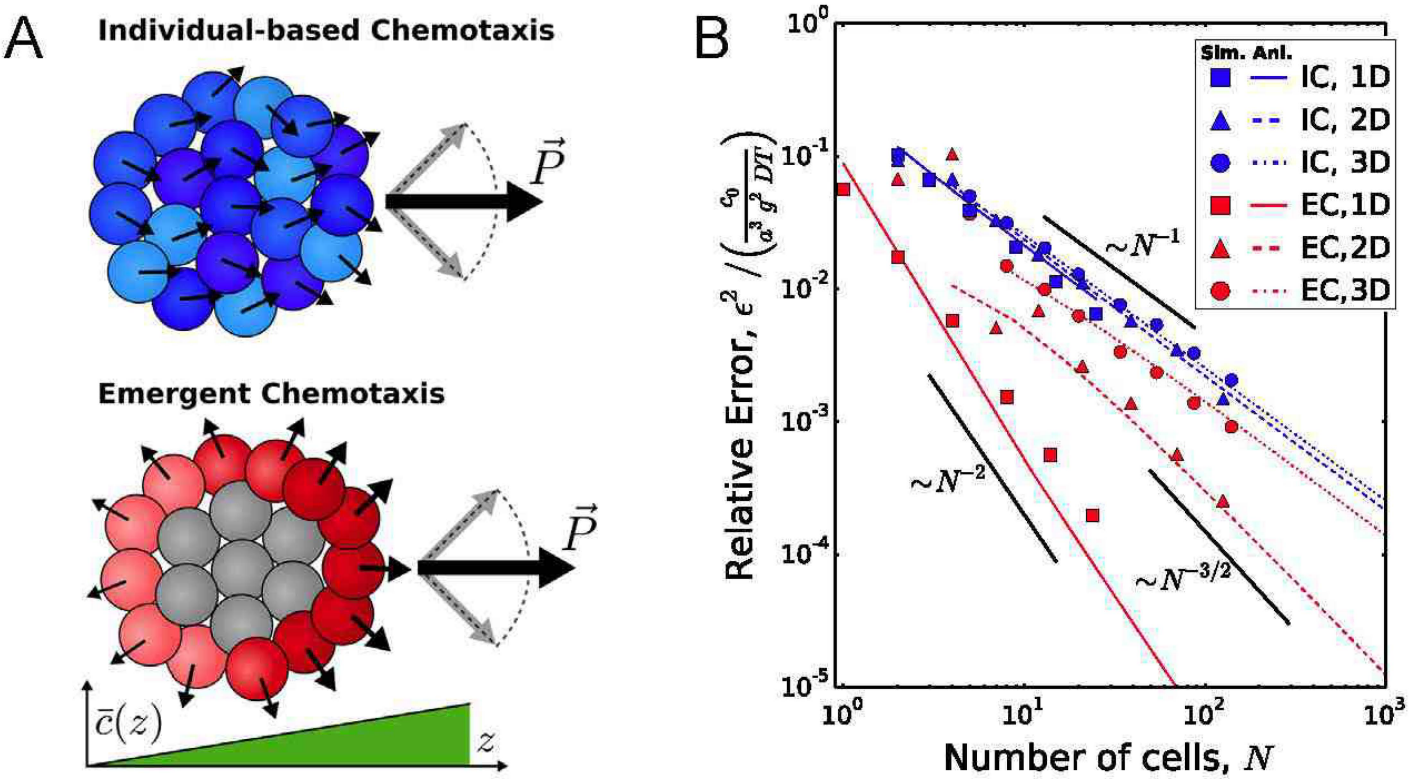



**Figure 3**. Emergent chemotaxis leads to more precise migration than individual-based chemotaxis. (A) Cells either sense a chemical gradient individually and migrate collectively (individual-based, top), or they also sense the gradient collectively (emergent, bottom). (B) Sensory error falls off more steeply with the number of cells in emergent chemotaxis, for one- or two-dimensional cell groups. From [5].

