APS physics™ | FECS
FORUM FOR
Early Career Scientists

Spring 2018 AMERICAN PHYSICAL SOCIETY aps.org/units/fecs

Message from the Newsletter Editor

Greetings, FECS members! We are delighted to present our second newsletter, for Spring 2018. We hope you find it informative and interesting. In these newsletters, in general, we aim to provide you with useful information about basic research in different fields of physics, information about our activities at conferences and elsewhere, opportunities to actively participate in FECS, and helpful guidelines toward furthering your career.

This issue features an overview of cosmology as an exciting field of study and opportunity, information about upcoming FECS activities and sessions at the APS March Meeting and April Meeting in 2018, tips on being successful in the process of finding a job and applying a Physics degree toward a career, and an overview of the APS Division of Fluid Dynamics (DFD) conference that happened in November.

I just wanted to say thank you to all the members of the FECS Executive Committee for your hard work and contributions to this issue, and thank you to all the FECS members for reading. If you ever have suggestions or comments about the newsletter, you can reach me at kludwick@lagrange.edu. I hope to see you and connect with you at upcoming APS meetings!

Kevin Ludwick

Newsletter Editor

Kevin obtained his Ph.D. from the University of North Carolina at Chapel Hill. After a two-year postdoc at the University of Virginia, he became an assistant professor at LaGrange College in 2015. His research is in theoretical cosmology, pertaining to dark energy and dark matter models.

IN THIS ISSUE:

Views and opinions expressed in articles are those of the author and are not necessarily shared by the editor or the APS/FECS.

Message from the Chair

Maria Longobardi, Chair

Dear FECS members,

It has been an honor and pleasure to serve this first year as Chair of the FECS. I would especially like to thank my colleagues on the Executive Committee whose enthusiasm made my job easy and exciting. Our community is constantly growing, and we are proud to represent currently more than 3000 members, and we hope to continue to attract scientists from all over the world.

The FECS are developing several activities, some of them jointly with other APS units, to provide increased opportunity for inclusion with members of the physics community.

In this newletter, you can find information on the FECS activities during the next APS Meeting.

At the March Meeting, the FECS and the Topical Group on Energy Research and Applications (GERA) will co-sponsor the workshop "The Future of Sustainable Approaches to Energy" and two sessions with

our partners at the Forum on Industrial and Applied Physics (FIAP) and the Forum on International Physics (FIP).

In addition, FECS will host a shared reception with the FIP on the evening Tuesday March 6 and another shared reception with FIAP on the evening Wednesday March 7. If you will be at the March meeting, please do come by.

At the April Meeting, we will discuss about physics and society in the session "Getting the Word Out" co-sponsored with our Forum on Physics and Society (FPS) partner. FECS and FIP will also celebrate the two winners of the APS Sakharov Prize for 2018.

More information about sessions will be on the FECS website in the next weeks, and I hope to see you all at our APS meetings.

As I wrote, it has been an honor and privilege to serve the FECS and to play a part in promoting activities, exchange and dialogue opportunities for the community of early career scientists. I am sure that in the next year this work will continue as the FECS grows into new challenges and opportunities.

I send all my best wishes to the Chair-Elect Jason S. Gardner for a fruitful and successful 2018 as Chair; I am sure that the FECS will be in very good hands. I want to thank again Kevin Ludwick for the FECS newsletter and Greg Hamilton for our Facebook group and all the other Executive Committee members for their valuable contributions: collaboration is our strength!

Best wishes to all of you for a wonderful 2018,

Maria

Maria Longobardi earned her Ph.D. in Physics from the University of Salerno, Italy in 2010 in experimental condensed matter physics. There she explored the local electronic and magnetic properties of superconductors, oxides and novel materials.

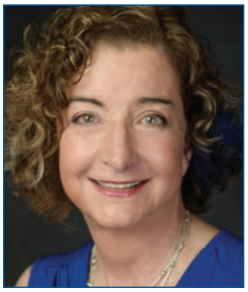
In 2011, she moved to the University of Geneva, Switzerland where her studies focused on the electronic properties of 1D systems at the atomic scale and on the atomics defects of 2D materials. She is currently at the Microbiology Department in Geneva performing interdisciplinary studies on novel hybrid biomaterials and bio-nanomaterials.

Maria is also a science communicator and freelance journalist. She has been active in the development of several international programs and outreach/educational activities.

During the past years, she served the APS as International Student Affair Officer and Newsletter Editor for the FGSA (2011-2015) and as Member at Large and Newsletter Editor for the FIP (2014-Current).

Message from Laura Greene

2018 APS Past President



It is a great pleasure and honor to welcome the Forum on Early Career Scientists to our APS Unit Family, with many congratulations on an extremely successful first year and growing membership. Supporting our young physicists is crucial to the future of APS, and to physics in general. APS only wishes to help FECS to meet the important objectives: to foster communication and cooperation among early career scientists. I am particularly impressed that your objective specifically states diversity: to reach beyond physicists, being inclusive of engineers, mathematicians, and people in other related areas. This is beautifully demonstrated by your 2018 March Meeting workshop, in which you pair with GERA for an Energy Workshop: Well done!

