

American Physical Society New England Section Newsletter

Co-editors

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Volume 21, No. 1

Spring 2015



Advances in Two-dimensional Crystal Physics and Multidimensional Teaching and Learning



New England Section of the American Physical Society

- Latest optical, electronic, and device physics in 2D crystals
- Online physics education for undergrad and high school students
- Blending online and in-person courses at research intensive universities
- Preparing future physics faculty – the next generation

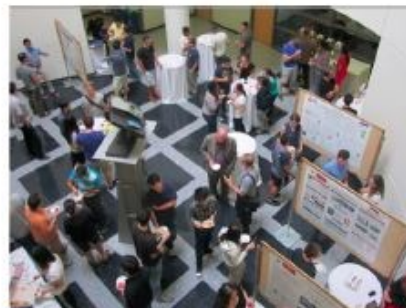
Dates: Friday and Saturday, April 24 – 25, 2015

Times: Friday 2-6pm & dinner; Saturday 8:30-12:00

Location: Boston University, SCI and LSEB Buildings

Confirmed speakers

Tony Heinz, Columbia University
Andrew Duffy, Boston University
Eric Mazur, Harvard University
Tomas Palacios, MIT
Jeff Williams, Bridgewater State
Scott Bunch, Boston University
Saif Rayyan, MIT



Contact: Prof. Charlie Holbrow, cholbrow@colgate.edu or
Prof. Bennett Goldberg, goldberg@bu.edu

Info: <http://www.aps.org/meetings/meeting.cfm?name=NES15>

Register: https://www.aps.org/memb-sec/meeting/startpage.cfm?event_id=1160



Recap of the Fall 2014 Meeting of the New England Section of the American Physical Society at Wentworth Institute of Technology

Physics of the Extremes



Dr. Zorica Pantic, giving welcome address

From the entire faculty, staff, and students of the Wentworth Institute of Technology family, we wish to thank the members of APS-NES for a thought provoking and stimulating two days in Boston. We are honored to have had such distinguished guests and contributing members of the northeast physics community on our small but lovely campus.

Friday, Nov. 7th, 2014

For the meeting of the APS-NES chapter, the local organizers at Wentworth Institute of Technology chose to develop a broad program concentrating on physics of the extremes. This choice was inspired by the overwhelming density and di-

versity of physics enthusiasts in the greater Boston area. With so many vibrant and growing fields of research, the program was meant to bring physicists together from all extremes of the subject to foster communication and discussion. Before the start of the meeting ninety members of APS were registered for the event. This number grew with many on-site participants, and in total the program was supported by over one hundred attendees, six plenary invited talks, twenty four contributed talks, fourteen poster presentations and a memorable keynote address from Nobel Prize Winner Wolfgang Ketterle.

The first day was welcomed by Dr. Zorica Pantic, president of Wentworth Institute of Technology. In her address, many of the new and exciting innovations featured at WIT were highlighted. In recent years, Wentworth has hired several new faculty in the physics department, built a new, state-of-the-art Center for Sciences and Bio-Medical engineering, and has been a leader in undergraduate research experiences through its EPIC learning model.

Assistant Professor James O'Brien, representative of the Physics department of WIT and local organizer of the event, served as emcee for the day. James extended his welcome to the diverse set of scientific minds in the audience and was pleased to welcome four invited speakers for the Friday talks. The invited talks all took place in the Watson Auditorium, a beautiful reception hall with seating for 250 guests which also served as the backdrop for the forthcoming poster session. The audience began at around fifty people and by the end of the day was filled to capacity with participation from APS members and WIT faculty



Ken Miller giving invited talk

and students.

The first of the invited speakers was Ken Miller from Columbia University speaking on "Merged Beams Studies for Astrophysics and Astrobiology." This talk was the perfect opener to the APS event, showcasing the extreme scales of the machines made here on earth to simulate extreme behavior in the cosmos. Next, Bob Kirshner of Harvard University took the stage and delivered a wonderful presentation entitled "The Accelerating Universe; What's Next?" This talk discussed the history and current state of affairs of large scale cosmolo-



Bob Kirshner, giving invited talk

Recap of Fall 2014 Meeting...

gy with an emphasis on future work pinning down the universe's most extreme questions such as dark matter, dark energy, and the cosmological constant.

The program then held a short coffee break for guests to mingle, and was resumed by Philip Mannheim of the University of Connecticut, whose talk was entitled "Metrication of the Fundamental Forces." The topic followed seamlessly from the previous speaker and gave a few prospective answers to the overall questions left at the end of Kirshner's talk. Mannheim's exciting and engaging presentation primed the audience for the final talk of the afternoon delivered by Max Tegmark of MIT. His talk entitled "Our Mathematical Universe, from Inflationary B modes to 3d Cosmic



Philip Mannheim, giving invited talk

Maps," provided the framework of the extreme work being conducted today by groups such as BICEP on inflation. Tegmark's presentation style added some much appreciated passion and humanity to the discussion, concluding the day's invited talks with great applause from the audience.

Another coffee break was then followed by the main event of the program. Dr. Russ Pinnizzotto,



Nobel Laureate Dr. Wolfgang Ketterle giving Keynote Lecture

Vice president for academic affairs and Provost of WIT, took to the stage to introduce our Keynote speaker. Dr. Pinizzotto holds a Ph.D. in Materials Science, a Master's in Astronomy, and is an expert in physical acoustics. Aside from his academic accolades, Dr. Pinizzotto also had the privilege of taking a class or two from Richard Feynman. Russ gave a heartfelt welcome to the program's Keynote Lecture, delivered by Dr. Wolfgang Ketterle of MIT. Dr. Ketterle is well known for his work on the manifestation of the first Bose Einstein Condensate (BEC) and received the Nobel

Prize in physics in 2001 for his work. Dr. Ketterle was welcomed by over 250 people in the Watson Auditorium, and delivered a truly unique and powerful presentation. The first segment of Dr. Ketterle's talk focused on his work in BEC's. He then switched gears and presented on new extreme work done by his group at MIT towards imprinting Magnetic Potential into atoms. Dr. Ketterle received a standing ovation at the conclusion of his talk and was quite gracious with his time, taking photos with students and spectators answering last minute questions.



Max Tegmark, giving invited talk

After the Keynote, the entire room simply moved to the opposite end of the auditorium for the poster session. Audience members still abuzz from Dr. Ketterle's talk engaged and discussed work with the poster presenters. Many extremes of physics were represented at the session, including a number of student presentations. Examples included undergraduate work from WIT students Ryan Wilson and Edward Winters on "Building the Wentworth Radio Array Telescope",

Recap of Fall 2014 Meeting...



WIT Provost Dr. Russ Pinnizzotto, Keynote speaker Dr. Wolfgang Ketterle, and meeting Chair Dr. James O'Brien of WIT

and graduate student work such as UCONN students Douglass Goodman and James Wells' poster "Cold Ion-Neutral Hybrid Trap." The poster session lasted two hours, laying the groundwork for future collaboration amongst guests and presenters while giving ample time for questions as well as a chance to work up an appetite.

The APS congregation then took a short walk across the WIT campus on a clear but cold November night. Things reconvened in the Multi Purpose room of the recently finished Flannigan Campus student center. Dinner and dessert were provided with over 60 people attending. After a nice meal together, everyone parted ways to prepare for the early start of the Saturday session.