Building a precise chemical sensor is a fundamental and challenging problem. Yet, cells have solved it. Indeed, cells reduce sensory noise to its physical limit. Even better, groups of cells beat this limit by communicating. Understanding cell sensing, like so many biological phenomena, requires answers—but also inspires questions—from physics. It will be exciting to see what new physics questions cells inspire next.

**References**

[1] J. Varennes and A. Mugler. Sense and sensitivity: physical limits to multicellular sensing, migration and drug response. Molecular Pharmaceutics 13(7):2224-2232, 2016.
[2] H. C. Berg and E. M. Purcell. Physics of chemoreception. Biophysical Journal 20(2):193-219, 1977.
[3] L. Turner, W. S. Ryu, and H. C. Berg. Real-time imaging of fluorescent flagellar filaments. Journal of Bacteriology 182(10):2793-2801, 2000.
[4] S. Fancher and A. Mugler. Fundamental limits to collective concentration sensing in cell populations. Physical Review Letters 118:078101, 2017.
[5] J. Varennes, S. Fancher, B. Han, and A. Mugler. Emergent versus individual-based multicellular chemotaxis. Physical Review Letters 119:188101, 2017.
[6] A. Prindle, J. Liu, M. Asally, S. Ly, J. Garcia-Ojalvo, and G. M. Süel. Ion channels enable electrical communication in bacterial communities. Nature, 527(7576):59-63, 2015.

*Research in the Mugler Group is supported by the Simons Foundation, the National Institutes of Health National Institute for General Medical Studies, the Human Frontier Science Program, the Ralph W. and Grace M. Showalter Research Trust, the Purdue Research Foundation, and the Purdue Graduate School Bilsland Dissertation Fellowship.*

# Saturday Morning Astrophysics at Purdue

David Sederberg

Saturday Morning Astrophysics at Purdue (SMAP) is one of the Department of Physics and Astronomy's flagship outreach programs. Aimed specifically at the middle and high school audience, SMAP brings students to the Department for monthly forays into topics in astronomy, astrophysics, and related areas of study and research. Conceived in the fall of 2014 by astrophysics Post Doc Matthew Wiesner and Dr. David Sederberg, Physics and Astronomy Outreach coordinator, SMAP began its fledgling run in the spring 2015 semester with about a dozen students. Three years later and building momentum, we now have a roster of over 40 students, with a waiting list.

SMAP is a hands-on activity based learning program focused on fundamental principles of science, current topics and groundbreaking research. In *Scaling the Cosmos*, for example, students constructed accurate scale representations to compare the relative sizes of the planets, and then distributed them outside to understand the relative distances between them. The unique part of this lesson is that both activities were done at the same scale.

*(Left)* Students used modeling clay to construct models of the planets that were proportional to actual size.

*(Above)* Students placed their models at the correct distances scaled down for the size of their models. The photo is taken from the Mars station pointing back at the Sun (red arrow). Seem far away? That's the point!

In other SMAP sessions, students have learned about the tools of science and discovered some of the ways by which we know what's out there. *The Search for Dark Matter* used a model detector with tennis ball neutrons and bocce ball wimps (weakly interacting massive particles, i.e. dark matter particles) interacting with ping-pong ball xenon atoms. Students recorded and analyzed the distinctive sound profiles to learn how researchers are able to distinguish types of particle interactions and signals from background.