APS will continue to be looking to the members and leadership of FECS for guidance in how we can help engage your members across all APS units and members.

All my best wishes to you all.

Laura

NEWS

The Forum For Early Career Scientists (FECS) Activities at the March and April 2018 APS Meetings

Jason S. Gardner, Chair-Elect – Forum For Early Career Scientists, NSRRC, Taiwan

Jason S. Gardner

It is important for a young forum like ours to develop name recognition and to make the APS membership aware of our objectives that separate us from all the other units. To meet this goal, we plan to spend the next couple of years maximizing our exposure to the community.

In 2018 we have doubled up on the number of sessions we can participate in at the meetings by co-sponsoring sessions. Within this newsletter, we have outlined the sessions that FECS are supporting. FECS is privileged to be a part of the Sakharov Prize, to recognise those upholding human rights. In March, our sessions on science on the International Space Station and data science should also be well attended. Sponsoring these important and popular sessions is good publicity, and I hope we will find many new FECS members in the crowd. I want to mention here that these fantastic sessions would not have happened without the hard work of Marilena Longobardi on the program committee.

The March 2018 meeting is expected to attract over 10^4 APS members to LA. FECS will begin working early by assisting the Topical Group on Energy Research and Applications (GERA) hold its annual workshop for graduate students and postdocs on Sunday, March 4th. In Los Angeles, CA the theme will be Energy Storage, Solar Energy, and Magnetics for use in Energy Applications. The Forum for Early Career Scientists will co-sponsor two receptions. At the FIP/FECS reception, we will celebrate international efforts in physics. Several prizes and fellowship pins will be awarded, and you might spot a Nobel Laureate at the bar. We are also working with FIAP to co-host a reception at the convention center. This is an excellent opportunity to meet other FECS members, including the executive committee members, and those scientists interested in the industrial and applied sides of research. Please look out for emails and flyers informing you of the time and place of all these events.

In Columbus, OH during the April meeting, the

executive committee will be available to discuss our mission and to listen to membership suggestions. The FECS will also man a membership table at both meetings where you can stop by, tell us what you think, sign up as a member, and take away a freebie. FECS strives to offer scientists, from undergraduates to junior faculty, the chance to interact with others working in academic and non-academic fields, both nationally and internationally. We would like to hear your ideas on how we should deliver this goal. The FECS executive meeting, also held in Columbus during the APS meeting, will discuss and expand on such activities.

If you attend the March or April meetings, we hope to see you there. Alternatively, you may write us an email. We always look forward to hearing your ideas.

After obtaining his Ph.D. at Warwick University in the UK, Jason worked for several national laboratories in North America before moving to Sydney, Australia in 2013. From Sydney, he manages a group of five people performing neutron scattering at ANSTO, Australia, and around the world. He is currently the Neutron Group Leader at the National Synchrotron Radiation Research Center, Taiwan. His scientific interests are primarily in frustrated magnets, but he's also performed research in many areas of condensed matter over thirty years of research. He has published over 120 papers and in 2008 was made a fellow of the Institute of Physics (UK). Jason is also a member-at-large of the APS Forum on International Physics.

Forum For Early Career Scientists (FECS) Sessions at the Upcoming APS Meetings

Jason S. Gardner, Chair-Elect – Forum For Early Career Scientists, NSRRC, Taiwan

As a new forum, we were delighted to be asked to create an invited session at both the March and April 2018 APS meetings. We maximised our contribution and exposure by co-hosting this quota with other APS units. The March 2018 meeting will be held in Los Angeles, CA between the 5th and 9th of March with about 10,000 expected attendees. The April meeting has a slightly different format and each session has only three invited speakers. This meeting will be held on April 14-17th in Columbus, OH, and will have the theme "Quarks to the Cosmos (Q2C)". In partnership with the Forum in International Physics (FIP), we will be co-hosting the Andrei Sakharov Prize session at the April 2018 meeting.

APS March Meeting, March 5-9, 2018 in Los Angeles, CA

Session 1 – Condensed Matter Experiments on the ISS (co-sponsored by FIP) – This will be held during the mid-morning session (11:15-2:15) on Friday, March 9th. Eric Furth (University of Delaware), Joe MacClennan (University of Colorado, Boulder), Hubertus Thomas (German Aerospace Center), John Goree (University of Iowa), Rob Thompson (NASA, Jet Propulsion Lab), and David Weitz (Harvard University) will discuss their work on colloids, plasmas, fluids and ultracold atoms on the International Space Station.