Saturday, Nov 8th, 2014

Attendees gathered Saturday morning at 8:00am to enjoy breakfast and coffee in Watson Auditorium. The remainder of the

morning was divided among over twenty contributed talks celebrating the theme of the meeting. Physics at the large scale, small scale, and other frontiers were described in three concurrent sessions.

Topics at large scales included the physical characterization of the universe and space-time, dark matter and grand unification, and expansion techniques in quantum field theory. At the small scale, magnetic models for bilayer manganites and biosensors, de Sitter particle production, the origin of the fine structure constant, and Van der Waals forces were discussed. Other extremes examined were new techniques in physics education, photoacoustic resonators, neutrino collisions, and energy and the environment.

The meeting served as a wonderful opportunity for collaboration between researchers throughout the region. The New England area was well represented by presenters from Harvard

University, Worcester Polytechnic Institute, Northeastern University, Naval Academy Preparatory School, Massachusetts Institute of Technology, Dartmouth College, University of Connecticut, Institute for Basic Research, Boston University, Boston College, and the host institution of Wentworth.

A late morning coffee break allowed some time for refreshment and contemplation before regrouping at 11 am for the final two invited sessions. Our last speakers exemplified the fantastic range of modern physical investigation. Marko Gacesa of Harvard ITAMP and UCONN explained his work at the extremes of temperature advancing our understanding of ultracold molecules. At the extremes of distance, James O'Brien then offered an alternative to dark matter with his discussion of conformal gravity. Finally, our meeting was brought to a close



Marko Gacesa, giving invited talk

with thoughtful remarks from the APS-NES executive committee.

As many of our talks made clear, the expanding frontiers of modern physics require special consideration toward the education and training of our next generation of scientists. A particular highlight of this meeting was the increased participation of

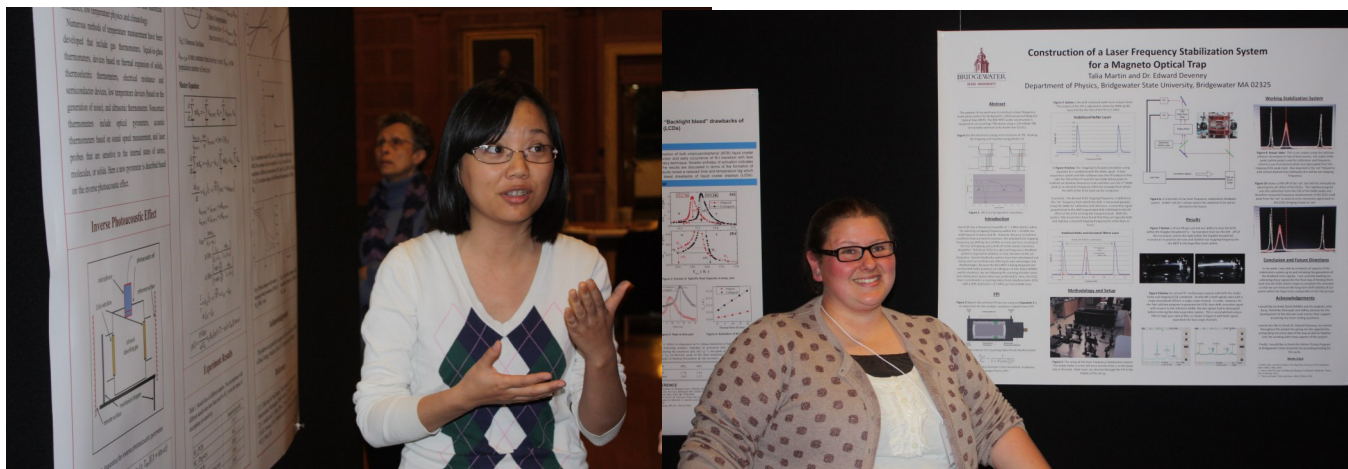
Recap of Fall 2014 Meeting...

students at both the graduate and undergraduate levels. Together, the invited speakers, contributors, and attendees underscored the ever increasing reach of physics and our comprehension of nature at the extremes.

Authors:

James O'Brien and Franz Rueckert, Wentworth Institute of Technology

(Meeting pictures courtesy of Peter K. LeMaire, Central Connecticut State University)

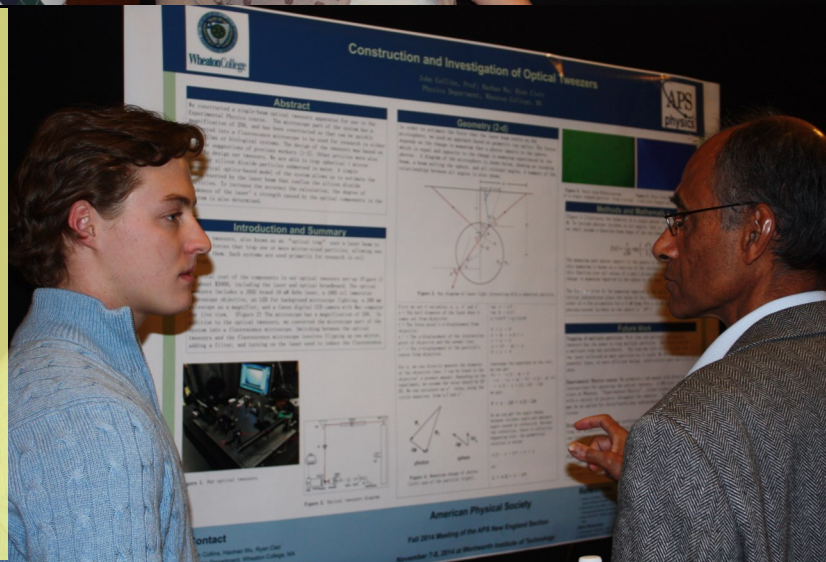


Top right: Students from Central Connecticut State University pose with Keynote speaker Nobel Laureate Dr. Wolfgang Ketterle

Middle left: Xiangling Meng of Brown University presents her poster on "Inverse Pyrometer"

Middle right: Talia Martin of Bridgewater State University presents her poster on "Construction of a Laser Frequency Stabilization System for a Magneto Optical Trap"

Right: Ryan Clair of Wheaton College discussing his poster on "Construction and Investigation of Optical Tweezers" with NES-APS Past Chair Dr. Partha Chowdhury.



Recap of Fall 2014 Meeting...