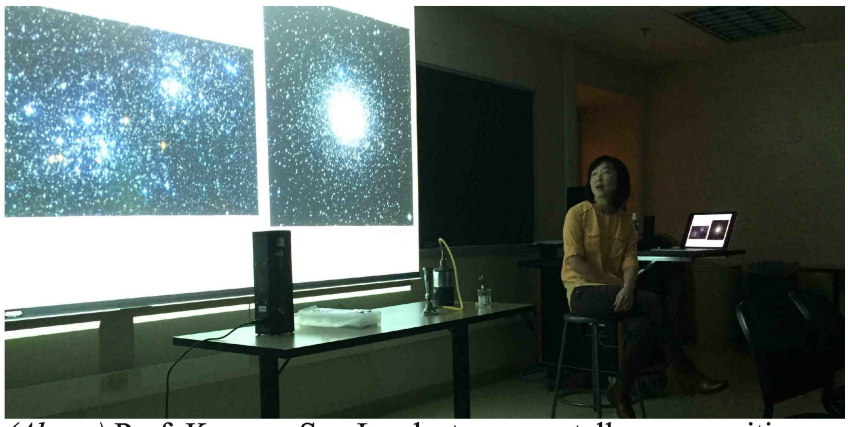
*(Right)* Matthew Wiesner leads a group of students through The Search for Dark Matter.

*(Above)* SMAP students build cloud chambers to detect radiation.

Other SMAP sessions have used open-ended investigations to pique students' curiosity. In *Radiation from Space*, for example, students constructed cloud chambers to see, first-hand, evidence that we are constantly bombarded with muons – ionizing radiation similar to what they observe coming from radioactive sources here on Earth.

***"[My child] truly enjoys the classes. That is why he [is] retaking them again this year. All the staff are helpful and friendly and encourage students to do their experiments without frustration. The classes are taught on the students' eye level. I really appreciate you offering this great workshop."***

SMAP serves Physics and Astronomy faculty as well as students, by providing opportunities for broader impact and engagement. In *Stars – What Are They*, for example, astronomer Kyoung-Soo Lee, introduced students to ways in which researchers know stellar composition. In her session, students used diffraction glasses to examine emission spectra to learn how we know the elemental make-up of a star and the type to which it belongs. Professor Chen-Lung Hung is currently providing resources for an upcoming session on gravity waves, in which SMAP students will assemble interferometers to how gravity waves are detected.



*(Above)* Prof. Kyoung-Soo Lee lectures on stellar composition.

SMAP has provided valuable and rewarding professional experiences for graduate students and post docs whose interests lie in teaching and outreach in addition to research. Post Doc Matthew Wiesner, for example, having created a number of SMAP sessions, has moved on to a faculty position at Benedictine College. Rodolfo Barniol Duran, now on the faculty at California State University at Sacramento, also designed and conducted SMAP classes while a Post Doc at Purdue. Current astrophysics Post Doc, Avery Archer recently led *The Search For Exoplanets*, in which SMAP students collected and analyzed data using a computer simulation created by service learning student Guna Kondapaneni. Matthew and Rodolfo continue to work with Outreach Coordinator David Sederberg, including SMAP contributions as broader impact components in their grant proposals.

SMAP relies heavily on the continued creativity, resourcefulness, and tireless effort by undergraduates enrolled in Physics and Astronomy service learning courses. Service learning provides our undergraduates experiences that build skills and develop deeper knowledge and at the same time contribute to the community and mission of outreach. An example of a student developed activity is one by physics undergraduate Colin Burke. Colin spent weeks developing the right terrestrial substrate to model characteristics of craters, and writing an appropriate protocol. In his activity, SMAP students used a giant slingshot to fire scale meteors into a sand mixture to calculate and compare energy of impact to crater dimensions. Yahia Aly, an undergraduate in aeronautical engineering, presented a lesson on rocket components and how rockets work. In his activity, Yahia had students design elements for and launch water bottle rockets to investigate the variable of fuel, force, mass and altitude.

SMAP is a working example of the kinds of synergies, partnerships and collaborations that are essential to Physics and Astronomy Outreach fulfilling its mission. We are particularly proud of and grateful for partnerships with the Wabash Valley Astronomical Society, Prairie Grass Observatory, and high school teachers who have not only contributed to SMAP, but use SMAP activities in their classrooms. Jefferson High School teacher and Director of the Planetarium, William Huston, has hosted multiple SMAP sessions at the Planetarium. Jefferson physics teacher Debbie Beck, a contributor to SMAP since its inception, has just completed a lab that will be the focus on an upcoming session on dark matter.