Session 2 –Data Science as the Driving Force for Industrial Physics (co-sponsored by FIAP) – This session will feature speakers discussing the collection and use of large data sets in an industrial setting. Speakers include: Neil Johnson from the University of Miami, recently awarded the *Joseph A. Burton Forum Award* by the APS; Sergey Yurgenson from DataRobot and St. Petersburg State University; Bryce Meredig from Citrine Informatics; David Purdy from Uber; and Sundeep Das from Netflix. This dynamic session will be held during the early morning session on Wednesday the 7th of March.

APS April Meeting, April 14-17, 2018 in Columbus, OH

We will co-host two sessions at the April meeting covering human rights and outreach. We expect these sessions to be well attended and believe it is important that young researchers realize they have a voice in these two important issues.

Session 1 – Physicists and Human Rights (co-sponsored by FIP) – This session will provide a platform for this year's recipients of the Andrei Sakharov Prize. In 2018, the co-recipients of this prize are Narges Mohammadi and Ravi Kuchimanchi. Narges Mohammadi is currently imprisoned in Iran so she will be represented by her brother Hamidreza Mohammadi. Ravi Kuchimanchi will

represent himself and present "Parity in our world and in physics". The third speaker in this session on physicists and human rights was selected by FECS. This will be Shelly Lesher of the University of Wisconsin at LaCrosse. The session will begin on Monday the 16th of April at 10:45.

Session 2 – Getting the Word Out (co-sponsored by FPS) – Saturday 14th April at 10:45. This session will feature three speakers in a discussion of the importance to scientists of disseminating their work to the widest audience possible. Drs. Bevitt, Silverberg, and Quider from Australia, Havard, and Northern Illinois University respectively will discuss how they do it and what people expect.

These sessions are often a bit different from the usual sessions championed by larger units like the divisions, but they are just as important. If you are at either of the meetings, please look out for our session and those of other forums, especially our sponsorship partners in 2018. These sessions are often more diverse, informative, and a nice break from hard-core scientific data.

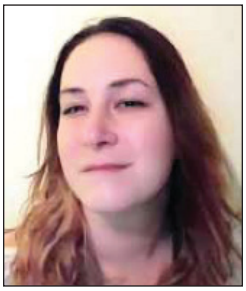
In addition to these invited sessions, the FECS will co-host two receptions during the March meeting with our friends from FIP and FIAP. If you will be at the March meeting, please do come by. Another FECS member will send out a reminder of this event before the March meeting.

In 2019, the APS will bring together both the March and April meetings, and participants will meet in Boston. This joint meeting will allow the forum to reach out to an even more diverse community beyond scientists, so we should take advantage of this opportunity. The program committee welcomes any suggestions for titles of sessions and/or individual speakers for the 2019 sessions. Please go to FECS Executive web page and email the chair-elect with your ideas.

Dr. Jason S. Gardner
Chair-Elect

From Graduation to Industry Employment: A Guide

Sara Clements, FECS Member at Large


Sara Clements

So you're graduating in May, and the world's looking bright. Everyone you meet exclaims either how smart you must be to have studied Physics or how science is such a valuable degree. You've decided not to go on in academia, so you look at industry job descriptions. The qualification lists are vague, possibly utilizing foreign enterprise terminology like 'excels at e-business functionalities', and all of them say they require *X* years of experience in a specific industry.

You think to yourself, "*I know how to solve Schrodinger's equation with appropriate boundary conditions; that's got to count for something!*" Well, it does, and this is a good-news-bad-news situation because (bad news) most interviewers don't know what this counts for, or even means, but (good news) there are plenty of ways to articulate exactly how this benefits any organization!

Applications 101 - Job Search and Resume Building

- **Consider your interests and how you can apply this to your career search.**
  - ◊ You don't have to have your life mapped out, but knowing what types of tasks you find generally interesting versus ones you abhor with a deep passion can help narrow down fields of interest. Does the idea of talking to people terrify you? You will definitely want to avoid listings that suggest the position is 'client-centric' or requires presentation skills. If you relish challenges and work excellently under pressure (read: you did all your studying within three days of your electromagnetism final and still managed top 70th percentile), look for 'works well under pressure', 'high-energy environment', etc.
  - ◊ Think of a couple key words to hone down listings.
    - If your favorite part in lab was collecting and analyzing the data, search for jobs with key words 'analyst' and 'data'. If you preferred putting

all of this together in a report and preparing it for presentation, use words like 'technical writing', 'data visualization', and 'presentation'.

- Remember that key words and job titles are different. While Data Analyst will have both data and analyst as key words, you may also find that job title is incredibly vague. Focus on the tools and skills required for the job; do these sound like things you already know? Are they things you would like to know better, or become an expert at? If not, keep moving. You don't want to end up bogged down working with Excel and VBA if what you are really interested in is learning R and SQL.