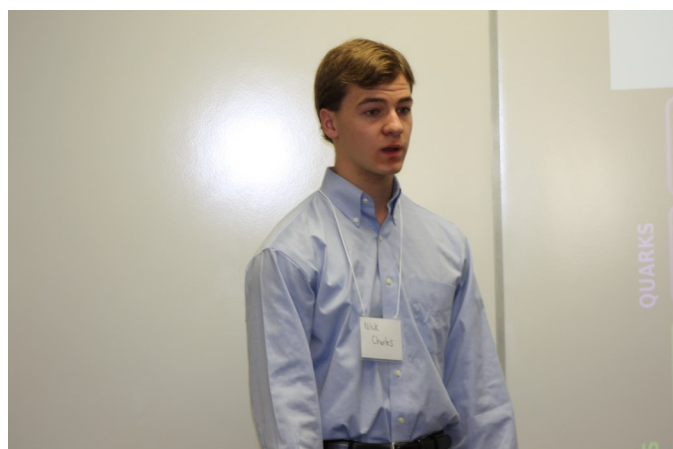
Frederick Trilling of Wentworth Institute of Technology giving his contributed talk on **“Bringing Together Physics and Business Management in Interdisciplinary Undergraduate Education”**



Dipti Sharma of Wentworth Institute of Technology giving her contributed talk on **“Kinetics of crystalline to smectic A(K-SmA) phase transition of 4-decyl-4-bipheylcarbonitrile liquid crystal”**



Paul Carr of Air Force Research Laboratory (Emeritus) giving his contributed talk on **“Weather Extremes and Rising Seas as Measures of Global Warming”**



Nicholas Charles of Harvard University giving his contributed talk on **“Dark Matter and Grand Unification in an Extension of the Standard Model”**



Left: Meeting Chair **James O'Brien** of Wentworth Institute of Technology giving a very well presented and well received closing invited talk on **“Recent Advances in Alternative Gravitational Models”** in which he gave an overview of “the Conformal Theory of gravity, an alternative theory which has been shown to be able to solve the rotation curve problem without the need for dark matter”

Fall 2014 Meeting...

Energy Extraction from Incident Ocean Waves by Heaving and Flexing Mechanical Systems

Energy extraction from ocean wave research activities is intense in Europe. In the US, research in this field is lagging behind. This article summarizes the talk given at the Fall 2014 Meeting of the APS New England Section [1], and addresses the dynamic and capability of a leading ocean wave energy contender, the Pelamis (Fig. 1), which is developed in the UK. It is composed of 4 or 5 linked cylinders floating half-submerged on the ocean. The conversion of energy occurs at the joints due to flexing.

We have developed analytical models for the prediction of its response to incident ocean waves and comprehensible guidelines to maximize the conversion of energy by Pelamis-like devices [2], multi-linked cylindrical mechanisms. The water waves are modeled as of fixed amplitude, constant frequency, and unidirectional. The analytical model uses dashpots at the joint locations (Fig. 2) and accounts that the energy dissipated at the joints would be the maximum energy available for extraction. It is understood, however, that



Fig. 1: Picture of the Pelamis

only a portion of that captured energy is converted to

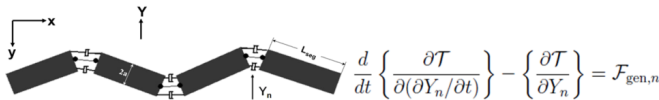


Fig. 2: Analytical model

electricity as there are losses due to friction, heat generation, and radiation.

The forces acting on the multi-linked cylindrical model are those associated with buoyancy, energy conversion, Archimedes (driving forces), scattering, entrained mass, viscosity. The design parameters are the number of segments (N), the total length of the device

($L=N \times L_{seg}$), the radius of the cylinder (a), the wave number (k), and the effective dashpot constant associated with the electromechanical energy conversion system (C_{conv}). Dimensionless parameters have been introduced, two of which are of relevance here: μ_{red} , which is proportional to the effective dashpot constant, and ϕ_{power} , which is a measure proportional to the power extracted.

Also, efficiency is not a good measure of the capability of an ocean wave device. A better measure of its capability is Capture Width (CW), which is the amount of energy captured over the power per unit length of wave crest by the incoming wave (w_{ww}). Capture Width has a unit of length. The capture width of a multi-linked device is derived as

$$[CW] = \frac{2k_w La}{[1 - (\omega/\omega_{res})^2]} \Phi_{power}, \text{ with } \Phi_{power} = \Phi_{power}(\mu_{red}, k_w L, N)$$

The power that would be converted to electricity is, hence,

$$\mathcal{P}_{conv} = [CW]w_{ww}$$

Fig. 3 shows that $N=5$ is a good segmentation. The sensitivity due to a variation in $k \times L$ is negligible.

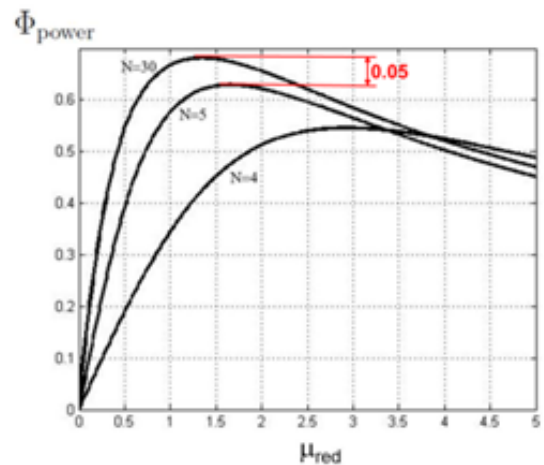


Fig. 3: Max power per segment

Also, a developed limped beam model supports the validity of the segmented beam model theory, $\phi_{power} \approx \phi_{limp}$ for large N, as shown in Fig. 4. The parameter ϕ_{limp} is the equivalent of ϕ_{power} for the limp beam model, which provides a good first insight on the capability of such device to designers. Its capture width is approximated as:

Fall 2014 Meeting...



Author (above):
Amadou Thiam
Boston University

$$[CW] = 2kaL \left[1 - \frac{3.7}{kL} \right]$$

This expression provides simple de-

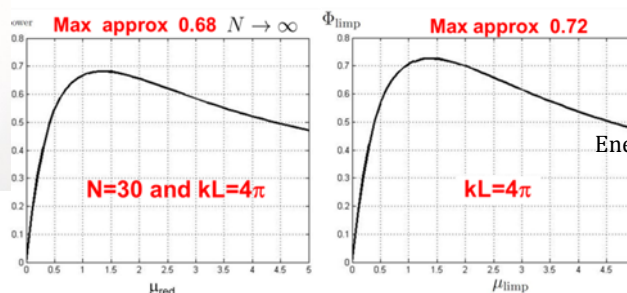


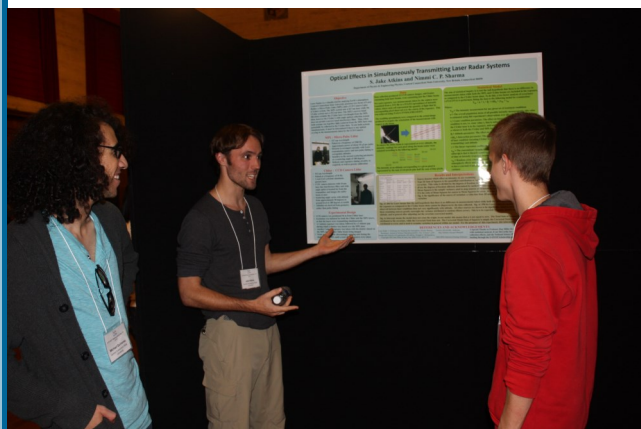
Fig. 4: Response for multi-slinked model compared to limped beam model

pendencies on cylinder radius, cylinder length, water wave properties, and number of segments.

