DEPARTMENT OF PHYSICS NEWSLETTER

FOR ALUMNI AND FRIENDS

VOLUME 2, OCTOBER 2012
DALY SCIENCE 316 (408) 554-4314 SCU.EDU/PHYSICS

SANTA CLARA UNIVERSITY

Inside this issue:

LETTER FROM THE CHAIR, JOHN BIRMINGHAM

As we begin the new school year, it is a great pleasure to update you on what has been happening here in the Department of Physics. Much has transpired since our first newsletter, and there are many new developments and exciting events to report. On the pages that follow you will read about progress in faculty research and learn of the achievements of some of our recent graduates. For me, one of the most exciting events of the past year was a visit in October from Fr. José Gabriel Funes, S.J., director of the Vatican Observatory. Fr. Funes toured our Ricard Observatory (still closed, unfortunately), and we discussed SCU joining the International Network of Catholic Astronomy Institutions (INCAI). We will be offering our first upper-division astrophysics course in the winter and will be looking to add an astrophysicist to the faculty in the not-too-distant future.

Our full-time faculty members continue to achieve in both the lab and in the classroom. **Guy Ramon's** work on spin physics in semiconductor quantum dots and the potential applications for quantum computation has been published in two papers in the journal *Physical Review B* and is featured on pages 2-3 of our newsletter. **Betty Young** served on the International Advisory Committee for the 14th International Workshop on Low Temperature Detectors held in Heidelberg, Germany last summer. Among her co-authors this past year were five SCU graduates from our department: Devin Wesenberg (now at University of Denver), Astrid Tomada (SLAC), Matt Cherry (Stanford), Dustin Ngo (Yale) and Craig Benko (University of Colorado). **Phil Kesten**, together with Prof. David Tauck in Biology, has written an introductory text book, "University Physics for the Physical and Life Sciences." Published by W.H. Freeman, the text blends calculus-based physics and physiology and is being adopted around the country at institutions that include Harvard, Brown, and Smith College. **Chris Weber** published his first paper with SCU student co-authors in May 2011, and he recently received a three-year research grant from the National Science Foundation for work entitled "Measurement of density of states of (Ga,Mn)As and diffusion of photoinduced order by ultrafast transient-grating spectroscopy." **Rich Barber** has two current research efforts: low-temperature measurements of superconducting phenomena and characterizations of polymer-based photovoltaic materials. The latter work is a collaboration with the SCU Department of Chemistry and involves undergraduates from both departments. Rich also serves as the Director of the SCU Center for Nanostructures. In my own lab, SCU undergraduates and I are involved in projects in computational neuroscience and neurophysiology. We utilize ideas from statistical physics, such as entropy and information, to analyze and interpret our results.

The past year saw two major departmental transitions. **Stanley Tharaud**, our long-time lab technician, retired in November after almost 34 years of service to Santa Clara University. Stanley brought to SCU expertise in both machining and electronics, and he designed and built many of the apparatuses that have been, and continue to be used in our faculty research labs. **Father Carl Hayn**, who retired a few years ago, relocated this past spring to the Sacred Heart Jesuit Center in Los Gatos. Father still makes it in to the department, although not as often these days. We did enjoy celebrating his 96th birthday at the Adobe Lodge in July (p. 7).

We always look forward to visits from alumni and friends of the Department. Upcoming events, such as colloquia, that are open to the public are posted on our departmental home page: http://scu.edu/physics/. In particular, we will be holding the third annual Physics Undergraduate Research Symposium on Saturday October 27. If you'd be interested in attending or have other questions about the department, please contact me via e-mail (jbirmingham@scu.edu) or phone (408-551-7185).

With best wishes,
John Birmingham

FACULTY SPOTLIGHT: DR. GUY RAMON, ASSISTANT PROFESSOR

Spin Qubits in Quantum Dots: Building Blocks of a New Computer Paradigm

From its inception, quantum mechanics enjoyed a reputation as a trouble-maker theory, stirring bitter disputes over its interpretation and far-reaching implications. Since the legendary Bohr–Einstein debates of the 1920s, questions concerning the foundations of quantum mechanics have been put aside by the majority of the physics community who adopted a shut-up-and-calculate approach. The theory works, no one intuitively understands it — what else is there to say?

Throughout the years a small group of physicists has nevertheless continued to grapple with these issues, until their tenacity paid off in an unexpected dividend. In 1982, Richard Feynman showed that a classical Turing machine – a hypothetical device simulating the logic of any computer algorithm – will need an exponentially long time to simulate quantum phenomena. Nature, being quantum mechanical, is apparently fluent with storing and manipulating the vast information hidden in quantum states. And thus, Feynman speculated, a machine whose building blocks obey quantum laws would perform exponentially faster than a classical computer. These building blocks, now known as qubits (a term coined by Ben Schumacher), are analogous to two-state classical bits with one important difference: a qubit is a two-state quantum mechanical system and as such it is allowed to be in any superposition of zero and one, thereby having access to an infinite amount of information.