- **Tailor your resume.**
  - Start with a general resume template. This should reflect your career-related interests (as described above) and the experience and school work that support those interests. If you did any undergraduate research, be sure to incorporate specific details from this that support the key words you've established for your search.
  - Keep it relevant. Even if you've done something impressive to your parents and friends, if it doesn't apply to the position or company, I assure you the hiring manager will not care. Your semester learning how to perfect a soufflé at Le Cordon Bleu will not help you snag that engineering position at Boeing.
  - Tweak and tailor your general resume to different job descriptions before sending it along. Don't be afraid to use the job description as direct inspiration for items to add to your resume.
  - One-page resumes are ideal! There are CEOs with decades of experience and schooling that manage to keep it to one page, so keep in mind as a new-to-the-professional-world college grad, you probably don't need more than one page either. It takes time to read a resume and managing directors/HR reps can get hundreds of them for just a single job posting. The cleaner and simpler it is, the more likely they will read through the entire thing.
  - Pro Tip: Check out Overleaf (https://www.overleaf.com/gallery/tagged/cv#.WlpbEainGUk) for free access to LaTeX based resume templates. Great and easy to manipulate designs available that can easily be converted to PDF format.

Applications 102 - Cover Letter and Interview

- **Getting personal.**
  - The cover letter is your opportunity to express why they should pick you. This is where you expand on your resume and apply the points you've incorporated directly to the role. It is also where a little bit of 'you' comes out, so don't be afraid to write a little from the heart. The last thing I wanted to read when hiring candidates was the same ripped-off online cover letter template.
  - Keep it brief. The best feedback I have seen comes from cover letters that were half a page. This may seem unreasonably short, but being able to communicate how awesome you are and excited you are for an opportunity in just half a page shows you're an efficient communicator. That right there is a chance to *show* a skill instead of just telling someone you have it.
  - Some structure is nice, but if you are sending carbon copies of a letter out *en masse*, you probably aren't utilizing this aspect of applications to its full advantage. Create a skeleton that works for you (intro paragraph, body, closing), and then cater it to the role. For example, if you choose your intro to be why the company/role appeals to you, and you apply to similar roles, you can keep some of the details the same, but make sure you include something specific about the company and what prompted you to apply in the first place. Flattery gets one (almost) anywhere.

- **Confidence is key.**
  - Remember, you are convincing them that you are the best they can find for this job. While being excited and eager for the position isn't a bad thing, you also want to ensure your confidence comes through in spades. Here is where you can touch on either a specific experience from your education or outside endeavors and how they relate to the job. See some basic job description key words below, along with how to spin your Physics degree to fit the qualification -
    - Collaboration: Think about your work with a lab partner or group. How was the work split up? Your role in this group is the most important aspect they want to hear about. Did you encounter any challenges, and if so, how were they overcome? Be sure to mention you enjoyed collaborating with your classmates! Bonus points if you worked with others in a research position.
    - Communication: Incorporate this into above story.
    - Problem Solving Skills: This one should be easy, but since everyone thinks they are a problem solver and a very large portion of the world is not, remember this - you got your degree in problem solving. Outright tell the people you are applying with. They might not know anything about Physics, or what the degree entails. But this is 100% it. Briefly (one to

two sentences max) explain how your degree centered around being able to solve complex problems with a limited tool kit. Remember that time you were given an example of how to solve for the magnetic field of a perfect sphere, then on the test you had to solve for the magnetic field of an oblate spheroid with a spinning disc inside of it? Most people don't have that skill set. You do. Don't forget that the ability to learn a simple solution and apply it to a complex problem is absolutely invaluable in every industry, and every role. This should come up in the interview too.

- Quick Learner: Throughout your degree, learning how to use various tools from MatLab to an amplifier from the 1980s with only a printed technical manual was part of what you had to do to get the job done (and fast!). Attach the fact that picking up these skills along the way to arrive at an unrelated end goal was part of the expectation. Also, that you enjoy discovering and learning new tools to find solutions.

◊ Pro Tip: Having a Physics degree is like being part of an in-group. If you see someone where you are applying has a Physics degree as well, try and direct your application her/his way if possible. I have seen this work many times for many people, myself included.

This guide can be used to start the often overwhelming process of jumping into the career world right out of academia, but don't forget you have other resources available to you. One of the most valuable resources is your network, and since you were smart enough to join with FECs, be smart enough to reach out for more advice! Utilize our Facebook page and ask questions. Want some extra eyes to review a cover letter or resume? Put it out there and see if someone has some time to spare. Most importantly, you are not alone in this process. Now best of luck getting out there and getting employed, graduates!

A graduate of the University of Texas in Austin with a B.S. in Physics, Sara now lives in Brooklyn, NY working remotely as a Data Analyst at United Healthcare for a team based in LA. At UT she worked with a research group studying the technique of Raman spectroscopy. A longtime proponent of supporting women in STEM, she has volunteered as a mentor for grade school girls with an interest in science and mathematics. Since leaving school she has picked up skills in computer science and analysis and hopes to continue to pursue that further with an advanced degree in data science.

"What Happens at the Division of Fluid Dynamics Meeting?"