References:

Energy Extraction from Incident Ocean Waves by Heaving and Flexing Mechanical Systems, DOI: 10.13140/2.1.3038.3686 Conference: Fall 2014 Meeting of the APS New England Section, At Boston, MA
Energy Extraction from Ocean Waves by Heaving and Flexing Mechanical Systems, DOI: 10.13140/2.1.3246.2406 Thesis for: PhD, Advisor: Allan D Pierce

Optical Effects in Simultaneously Transmitting Laser Radar Systems



Author (above middle):
Scott "Jake" Atkins, presenting poster
Central Connecticut State University

rangement in which a detector is aligned coaxially with the laser emission source, and has a distinct set of advantages for aerosol measurement including constant altitude resolution and the ability to operate in the daytime. A second system in use by CCSU is the CCD Camera Lidar (CLidar), which benefits from greater precision at near-ground altitudes where system performance is more important. The CLidar system operates on a *bistatic* arrangement where the entire laser beam is imaged from the side by a CCD camera at a fixed distance from the emission source.

While both the MPL and CLidar systems generate vertical aerosol distributions, the manner in which they perform this task and the parameters on which they rely are different: the MPL system is sensitive to the 180 degree scattering angle (backscatter) exhibited by aerosols that the laser beam comes into contact with, while the CLidar system is sensitive to a larger portion of the aerosol phase function (90 to 180 degrees). By running the two systems simultaneously, it would be possible to place additional

constraints on the phase function, and produce more useful information regarding the observed aerosols. At present, this type of research is completely unprecedented.

The monostatic design of the MPL system is such that a narrow band filter can be used to eliminate background signal from sources other than the device's own laser beam. However, the bistatic CLidar system makes use of wide angle optics, and therefore does not permit a narrow band filter. Since the MPL and CLidar systems run on wavelengths that are very close together—527 and 532 respectively—it is necessary to determine if the CLidar system observes any optical crosstalk when the two systems are operated simultaneously.

An experiment was performed in which alternating CLidar exposures were taken with either both system's beams or just the CLidar beam imaged by the CCD camera. The resulting data sets were rigorously tested for a statistically significant difference using an analysis of covariance in which the effect of time was effectively discounted, and it was deemed that the presence of the MPL laser beam in the CLidar exposure had no significant effect on the data. From these findings, it is possible to move forward with the applications of simultaneous operation of bistatic and monostatic Lidar systems.

Central Connecticut State University owns and operates of two different types of Laser Radar (Lidar) systems for use in studying Earth's atmosphere. The more common of the two Lidar systems in use at CCSU is the Micro-pulse Lidar (MPL); these types of devices are widely use by NASA in their efforts to map vertical aerosol distributions around the world through the Micro Pulse Lidar Network (MPLNET). The MPL operates on a *monostatic* ar-

Recap of Winter 2015 CUWiP at Yale University



Conference coordinators for 2015 CUWiP at Yale University. Author (above top left): Associate Professor Sarah Demers.

On January 16-18 the APS Conferences for Undergraduate Women in Physics were held simultaneously at eight locations around the country with over 1,200 students participating. (url: <http://www.aps.org/programs/women/workshops/cuwip.cfm>) These conferences have been running and growing annually since beginning at a single site in 2006. They have the stated goals of “helping undergraduate women continue in physics by providing them with the opportunity to experience a professional conference, with information about graduate school and professions in physics, and with access to other women in physics of all ages with whom they can share experiences, advice, and ideas.”

In 2015 the northeastern region of the US was served by the conference at Yale University. Our 179 participants from 50 institutions across the Northeast made the trek to a bitterly cold New Haven, CT where, in true New England fashion, we didn't let the wintery conditions slow us down. A welcome address from Yale President Peter Salovey followed by a keynote speech by AAS President and former Chair of the Yale Physics Department, Meg Urry, launched the conference on Friday evening. Both Presidents Salovey and Urry addressed the idea of implicit bias. They noted that truly excellent science requires maximizing the available talent pool, which certainly means including women and under-represented minorities. And President Salovey gave a fairly complete history of New Haven cuisine, perhaps doing his part to try to recruit some of these women to future study at Yale through our local (excellent) pizza.

Some components of the conference were very typical in that there were research talks by eminent scientists. These included Yale Professor Bonnie Fleming, SUNY Buffalo Professor Andrea Markelz and McGill Assistant Professor Lilian Childress. However, the topics were not limited to neutrinos, bio-physics or defects in diamonds. In addition to talking about their work the speakers discussed their career paths and gave participants advice about being successful physicists. The questions from participants addressed the science topics but also issues related to work-life balance and being a woman in physics.

Recap of Winter 2015 CUWiP at Yale University

The participants had an opportunity to present their own work at a poster session and to get to know each other during long coffee breaks and a liquid nitrogen ice cream party. They learned about career options through a graduate student panel and a career panel where both academia and industry were represented. A graduate school fair starred intrepid faculty and students from more than a dozen graduate programs who fought through icy conditions to recruit and advise on Sunday afternoon.

One of the topics that popped up a few times during the sessions and informal discussion was the idea of imposter syndrome. (url: http://en.wikipedia.org/wiki/Impostor_syndrome) I couldn't help but wonder, "at what point do our students, men and women alike, begin to feel like real physicists?" As the faculty advisor for this conference I can assure everyone who might be inclined to doubt it, which research shows might include the students themselves, that the participants we hosted were already physicists. This became painfully clear to me through two small conference catastrophes, both involving coffee, that luckily were about as bad as we faced in terms of having things not go as planned.

On Saturday morning, the first full day of the conference and following a rather late Friday night due to tours, a movie and a planetarium showing that the participants chose between, our caterers arrived with coffee, but no coffee cups. How much of a problem did this turn out to be? It was a significant problem (sign one that physicists were in the house) that led to immediate and impressive improvisation (sign two.) Relief came within 30 minutes, and most importantly before the first talk of the day, in the form of a stack of cups but not until I'd seen the caffeine-hunger and confident scanning of their surroundings for raw materials that I'd seen, not always simultaneously, in other contexts so often in my research colleagues' eyes. (And, of course, those students who did not drink coffee had the familiar blend of exasperation and acceptance that my caffeine-free colleagues wear when putting up with the stereotypical coffee obsessed physicist heading out for yet another cup.)

The second conference coffee catastrophe was the clincher. On Sunday morning our caterers arrived proudly bearing both coffee AND cups, but the reservoirs were not labeled "regular" or "decaf". In no time the talk turned to solving an optimization problem. There were three containers and we knew, based on previous experience, that two contained caffeinated coffee and one contained decaf. One camp quickly emerged advocating filling your cup with 33% from each container, assuring a 66% cup of caffeinated coffee. A more optimistic camp formed, suggesting attendees should fill their cups half with one container and half with another container. At the worst this would give 50% decaf and at the best 0% decaf, giving the chance for a 100% cup of caffeinated coffee! The scientists, distracted with their debate, happily drank and argued their way through breakfast.

Coffee catastrophes notwithstanding, I could only describe the conference as a huge success. The students learned physics and networked with each other and with people who are further along in their careers, both in academia and industry. Thanks to support from APS, the Department of Energy and the National Science Foundation, their lodging and meals were paid for, and in many cases their home physics departments sponsored their travel. The energy in the halls was palpable all weekend.

The success was possible only with the strong support of the Yale Physics Department and various administrative offices throughout the university that sponsored us. And the coffee catastrophes would have been the least of our concerns if a team of ten Yale Undergraduate organizers, led by Senior physics major Megan Phelan, had not been hard at work for the months leading up to the conference and ridiculously hard at work during the conference itself. We bonded over vegan and gluten free meal options and bus schedules and did everything we could to make sure that the participants could focus on physics and each other during the event. The participants more than obliged, remaining gracious even during the most desperate moments of being so close yet so far away from their cups of morning coffee!