The success of Saturday Morning Astrophysics at Purdue is evident by the number of students returning for a second or even a third year, the praise from parents whose children attend, and by the ever increasing number of registrations. One challenge is our ongoing search for new ideas and topics for investigation. Another is finding ways in which we can make content relevant and appropriate to an audience with limited knowledge of physics and mathematics.

***"Thank you again for organizing such a tremendous experience. [My child] talked at length (for real :) ) on the way home from Prairie Grass Observatory. He especially liked the LA - NYC [size of our galaxy] – quarter [in the desert (for our solar system)]; and football field full of birdseed [stars in our galaxy] examples because they really helped to downsize and make familiar the enormity of space. His favorite part of the evening - by far - was looking at [the night sky] with Stellarium. He said he could have stayed for another two hours looking at the nebulas especially. Saturday evening really invigorated him; he wants to use our [telescope] on a more regular basis."***

*(Above)* Lafayette Jefferson High School students work on the *Impact Crater* activity developed by Physics and Astronomy Undergraduate Colin Burke.

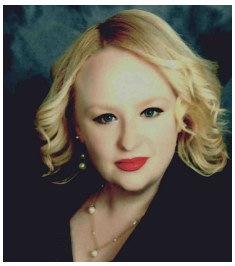
*Saturday Morning Astrophysics at Purdue is supported by the College of Science Outreach Program, the Indiana Space Grant Consortium, and through the generous contributions of friends and alumni.*

For more information on SMAP and other Physics and Astronomy Outreach activities, vist www.physics.purdue.edu/outreach.

**Did You Know?**

In 2017, Physics and Astronomy Outreach led science activities with over 7,000 students in K-12 classrooms throughout Indiana.

# From the Director of Development



Greetings from West Lafayette! It is beautiful here this time of year, and I would love to see you back on campus soon! Since taking the role of Director of Development in March of 2016, I have had the pleasure to meet many of our alumni and friends across the United States. As a fellow Boilermaker, I am excited to continue meeting with Physics and Astronomy alumni and friends in order to celebrate your education, your career and discuss the ways the department is able to continue producing strong professionals able to succeed in a variety of disciplines.

Publicly launched in October of 2015, with a goal of $2.019 billion, the Ever True campaign is the largest fundraising effort in Purdue history. The campaign spans July 1, 2012, through June 30, 2019, concluding in the University's 150th anniversary year. This campaign will propel the Purdue Moves initiatives—Affordability & Accessibility, STEM Leadership, World-Changing Research, and Transformative Education—and reinforce the University's overarching commitment to keep a rigorous college education within students' financial reach. As of September 30, 2017, the campaign has reached $1,592,533,363 (78.80%) of the $2,020,968,452 goal.

Your gifts to Physics and Astronomy help achieve those goals in STEM Leadership – no matter the size! 86% of our donors have given $1,000 or less. EVERY GIFT MATTERS. Faculty professorships are the department's greatest need as they are necessary for attracting and retaining faculty. Ongoing needs also include graduate fellowships, undergraduate scholarships and Physics building updates necessary for giving the next generation of alumni the tools needed to succeed.

I would like to extend a personal invitation to join other fellow Boilermakers, through private giving and personal involvement, to help achieve our goals—and, in doing so, to boldly advance our University as a national and global leader that continues to move the world forward. Our students, faculty and administration cannot thank you enough for your continued generosity and loyalty!

Boiler Up!
Ever Grateful,
Becky Spears '06 '10

# 2017 Distinguished Alumni Award

The Department of Physics and Astronomy recognized Prof. Beers on April 7, 2017.