Mark Owkes, Member-at-Large

Mark Owkes

The Division of Fluid Dynamics (DFD) is the largest of the APS divisions and hosts the second largest APS annual meeting. However, what occurs at the meeting and the research that is occurring in this area of APS is often unknown by much of the rest of APS. This article aims to share some of the exciting things occurring at the DFD meeting.

The DFD meeting occurs every November the Sunday-Tuesday before the Thanksgiving holiday. This past year, ten minute talks in thirty-nine parallel sessions over three days provided the fast-paced exchange of fluid dynamics research that occurs every year. Talks are on a wide range of fluids topics, including new experimental techniques such as x-ray imaging and electrically charged particles, numerical methods including approaches to discretize singularities at triple points and algorithms that are well suited for GPUs, and analytical work, for example, on a statistical theory of turbulent transition. Many of the topics are likely not unique to fluid dynamics, such as developing numerical methods to handle discontinuities, petascale computing, experimental imaging, model reduction, and techniques to handle big-data.

Fluids education and outreach is an area that has grown over the last decade and overlaps work done in other areas of APS. The sessions and lunch focus on best practices for

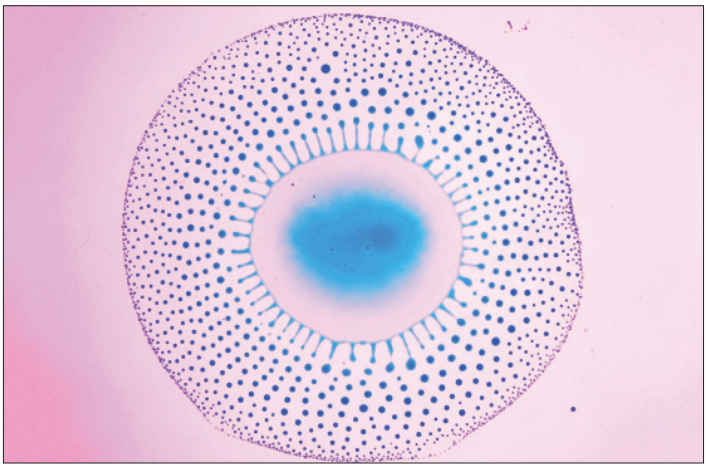
teaching fluid dynamics and engaging with the public.

Besides the technical presentations, the DFD meeting provides an opportunity to share some breathtaking posters and videos focused on fluid dynamics through the Gallery of Fluid Motion (GFM). The submissions illustrate science as well as the beauty of fluid motion. Additional information can be found at https://gfm.aps.org.

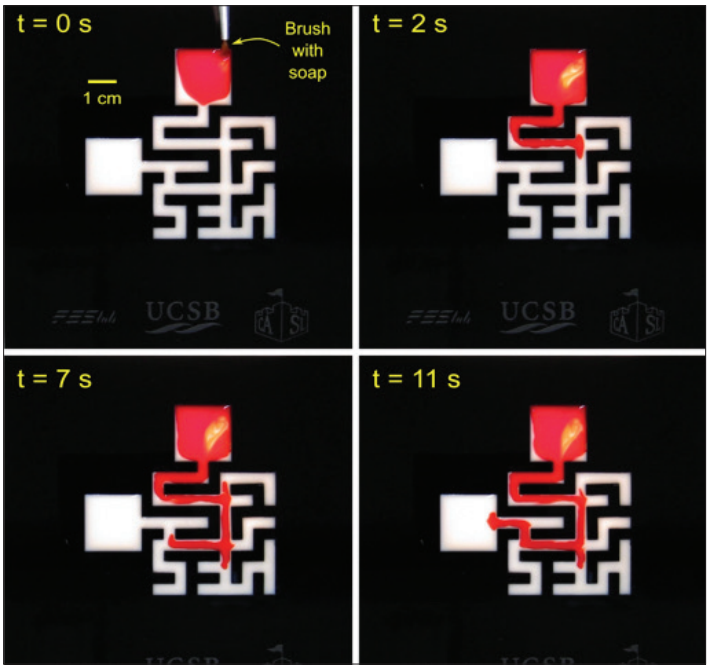
The DFD meeting is the world's leading conference for sharing and learning about advances in fluid dynamics research. To learn more about the meeting, see https://www.aps.org/units/dfd/, and if interested join us in Atlanta, GA, November 18-20, 2018.