The slate of meetings for 2016 has already been set, with Conferences planned for January 15 – 17 at Black Hills State University, Georgia Institute of Technology, Old Dominion University/Jefferson Lab, Ohio State University, Oregon State University, Syracuse University, University of California San Diego, University of Texas San Antonio, and Wesleyan University. We look forward to many more years of the conference, where the experience of having so many women in physics gathered together becomes less unusual year after year.

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**For more information on
Women in Physics,
including speaker lists,
workshops and meetings
etc., please visit**

www.aps.org/programs/women/

Wesleyan to Host 2016 CUWiP

Wesleyan University has been selected as one of the host sites for the 2016 Conference for Undergraduate Women in Physics, which is sponsored by the APS, DOE and NSF. This is the first time in the CUWiP 10 year history that a small liberal arts university has hosted this event. We are honored to be chosen for this opportunity, and hope that we will be able to showcase the vibrant research done at liberal arts institutions across the Northeast. It is our hope that we will attract widespread participation, however, in particular we hope to strengthen interactions between the Five College Consortium and the NESAC. Through this event we hope to highlight the diverse opportunities available to young women who obtain undergraduate degrees in physics.

As part of its distinguished liberal arts program, Wesleyan is home to a highly active undergraduate and graduate research community, especially in the physical sciences. Undergraduates at Wesleyan both participate in research conducted by professors and create their own research projects and topical courses. Wesleyan also boasts a highly interdisciplinary program emphasizing collaboration in biophysics, planetary sciences, and environmental studies.

Wesleyan University's central New England location - almost exactly halfway between Boston and New York City, Providence and the Five College Consortium - is within easy driving distance of most major metropolitan areas in the Northeast. Therefore we are able to draw on the resources of these urban centers, including job and research opportunities and the related personnel to help us facilitate a diverse and interesting program for the event.

Included in our proposed agenda are discussion panels regarding careers in science (including careers beyond academia), underrepresented minority STEM participation, undergraduate research opportunities, and scientific writing and research skills. Additionally, we want to provide tours of Wesleyan's extensive lab facilities, which convey the breadth and depth of research at liberal arts institutions. We intend to select program speakers in order to emphasize a broad range of positions and occupations to include scientists and researchers from other institutions, engineers, CEOs and/or employees of STEM companies, recent Wesleyan graduates, current graduate and undergraduate students, and government employees. The unique views and experiences of these people will provide a wide array of panel topics that will cover multiple career options. We would also like to highlight job application skills including how identify career opportunities, how to

craft a resume or curriculum vitae, and how job applications differ inside and outside of academia.

We are also planning a career fair. We hope to attract graduate program recruiters as well as local industrial partnerships for this event.

We want to illuminate the integral nature of undergraduate research in career development by hosting dedicated research sessions featuring talks by student researchers as well as a poster session. By facilitating these interactions students will gain valuable experience as well as learn about the fascinating research being conducted by their peers at neighboring universities.

We will begin advertising this event by contacting department chairs next fall. You may also check in on our website, which is currently under construction, cuwip.conference.wesleyan.edu If you are interested in participating in this event, or would like additional details, please contact Christina Othon at cothon@wesleyan.edu.

Authors:

Christina Othon, Meredith Hughes,
Julia Zachary '17 and Nisha Grewal '17

Do you have interesting Physics related articles, new programs, research report, physics talking points etc. that you will like to share with the New England Physics Community?

**Send them to the co-editors:
Ed Deveney (edeveney@bridgew.edu)
Peter LeMaire (lemaire@ccsu.edu)**

UConn Advanced Lab in the Spot Light: Chip-Level Microcontrollers

Chip-level Microcontrollers for Advanced Teaching Laboratories and Research

There has been startling growth in the capabilities of self-contained microcontrollers in recent years, to the point that a single-chip processor costing between \$2 and \$10 can in many ways outperform a typical full-scale laboratory computer from the 1990s. At UConn, we have been working for some years to incorporate homemade microcontroller-based instrumentation into the research laboratory, and more recently into the teaching laboratory. A pair of articles in the *Review of Scientific Instruments* describes portions of this development effort, with an emphasis on research laboratory applications.^{1,2} This note complements the earlier articles by emphasizing applications to upper-level undergraduate laboratory courses.

There are two basic approaches when designing a microcontroller system in an educational environment. By far the best-publicized method is to employ system-level solutions using standard hardware and software interfaces, such as Arduino and Raspberry Pi. This has several advantages, most notably instant out-of-the-box usability and support from a large user community. Nevertheless, it is also quite reasonable to devise chip-level solutions using homemade circuit designs and self-contained programs. We have taken this approach for the numerous systems developed by my group at UConn, several of which are described in detail on my web page.³ While a substantially greater initial design effort is required, there are several benefits:

1. Very low cost for the core system, typically \$5 or less for the microcontroller and a comparable amount for the essential supporting components.
2. Unfettered full-speed access to all

interface lines and internal peripheral devices (counters, serial interfaces, etc.) A response to interrupt events within a few hundred nanoseconds can be guaranteed.

3. Full programming control, typically with using a free C or C++ cross-compiler, allowing fast and efficient programs with no hidden system code. A simple function can be executed within a few microseconds.
4. For students, the knowledge and satisfaction of building a complete device from individual chips.
5. For instrumentation, the ability to use laboratory-quality supporting electronics providing precision at minimal expense, including oscillators accurate to 10 parts per million, fast 16-bit data converters, broadband rf generators, low-noise amplifiers, and phase-sensitive detectors operating in full differential mode.
6. Ultra-compact instruments that take advantage of direct interfacing to the processor chip. Our newest design is a complete 16-bit data acquisition system on a “daughter board” measuring just 1.5” × 0.8.” It fits a multipurpose socket on our general-purpose laboratory interface board, itself measuring just 5” × 2 .25.”

I will start by describing simple single-chip computers used in our course on electronics for scientists. I then describe the modular design approach used for most of our more complex instrumentation, and a few of its uses for both teaching and research.

I. Single-chip computer on a breadboard

Our Physics 3150 course, Electronics for Scientists, has recently been updated to include a three-hour laboratory session in which each pair of students builds a single-chip computer using a Microchip dsPIC30F3013-30I/SP processor. This is a highly capable 16-bit microcontroller that costs less than \$5 and is available in a 28-pin DIP package that plugs directly into standard electronics prototyping breadboards. It operates from a single 5V supply and incorporates numerous built-in peripheral devices such as serial interface UARTs and an analog-to-digital converter (ADC) that are self-contained once initialized, able to operate concurrently with ongoing execution of the main program. The only essential external components are a crystal oscillator, itself costing just a few dollars, and a programmer to allow new programs to be entered into the chip’s internal flash memory (Microchip PicKit3, about \$48, can be shared by several lab groups). We also add an external serial LCD display (Sparkfun LDC-09395, about \$20) that allows convenient real-time display of text and numerical data. Fig. 1 shows an illustration of the completed computer on a breadboard, together with its schematic diagram.