Superposition and the related phenomenon of entanglement – the ability to form a multi-qubit state in which none of the single qubits lives in its own well-defined state – are at the heart of the computational resources offered by a quantum computer. However, there's a catch: if you try to get a glimpse of the enormous amount of information processed by the qubits by measuring their states, you will collapse the wave-function to a single (classical) bit of information per qubit. The crux of quantum algorithms is thus to find devious ways by which useful information can be retrieved without directly measuring the qubit's state. This is typically done using ancillary qubits, which are not part of the computational space, but whose measurement indicates its outcome.

The first example of a quantum algorithm that outperforms its classical counterpart was invented in 1985 by David Deutsch. It was only in 1994, however, with Peter Shor's algorithm for finding the prime factors of integers, that quantum computing became the focus of attention in the larger scientific community. Factoring, which is intimately connected with the Fourier transform, is known to be a hard problem. By "hard" it is meant that the most efficient algorithm running on a classical computer solves the problem in a time that grows exponentially with the size of the input number. Shor's quantum algorithm instead solves the problem in a polynomial time. If you're not impressed, consider a number with 300 digits. It would take over 2000 years to factor it using the newly deployed IBM Sequoia in Livermore National Lab – currently the world's fastest supercomputer. It would take much longer than the age of the universe to factor a 400 digit number. In comparison, a quantum computer with merely a few thousand qubits will crack the problem in a split second.

Still think this is a mathematical mumbo-jumbo hardly relevant to your daily life? Not so, as the most widely used public-key cryptography schemes are based on the presumed computational infeasibility of large number factorization and are used to encode virtually everything, from credit card transactions to emails and web security. The prospects and current status of quantum computers in this respect are vividly summarized by the following two limericks:

If computers that you build are quantum,
Then spies of all factions will want 'em.
Our codes will all fail,
And they'll read our email,
Till we've crypto that's quantum, and daunt 'em.

Jennifer and Peter Shor

To read our E-mail, how mean
of the spies and their quantum machine;
Be comforted though,
they do not yet know
how to factorize twelve or fifteen.

Volker Strassen

With such high stakes it is not surprising that massive resources and some of the brightest scientific minds have been invested in the last two decades in trying to find a physical system that will realize quantum information processing. Despite heroic efforts and impressive technological progress, we are still very far from having a commercial quantum machine. The problem is "decoherence" – the uncontrolled interactions between qubits and their surroundings. Simply put, to qualify as a viable qubit, a two-level quantum system needs to be sufficiently isolated from its environment so that the information stored in its fragile quantum states remains intact throughout the computation time. More precisely, the ratio between coherence time and manipulation time (e.g., the time it takes to flip the qubit state from 0 to 1) should be larger than 10^5 – the current noise threshold of fault-tolerant quantum error correction codes. Unfortunately, the requirements for long coherence time and short manipulation time are often contradictory, making the above threshold a formidable challenge in any of the currently studied systems, even at the extremely low temperatures at which they are operating.

Professor Guy Ramon at SCU and his students study the theory of semiconductor quantum dots as potential qubit hosts. These are small islands that contain between ten thousand and ten million atoms each. Since their electrical and optical properties can be engineered by state-of-the-art material growth techniques, they are often referred to as artificial atoms. In recent years researchers in several labs around the world have acquired a remarkable level of control enabling them to isolate single electrons on quantum dots and manipulate them across several dots. The likely contender qubit in these devices is the electron spin, whose interactions with other degrees of freedom in the system are weaker by far than

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those of the electron's charge, resulting in longer coherence time. Spin is a fundamental attribute possessed by all elementary particles in addition to their mass and charge. The spin can be thought of as the angular momentum associated with the electron motion about the center of mass, distinctive from the orbital angular momentum associated with the electron motion around the nucleus. While the analogy with classical planetary motion is helpful, it should be remembered that as far as we know, the electron is a point particle and its spin has nothing to do with its motion in space. Rather it has an intrinsic unchangeable value of 1/2, which conveniently quantizes to two possible states – spin up and spin down.

So, if the electron spin is identified as a natural two-level system; why can't we declare victory? For one thing, although a quantum dot loaded with a single electron resembles the hydrogen atom, unlike the latter it includes millions of nuclei buried in its substrate. In GaAs, one of the leading semiconductor materials used to make quantum dots, these nuclei carry their own spins, which couple to the electron spin via the hyperfine interaction. These nuclear spins fluctuate, causing random precession of the electron spin, which consequently loses its coherence within 10-20 nanoseconds – hardly enough time to perform any coherent manipulation. One possible remedy is to polarize the nuclear spins thereby reducing their fluctuations. Remarkably this can be achieved by harnessing the hyperfine coupling – the same mechanism that mediates this decoherence channel. By preparing the electron spin in a definite state (say spin up) and repeatedly going through a polarization cycle, conservation of angular momentum dictates transfer of electronic-to-nuclear polarization and the nuclear spins get polarized one at a time.