Dr. Mark Owkes
Member-at-Large

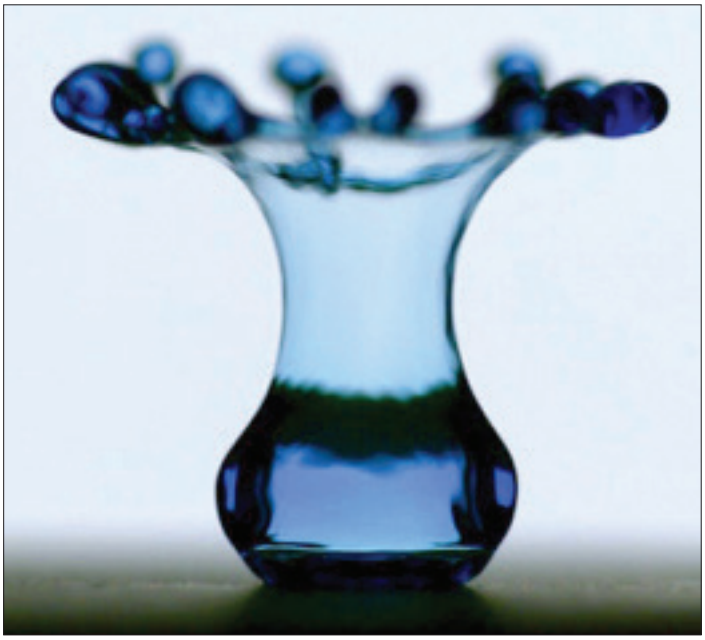
Mark is an assistant professor at Montana State University in the department of Mechanical and Industrial Engineering. His research interests include developing numerical methods to study gas-liquid multiphase flows such as the atomization of a liquid fuel.



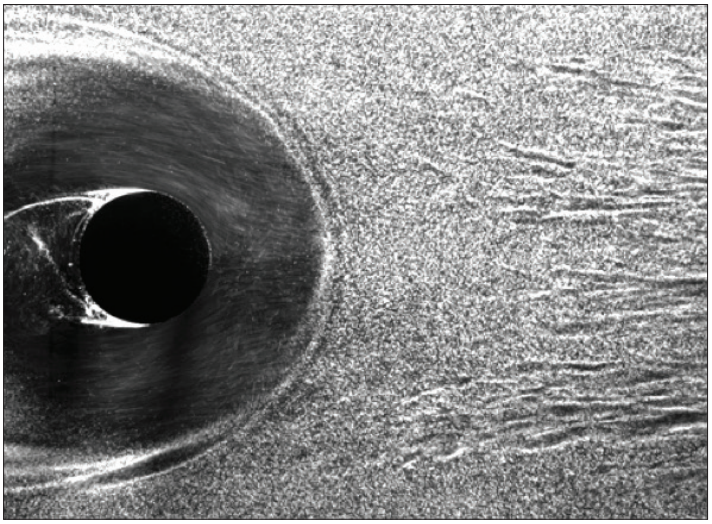
Spreading of a blue water/alcohol mixture into bath of sunflower oil. Fingering and droplet formation due to different evaporation rates of water and alcohol. Durey et al., "V0020: Marangoni Bursting: Evaporation-Induced Emulsification of a Two-Component Droplet", Gallery of Fluid Motion, 2017



Red dye "solving" maze filled with milk, after the addition of soap at the inlet. Temprano-Coleto et al., "V0098: Soap opera in the maze: Geometry matters in Marangoni flows", Gallery of Fluid Motion, 2017



Droplet breakup due to impulsive upward motion of plate underneath droplet. Chantelot et al., "V0080: Kicking Droplets", Gallery of Fluid Motion, 2017



Coherent structures within turbulent flow around a cylinder. Branson et al., "V0053: The Coexistence of Order and Chaos in C-major", Gallery of Fluid Motion, 2017

The Forum on Early Career Scientists Off to a Great Start!

Trish Lettieri, APS Director of Membership

After a full year of existence, the total FECS membership is just over 2,900. That's an impressive percentage of the total 4,100 Early Career members in APS (although membership is not limited to EC members). Your FECS officers have been working hard with other APS units to have a presence at all the national APS meetings, and it's paying off! If you will be attending either of the upcoming March or April meetings, be sure to look for FECS sessions and special career-related events.

APS has been focused on providing relevant information and career resources to those in the Early Career member category. Three years ago, the name off the "Junior" member category changed to "Early Career", and eligibility was also extended from three to five years. This member category allows for a half-priced membership, with full benefits, along with a reduced APS Meeting registration fee for the March and April meetings.

Be sure to take advantage of other benefits and services that specifically have our Early Career and Student members in mind. A couple programs mentioned in previous newsletters include the APS Local Links and IMPact Programs. They both provide excellent opportunities for networking and mentorship outside of the framework of APS scientific meetings. APS Local Links brings together physicists from all sectors at the local level to meet on an informal basis every six weeks or so to build relationships and learn about opportunities. Many industry employers utilize Local Links gatherings as an opportunity to recruit recent graduates or those close to graduating. The APS Industry Mentoring for Physicists (IMPact) Program creates an opportunity for graduate or early career physicists to connect with mentors in industry for individual guidance on how to pursue careers in industry.