Because C-language programming is new to many of our students, we supply a working program preloaded on the chip, plus a full listing with detailed comments.⁴ The main program loop is intentionally kept very simple, as shown in the code fragment in Fig. 2. It repetitively reads the internal ADC and displays information on the external LCD readout. For the laboratory exercise, the students initially construct and debug the computer until the supplied program works. They then make some minor updates to the C program of their own devis-

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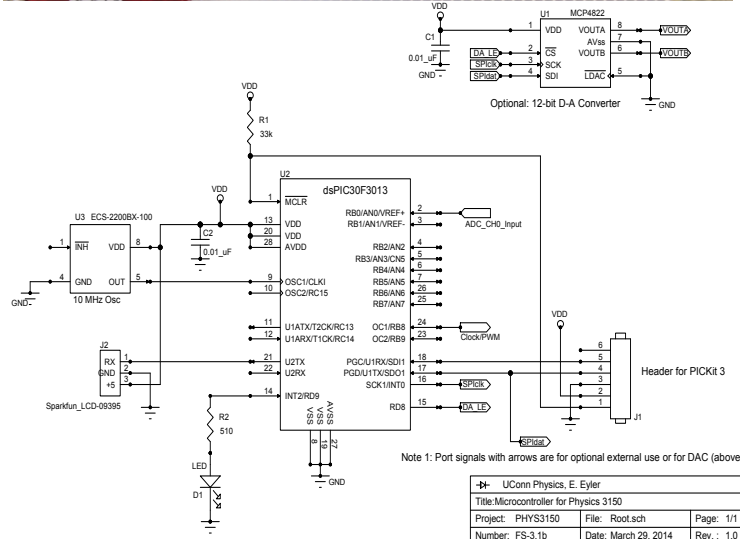
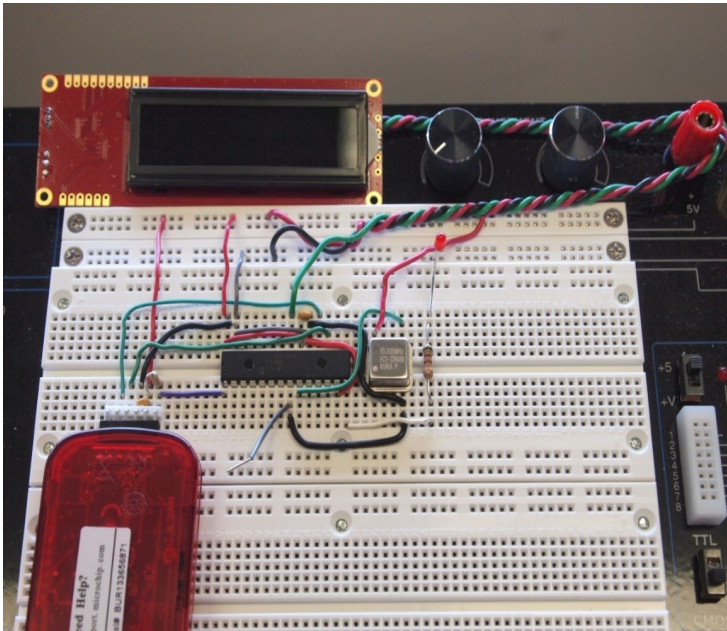


Fig. 1: Top: Basic single-chip microcontroller on a breadboard, with LCD display and programmer (red box at lower left). Bottom: schematic diagram, also showing an optional digital-to-analog (DAC) converter, Microchip MCP4822.

ing, using a free cross-compiler running on a standard PC system, and program the modified code to the microcontroller using the simple six-pin programming header visible at the lower left of Fig. 1. To provide a simple starting point, they start by making a trivial modification so that the LCD displays the ADC value rather than an incrementing count.

The course also includes an independent project for each lab group. In the fall of 2014, two of the eight lab groups chose microcontroller-based projects. One was an audio spectrum analyzer using fast Fourier transforms (FFTs) on a 32-bit version of the microcontroller. The other was a precision time reference based

```

/* Initialize Timer 3 and output comparator OC1 to provide a PWM output on pin OC1.
 * The periods are measured in units of 12.8 microseconds for a 20 MHz instruction clock,
 * and will be accurate within 10-20 parts per million. */
tmrPeriod = 20000; //Set the timer period using a Microchip-supplied library routine
OpenTimer3(T3_ON & T3_GATE_OFF & T3_PS_1_256 & T3_SOURCE_INT,
tmrPeriod-1); //Note that actual period is count-1, so we adjust accordingly
ocPeriod = tmrPeriod/4; //Set PWM 'on' time to 25% of the clock cycle
//Call another library routine to set up and start the output comparator unit
OpenOC1(OC_TIMER3_SRC & OC_PWM_FAULT_PIN_DISABLE,ocPeriod,ocPeriod);

/* Now enter an infinite loop and just keep running things. */
Done = 0;
count = 0;

while (!Done) {
// Check for a Timer 3 "tick" by looking at its interrupt flag, and update everything
// if a timer reset event has just occurred
if (IFS0bits.T3IF) { //The timer 3 interrupt flag has been set
count++; //Increment the count
IFS0bits.T3IF = 0; //Reset the timer flag to await the next tick
LED = !LED; //Toggle the LED as a quick visual check that we are here

//Read the ADC, which is triggered by the timer
while (!ADCON1bits.DONE) {} //Wait for the conversion is presently in progress
adcVal = ADCBUF0; //Read the 12-bit value, storing it as adcVal

// Write to the LCD display. For data rates > 50 Hz, comment out this section.
UART2_StringOut("wFEx80"); //Reset the Sparkfun display cursor to row 0, column 0
//Write an unsigned integer value to text string outstr, in a 5-character field width
sprintf(outstr, "Value: %5u", count);
UART2_StringOut(outstr); //Send the text string to the display
}

} // end of while (!Done)
    
```

Fig. 2: Code fragment for Microchip C compiler, showing part of the device initialization and the main program loop.⁴ This loop repeatedly reads an internal analog-to-digital converter (DAC) and writes text to an external LCD display

on a microcontroller interface to a GPS chipset — it not only displayed the time, but also provided a once-per-second synchronization pulse stable to within about 100 nanoseconds in absolute time.

II. Modular system design with an Android tablet interface

A breadboard-based computer is very useful for an electronics experiment, but for any other application a more compact and permanent configuration is needed. We have designed numerous printed circuit boards for simple high-performance instrumentation, and even a few not-so-simple applications, as described in Refs. 1–3. Initial designs were based on the same 16-bit processor series used in Section I above, but our recent designs are based on more capable 32-bit processors, most recently the Microchip PIC32MX270F256D. It provides a full 32-bit instruction set with a 50MHz cycle clock for about \$5, with ample on-chip program and RAM memory. Its 44-pin surface-

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mount package turns out to be a good choice, since it has enough program-assignable peripheral pins to handle most lab tasks, yet the pins have a sufficiently coarse spacing that most students can reliably solder the chip to a circuit board using solder paste and an affordable hot-air soldering station (Aouye 968A+, about \$175).