**Timothy C. Beers (BS 1979)**

Prof. Tim Beers, BS 1979 has distinguished himself as a leading in the astrophysics community. In his early career at Harvard (1979-1983) and later as a Bantrell Postdoctoral Fellow at Caltech (1983-1986), Beers' work on the structure and evolution of galaxy clusters demonstrated the importance of cluster substructure, at a time when this was still very much an open question. From 1986 to 2012, Beers was a professor at Michigan State University has concentrated his efforts on the discovery and analysis of the first generations of stars and surveying the Milky Way as part of the Sloan Foundation's Digital Sky Survey. Beers' early contributions to the area of Galactic Archaeology, for which he is recognized as one of the founding fathers, were in the design and execution of the large-scale surveys required to find the exceedingly rare examples of the very oldest stars in our own Galaxy. Beers served as Director of Kitt Peak National Observatory from 2012 to 2014 and currently holds the Notre Dame Chair of Astrophysics at Notre Dame University. He is co-PI and Associate Director of the highly successful NSF Physics Frontier Center, JINA: Joint Institute for Nuclear Astrophysics, which brings together the work of nuclear physicists and astronomers at numerous institutions worldwide to make transformational progress on understanding of the formation of the elements, and the astrophysics of the sites in which they were produced.

# 2017 Outstanding Alumni Award

**Naresh Menon (BS 1993, PhD 1999)**

Naresh is the founder of ChromoLogic, a company that develops novel biomedical solutions that improve healthcare outcomes while reducing costs. His PhD research at Purdue under Professor Ian Shipsey emphasized sensor fabrication, instrumentation and novel data analytic methods that he has applied to fundamental physics discoveries at laboratories across the globe and to industrial applications during his early career at Corning Incorporated and Northrop Grumman Mission Systems. Naresh currently serves on the University of Maryland Bioengineering External Board of Advisors, NSF PREM External Advisory Board, Healthcare IT State Wide (California) Community College Curriculum Committee, Industry Panel, and the Adaptive Business Leaders Healthcare Round Table – 2010 to date

**Ted Moore (BS 1987, MS 1991)**

Ted is a serial entrepreneur who currently serves as Chief Technical Officer at Indy Audio Labs, a company he co-founded in 2009 that develops technically advanced immersive and connected home audio products. As founder of Solmirus Corp., Ted designed and developed infrared and visible spectrum astronomical instruments that are in use at key telescope facilities in Arizona and Chile. Ted also served at Sr. Director of Electronics at Klipsch Audio Technologies where he led the program to create a suite of home theater products for mass-market distribution. Ted serves as a member of the Purdue College of Science Alumni Board, is a member of the American Physical Society, the Audio Engineering Society and his company IAL is a member of the Custom Electronic Design and Installation Association.

# Physics Degrees December 2016 - August 2017

### Bachelor of Science

| | | | | | |
|---|---|---|---|---|---|
| Christian Bachman | Gavin Cox | Matthew Knowles | Ashley Marinik | Carl Olthoff | Peter Thompson |
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| Dalton Chaffee | Grant Harrell | Yanjun Li | Yang Mo | Elizabeth Spiers | |
| Nicholas Cinko | Alison Hoe | Corey Loescher | Scott Mulles | Andrew Spring | |
| Kevin Colbert | Cheng Ji | Stephen Macnak | Colby Neumann | Daniel Sweeney | |

### Master of Science

| | | | | | |
|---|---|---|---|---|---|
| Fan Chen | Ridhi Mehta | Daniel Merrill | Michael Muetherties | Gregory Neeser | Emma Rieth |

### Doctor of Philosophy

| | | | | | |
|---|---|---|---|---|---|
| Peter Anderson | Mridula Damodaran | Jignesh Mehta | Cassie Reuter | Deke Sun | Haoyu Wang |
| Fan Chen | Yijue Ding | Jacques Pienaar | Yanfei Shen | Hao Sun | Qiang Zhang |
| Jun Cheng | Jordan Kendall | Shayne Reichard | Valentyn Stadnytskyi | Cyrus Vandrevala | |

***Congratulations to our newest alumni!***

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