Lastly, make sure you take the opportunity to get involved; volunteering can range from helping plan a session at an APS meeting, participating on one of the Forum committees, or serving on the FECS Executive Committee. All these avenues are not only great ways to learn how APS as an organization works and to offer feedback into how the Society should operate, but they also provide opportunities to network with colleagues from all backgrounds - up to and including Nobel Prize winners. FECS will also be eligible to elect a representative to the APS Council of Representatives once the Forum membership exceeds 6% of the total APS membership for two consecutive years (the 2018 official count looks to be right around 5%). Please spread the word to colleagues who may not be a member, and then consider nominating a FECS colleague, or even yourself, to serve when you receive a call for nominations!

If you know someone who is not an APS and/or FECS member, please send them to the APS Website to join!

Trish Lettieri
APS Director of Membership

The Many Paths of Cosmology

Kevin Ludwick, Newsletter Editor

Cosmology is a vast field, enveloping many possible research pursuits. This fact is partly because cosmology is the intersection of many seemingly disparate fields of physics. It covers a wide range of times, from the beginning of our universe to its different possible fates, and a wide range of length scales, from the chaotic Planck scale where space-time is ruled by quantum gravity to the size of the causally connected universe and beyond. There are many research and career avenues one can take in the field of cosmology.

Probably the most recent and prominent endeavor making headlines is the work of the Laser Interferometer Gravitational Wave Detector (LIGO) and the Virgo interferometer. Thanks to the interferometers, which can detect a warp in space-time of the order of a proton radius, and the hard work of the collaborating scientists, gravitational waves that have travelled megaparsecs to Earth have been discovered. Based on the waveforms of these waves, the source of these waves can be inferred. Binary black holes produced the first five wave events, and the most recent sixth event originated from a binary neutron star system. This event was the first multi-messenger event, meaning that the gravitational wave signal was accompanied by an electromagnetic counterpart, which implied very strict limits on the speed of gravitational waves in gravity models, more precise localization of the binary neutron star system, and a deeper glimpse into the nuclear r-process involved in the kilonova that resulted from the merging of the binary system. The precise equation of state describing the contents of a neutron star is not known; perhaps there is a very dense quark-gluon plasma at its core, or perhaps the core is something else. It is hoped that this event and others like it will lend insight into this mystery. The inception of multi-messenger astronomy will also provide more accurate measurements of the rate of universal expansion, given by the Hubble parameter, since such measurements are independent of the cosmic distance ladder. (Our knowledge of distances to luminous objects in the sky is built up rung by rung on the cosmic distance ladder, starting from our knowledge of distances from closer objects and inferring distances, via potentially dubious assumptions, to farther objects such as supernovae.) Already, we have high-energy particle physics, nuclear physics, general relativity,

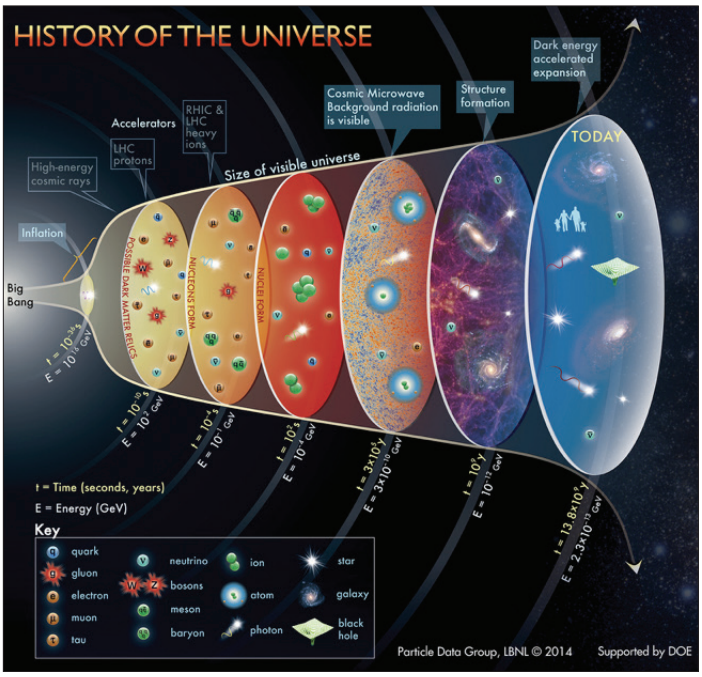


Image source: https://mappingignorance.org/category/science/cosmology/

and alternative theories of gravity coming together in this exciting work. Other proposed gravitational wave detectors, such as the Laser Interferometer Space Antenna (LISA) and the Einstein Telescope (ET), are currently in development, and determined experimentalists and theorists are needed to push these projects forward.