The system design concepts are described in detail in my earlier articles. In brief, each instrument includes internal power converters that operate from a single 6V supply, a small USB interface module, and a six-pin programming header. An Android tablet app provides an interactive graphical user interface, with menu items customized at startup by each microcontroller program. The microcontroller stores all parameter changes entered via the tablet, so that it can continue to operate autonomously when the USB tablet interface is disconnected. Most of the designs also include at least one socket for a 20-pin daughter board measuring $1.5'' \times 0.8''$. The present repertoire of daughter boards includes DACs, ADC sub-systems, lock-in amplifiers, and an arbitrary waveform generator.^{1,3}

While dedicated printed circuit boards (PCBs) have been designed for certain task such as precision temperature control and broadband rf frequency synthesis, most of our instrumentation is based on a single highly flexible PCB, the LabInt32 laboratory interface board. It is shown in Fig. 3 connected to three user interface devices: an Android tablet, a serial LCD display, and a high-quality “universal knob,” a quadrature rotary encoder with up to 256-position resolution (Bourns EM14A0D-C24-L064S). The basic LabInt32 board also provides $\pm 12V$ and $-5V$ power supplies, a dual 16-bit DAC with a temperature-stable voltage reference (AD5689R), an instrumentation amplifier, and a digital potentiom-

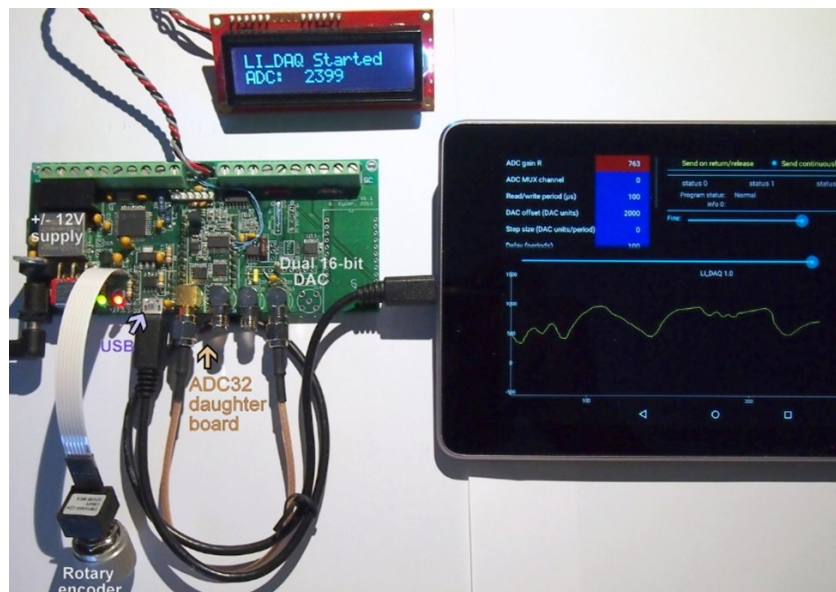


Fig. 3: LabInt32 general-purpose laboratory interface board. The LCD display and shaft encoder can provide a basic user interface, while a 7" Android tablet, pictured at right, provides a full high-resolution graphical interface. A single Android app programmed in Java, “Micro Controller,” provides a common interface that is customized at start-up by each microcontroller program. The ADC32 data acquisition daughter board adds a protected multiplexer, a variable-gain differential amplifier, and an ADC

eter. For other functions the two daughter board slots can be populated as needed. Screw terminal blocks are provided for digital I/O connections, and optional SMA connectors for analog and rf signals.

III. Instrumentation for advanced labs and research

Over the past five years we have designed and programmed numerous instruments using both the LabInt32 board and more specialized PCBs, most of them originally intended for graduate-level research in Atomic and Molecular physics. These designs are fully document, albeit not always very promptly, on my web page.³ Examples include a digital event sequencer with 50 ns resolution, rf frequency synthesizers operating from 25-3000 MHz with 10 ppm long-term stability,

temperature controllers stable to 0.1 mK, high-voltage drivers for spectrum analyzers and PZTs, event counters, laser current controllers, and laser frequency locking circuits. Most recently we have added the ADC32 board shown in Fig. 3, which offers a 15+-bit noise level at an 80 kHz sampling rate with full 16-bit settling. Presently under development is a lock-in amplifier daughter board based on the Analog Devices ADA2200, an adaptive synchronous filter that is somewhat limited in dynamic range, but offers simplicity, low cost, and excellent immunity to crosstalk due to a fully differential signal path.

We are gradually incorporating some of these same instruments into our upper-level teaching laboratories, which include Electronics, Optics, and a general laboratory course taken by

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nearly all physics majors. For example, a stabilized laser diode system now under construction will use three microcontroller systems for temperature and current control and frequency stabilization. In general, our experience to date has been that it is unwise to substitute homemade instrumentation for readily available general-purpose devices such as digital function generators, since the cost savings are offset by a reduction in robustness and ease of use. On the other hand, homemade instruments can be indispensable for special-purpose use, or when commercial instruments are too expensive to afford.

An interesting example recently arose in our Optics lab. When setting up a Michelson interferometer to make laser wavelength comparisons, we realized that it was impractical to hand-count a sufficient number of fringes, and that a standard Agilent frequency counter could not reliably distinguish actual fringes from random fluctuations. Fortunately, I was able to adapt a LabInt32 PCB in just a few hours to serve as a specialized photodiode amplifier and fringe counter, and then to copy the changes to a second unit. The fringe counting program includes a user-adjustable threshold level, a time-domain filter, programmable hysteresis, and a programmable dead-time interval. This makes it possible to

reliably count thousands of interference fringes in less than a minute.

Looking ahead, the role of microcontrollers in experimental physics will continue to increase as the capabilities of these ultra-low-cost computers become better-known. Many niches will be filled quite nicely by standardized architectures such as Arduino or Raspberry Pi, particularly in the introductory physics laboratory. By contrast, for more advanced courses, homemade designs like those described here are likely to flourish for two reasons: (1) For courses on electronics or experimental design, students can design and construct a complete system on their own, at the chip level. (2) For specialized instrumentation, custom designs using high-precision supporting components allow research-grade performance at hobbyist-grade prices, in a compact and highly flexible package. Finally, designing and programming these systems is not only a valuable educational experience; it can be great fun, too!

References:

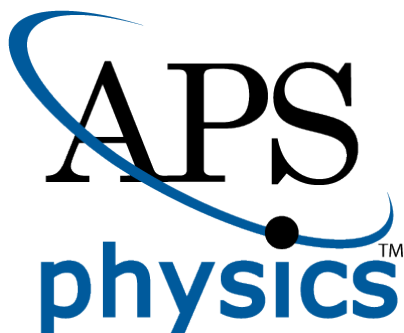
1. E. E. Eyler, "Instrumentation for laser physics and spectroscopy using a 32-bit microcontroller with an Android tablet interface," *Rev. Sci. Instrum.* **84**, 103101 (2013).

2. E. E. Eyler, "A single-chip event sequencer and related microcontroller instrumentation for atomic physics research," *Rev. Sci. Instrum.* **82**, 013105 (2011).

3. E. E. Eyler, Microcontroller Designs web page, <http://www.phys.uconn.edu/~eyler/microcontrollers/>.

4. The lab write-up and C-language program code are available on the University of Connecticut Physics 3150 web page, <http://www.phys.uconn.edu/~eyler/phys3150/>. See the "Labs" section (Lab 10) and also the "Resources" section.

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Recap of Fall 2014 meeting continued...



Above: University of Connecticut alumni and faculty pose for keepsake
Below: Meeting attendees at the Friday night banquet



A New Era of Physics at Central Connecticut

In 2014, Central Connecticut State University (CCSU) made a major move to strengthen STEM education in the state of Connecticut with the formation of the School of Engineering, Science, and Technology (SEST). As part of this initiative, an independent department – The Department of Physics & Engineering Physics (PEP) was formed to provide a critical contributory piece to the future of education, innovation, research and manufacturing and the overall improvement in the economy of the State.