The cosmic microwave background (CMB) is another great source of cosmological data. When the universe cooled enough so that electrons and protons could form hydrogen atoms, thermal radiation was no longer being constantly bounced back and forth between the particles and could freely propagate away, and this was the first moment of electromagnetic transparency for our universe. This radiation left over from the Big Bang is fairly uniform over the sky, fitting a blackbody spectrum of temperature of about 3 Kelvin. However, there are small-scale anisotropies in the midst of the overall large-scale uniformity of the radiation, and the distribution of these anisotropies provides constraints on different cosmological parameters such as the Hubble parameter, the relative contributions of dark matter and dark energy to the universe's energy density, and others. The Planck

satellite and the Wilkinson Microwave Anisotropy Probe (WMAP) have made very precise measurements of the CMB and have provided strong observational constraints on these parameters. Before light decoupled from baryonic matter and propagated away to form the CMB, the counteracting forces due to inward gravitational attraction and outward radiation pressure caused baryonic acoustic oscillations, or BAO. Imprints of the characteristic size of these oscillations were made once radiation decoupled and formed the CMB, and these oscillations can be compared to their size today inferred statistically from galaxy surveys to constrain the expansion and acceleration of the universe over this time period in between. Another aspect that cosmologists study is the polarization of the CMB. The radiation can be polarized as either E-modes or B-modes. B-modes, which have vanishing divergence (much like the magnetic field in Maxwell's equations), are produced by the gravitational lensing of E-modes, and the South Pole Telescope has measured such modes. Collaborations such as the Background Imaging of Cosmic Extragalactic Polarization (BICEP) and Keck Array also measure B-modes of the CMB. An important discovery that they hope to make in the future is the detection of B-modes produced by gravitational waves from cosmic inflation, which would be bolstering evidence for cosmic inflation, the supposed rapid expansion of the early universe that provided causal connectivity between distant parts of the CMB sky and a natural explanation for the observed spatial flatness of our universe.

In my opinion, one of the most fascinating aspects of our universe is that about 96% of it is comprised of stuff we do not really understand! About 28% of our universe is dark matter, and about 68% is dark energy.

Dark matter has only been detected gravitationally so far, and the candidates for dark matter include macroscopic objects, such as black holes and massive compact halo objects (MACHOs), and many non-baryonic particle models, including weakly interacting massive particle (WIMP) models. Dark matter was first inferred from the rotation curves of galaxies, which seemed to indicate that there must be some unseen mass providing the gravitational potential needed for the orbiting rates of stellar matter near the outer reaches of galaxies to be as high as observed. Direct detection experiments that look for direct interaction between dark matter and a target material have strongly constrained the allowed interaction cross section due to non-observation, and indirect detection may potentially come from the detection of decay products, such as neutrinos that the IceCube experiment may detect, or cosmic rays accelerated by supernovae that the AMS-02 experiment has studied. There is currently a 3.5-keV radiation signature coming from certain galaxies (and which is noticeably absent in others) that may be explained by interactions with dark matter.

Dark energy was first inferred from studying light spectra coming to us from Type Ia supernovae, and the way their emitted light was redshifted implied they were accelerating away from us. Other observational sources have confirmed the signatures of dark energy and dark matter as well. Dark energy could be due to a new field not included in the Standard Model of particle physics, or it could be vacuum energy due to a cosmological constant term in Einstein's equation of general relativity. The measured value of dark energy as a cosmological constant and the calculated Standard Model vacuum energy are inconsistent by over 100 orders of magnitude! This discrepancy is known as the cosmological constant problem. The energy density of dark energy as a cosmological constant is constant as the universe expands, which is counterintuitive compared to the decreasing density of normal matter as the universe expands. Cosmological data also leave room for an exotic form of dark energy known as phantom dark energy, which is dark energy that causes an acceleration rate that increases over time. Thus, at some finite time in the future, the universal acceleration could be strong enough to rip apart bound structures, from galaxies to tiny atoms, and this fate of the universe is known as the big rip. Some of my research has concentrated on phantom dark energy, including the classification of alternative fates of the universe.

As we have seen, there are many avenues of research and various fascinating phenomena to study and observe in the vast field of cosmology, spanning from the earliest observable times to the possible end of the known universe. It integrates many subfields of physics that describe the smallest of particles to the largest of cosmic structures. We still have not covered all the purview of cosmology, including the study and simulation of cosmic structure formation, the detection of cosmic rays from blazars accompanied by neutrinos of unexplainably high energies, the complex baryonic dynamics and interactions in galaxies that are not fully understood, the effects of quantum gravity on density fluctuations in the early universe and at the center of a black hole, and much more. However, I hope this article has piqued your interest and given you a glimpse into an exciting field with many fulfilling research and career paths. All of the collaborations and experiments I have mentioned (along with others I left out) require dedicated theorists and experimentalists to advance the field further into our current era of precision cosmology. The future of the field is unknown, but it is sure to reveal even deeper and more beautiful mysteries.

Dr. Kevin Ludwick
Newsletter Editor

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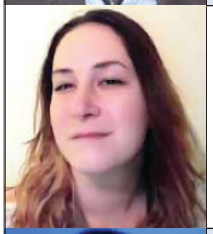

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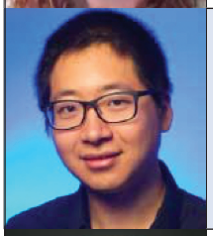

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