The PEP faculty, in consultation with other STEM colleagues, got to work quickly and tirelessly, to chart the future of the newly independent department. Priority number one was to provide the best programs in Physics and to expand the options available to students. A program for a new B.S. degree in Engineering Physics, with Concentrations in Aerospace, Robotics and Mechatronics, Materials, Photonics, and Mechanical Engineering was designed. The existing Physics B.S. with a minor (usually in Math), was modified to allow for Concentrations in Biology, Biomolecular Sciences (BMS), and Finance. A double major in Physics and Economics is also under consideration. These programs are being sent through the normal processes for approval at the university level and at the Board of Regents level.

The backbone of the economy of the State of Connecticut is technology. Using selected existing Engineering courses, the new B.S. in Engineering Physics will produce students with the unique combination of very high level analytical, problem solving, and all important hands-on skills required for innovation and development in science and technology to keep the state competitive in the global marketplace. In addition to technology, the state is home to a large number of Financial Institutions. Physics, Finance and Economics majors are sought after in Fi-

nancial Institutions on Wall Street, in Government and elsewhere. This is due in part to the great analytical, problem solving, and critical thinking skills that physics majors learn to be very good at and are very much needed in financial institutions, Economic planning and Policy. Moreover, a number of financial and economic theories have their basis in Physics, leading to Physicists being the authors of some of the well known Financial and Economic theories. The Concentrations in Finance, and Economics, will produce a workforce with in depth knowledge of Physics, Finance and Economics, and thus provide a cadre of ready-made analytically skilled professionals for these institutions. In the last several years, the state and the country as a whole has placed a lot of emphasis on developing the field of nanotechnology for economic development and application in all areas of science and technology, including medicine. Biological systems are rife with such opportunities but here again the requisite knowledge and analytical and problem solving skills required are acquired mainly from the study of physics. The B.S. in Physics with Concentrations in Biology, and BMS, will prepare students in this all important area. Physics majors over the years have consistently been top performers in the Medical Schools admissions test MCAT. These Concentrations will also provide a strong pathway to the Health Professions including Medical School and Medical Physics, to help address the continued need for medical professionals in the state and in the country as a whole.

CCSU PEP seeks to work closely with local institutions such as High schools, Community organizations and Community Colleges to create a seamless pipeline into STEM programs. As part of this initiative, in the Fall of 2014, CCSU PEP hosted about 70 high school students as part of a Physics Day. Such events allow us also to project the true value of physics in education and the role of physics in everyday life, as well as all the exciting career options the study of physics makes available to students, as exemplified by CCSU Physics alumni who have gone on to work at places such as Supramagnetics, Pratt & Whitney, United Technologies, US

Patent Office, US Army Research labs, and National Labs doing cutting edge research, to list a few, as well as High School teachers in Connecticut. The department is working to establish articulation relations with the state's Community Colleges. This will create the necessary connected pipeline that will allow students to start their STEM education in Community Colleges and smoothly transition to complete their B.S. degrees at CCSU.

With the needs of the State of Connecticut, CCSU Mission, and our students as the guiding principles, the CCSU PEP is expanding its programs to continue to

- produce well prepared and increased numbers of physics graduates for all sectors of the economy, including education, industry, health systems, financial systems, as well as for research and graduate school.
 - effectively and adequately prepare our students to be professionally ready to participate in the technology driven "new economy" through strong and effective programs and teaching methodologies, involvement of students in cutting edge research projects, and effective and timely advising.
 - build multidisciplinary, synergistic, and collaborative instructional and research relationships with sister institutions, other departments, and local and national institutions
- The CCSU Department of Physics & Engineering Physics is poised to do great things!

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Report from the NES-APS Chair, Charles H. Holbrow



NEW OFFICERS

On January 1, 2015 I became Chair of the New England Section of the American Physical Society. I call it the NES-APS; others call it APS-NES or APS/NS. What do you call it?

Partha Chowdhury is now Past Chair. He did a great job last year as Chair and helped Win Smith -- then Past Chair -- put together a ballot that brought on to the Executive Committee John Collins (Wheaton College) as Vice Chair, and Naomi Ridge (Wentworth Institute of Technology) as Secretary/Treasurer.

NEW MEMBERS-AT-LARGE

From this same ballot the membership elected as new members-at-large Ted Ducas (Wellesley College), Grant O'Rielly (UMass Dartmouth), Aparna Baskaran (Brandeis University), Michael Naughton (Boston College), and Adrienne Wootters (Massachusetts College of the Liberal Arts). Along with continuing member-at-large Courtney Lannert (Smith College), these new electees bring the Executive Committee up to full strength.

RETIRING OFFICERS

Win Smith (UConn) moved out of the chair-sequence. He has been a long standing and devoted contributor to the NES-APS and his tact, grace, and experience have been invaluable.

Rama Bansil (Boston University) retired from being Secretary/Treasurer. The Executive Committee gave her a strong and sincere vote of thanks for her service. If you know how volunteer organizations run, you know how important this position is.

NEXT YEAR'S CANDIDATES

But all the positions are important, and you, dear reader, should eagerly volunteer to be a candidate for Vice Chair or for either of the member-at-large positions to be chosen next fall. Let Partha or me know if you would like to be considered by the nominations committee.

The Executive Committee would gain broader perspective if it had members who work outside academia. A broader geographic distribution of EC members would also be good.

FUTURE MEETINGS

The main task of the NES-APS is to instigate two regional meetings a year. We will have our spring meeting at Boston University where Bennett Goldberg is doing an outstanding job of putting together an interesting program around the physics of 2-D crystals (graphene et al.) and online teaching and learning of physics.

November 6-7, 2015 we will meet at Dartmouth College in Hanover, NH. Marcelo Gleiser is hard at work planning a program with a focus on cosmology. This meeting will be joint with the NES-AAPT (American Association of Physics Teachers).

Our site selection committee has possible hosts for 2016, but it's time to be thinking about 2017 and 2018. NES-APS meetings are fine opportunities to showcase your programs and your faculties and their work to an audience of less than a hundred actively interested physicists and physics students. Contact me if you would like to host an NES-APS meeting. Typical attendance is about 80 people; the meeting runs from Friday noon to early Saturday afternoon; many of the meeting's administrative tasks are done by the APS national office.

BOSTON LOCAL LINK

In February Naomi Ridge, John Collins, and I attended the APS Units Convocation at the American Center for Physics in College Park, MD. We learned about Boston Local Link, an APS effort to build a network that connects physicists who have gone into industry with early-career physicists and physics students. John and I subsequently attended the Boston Local Link's first meeting. We and the BLL planning group agree we need to cooperate because we share a common interest in stimulating communication among everyone interested in physics in New England.

BYLAW REVISION

While at ACP I also explored with Mac Beasley, chair of the APS Governance Committee, what changes need to be made in the NES-APS Bylaws to bring them into conformance with the new APS constitution. Changing the Bylaws is a cumbersome process, but it is under way. Changes require approval by the NES-APS membership, so look forward to hearing more about the changes and voting on them. An important goal has been to provide the NES-APS organization with the flexibility it needs to fill its offices and engage its members.