A different technique, borrowed from the science of NMR, uses control pulses to prolong coherence time. Imagine an electron spin subjected to fluctuating nuclear or charge environment. The electron spin state precesses, gaining some phase after time *t*. Now, if these fluctuations are quasi-static, and we flip the electron state at *t/2*, it will acquire a phase of the same magnitude but in an opposite direction, so that at the end of its evolution the qubit state is refocused to its original form. This control pulse, called spin-echo, is the simplest form of a family of protocols, collectively called dynamical decoupling sequences, which are designed to remove low-frequency noise. Using dynamical nuclear polarization and control pulses, researchers at Harvard have recently measured electron spin coherence times in excess of 200 microseconds – over five orders-of-magnitude improvement.

In his research, Professor Ramon uses a combination of numerical and analytical tools to analyze the complex dynamics of electron spins localized in quantum dots and their interactions with their environment. These analyses reveal the leading decoherence mechanisms and suggest ways to mitigate them. For instance, a particular sequence of control pulses may be effective at eliminating nuclear-induced decoherence but less so when the main noise source is charge fluctuations. Identifying the main decoherence channels allows the exploration of the most suitable pulse protocols for a given scenario. A different effort is focused on finding mechanisms that may be used to manipulate and couple spin qubits – the physics analogues of logical gates. Two-qubit gates are an essential part of any quantum algorithm. Physically they amount to performing a conditional operation, e.g., flipping a spin in one dot, conditioned on the state of the spin in the second dot. Analyzing the various interactions within quantum dot molecules and more complex devices, Ramon is able to propose working positions and quantum dot geometries that facilitate controlled coupling between the spin qubits. But, it's kind of like *Catch–22*: in order to come up with a successful design for a spin-based quantum computer, one needs to simulate the rich dynamics of the qubits – the very one that gives them their edge – using, alas, a classical computer.

So, should you postpone your next computer upgrade until quantum computers become available in either PC or Mac flavor? No physicist will advise you to hold your breath, but science moves in mysterious ways. The quest for technologies and materials that will host this dream machine has already yielded a multitude of new techniques to control quantum systems at the nano-scale. Some of these are likely to be central in a variety of novel solid-state devices that will affect our everyday lives in one way or the other.

Professor Guy Ramon received his B.A., M.Sc., and Ph.D. in physics from the Technion – Israel Institute of Technology in 1991, 1998, and 2002, respectively. He joined the Santa Clara faculty in 2007, and he is always happy to chat with students, colleagues, alumni, and friends about his research.

Professor Ramon is the proud father of three sons and a (classical) computer. While no match for his three siblings, the non-human progeny boasts 40 processor cores and over 100 GB of RAM (and growing), which are intensively used to simulate potential architectures of spin-based quantum computers

CATCHING UP WITH ALUMNI: UPDATES FROM SOME OF OUR FORMER STUDENTS

Andrew J. Giustini, B.S. Physics '06

I graduated from SCU in 2006 with a B.S. in Physics (and minors in Chemistry and Religious Studies). While there I was fortunate enough to do research with Profs. Barber and Granger (now at Cal Poly) in the Department of Physics and in Prof. Atom Yee's lab with his post-doc Paul Davis in physical chemistry. Working with these wonderful mentors I discovered a passion for research. From the courses I took in the physics department at SCU I learned how to approach problems in a variety of fields. Ultimately, however, I decided to shift my research focus from the physical to the biological.

In August of 2006 I moved to the (very cold) state of New Hampshire to start a combined M.D./Ph.D. program at Dartmouth's Thayer School of Engineering and Geisel School of Medicine. I completed my first two years of med school in June 2008 and then started my Ph.D. research through the engineering school in the laboratory of P. Jack Hoopes, a veterinary pathologist and radiation biologist who directs the Surgical and Radiation Oncology Research Laboratories at Dartmouth. The lab's research is focused on using ferromagnetic nanoparticles heated with an alternating magnetic field to kill tumor cells. This research is part of a collaboration of fourteen Dartmouth professors (half in engineering and half in medicine) and their laboratories to use nanotechnology to image and treat tumors. My specific projects used ionizing radiation to demonstrate the efficacy of combining the two therapies and to modify the tumor microenvironment to increase nanoparticle accumulation in tumors. I also quantified nanoparticle-cell interactions in vitro and in vivo using, among other techniques, a novel method called Magnetic Spectroscopy of Brownian Motion (MSB).

During my graduate studies I participated in Dartmouth's Ph.D. Innovation Program, which teaches engineering graduate students about intellectual property, venture capital, corporate finance, venture creation, innovation and entrepreneurship. As part of this program I completed a three month internship with a Boston-area company working on a device to treat spinal cord injuries. I was also fortunate enough to receive a Dartmouth-NIH Fogarty fellowship to spend a few weeks at an eye hospital in India with an ophthalmologist from Dartmouth, conducting research and learning from some of the physicians there. Since finishing my thesis work, I've started working on a research project with a Dartmouth otolaryngologist, comparing the outcomes of robot-assisted surgery for oral tumor removal with more traditional techniques.

Now that I've completed my Ph.D. I'll return to Geisel to finish my final two years of medical school. After that, I plan to further my medical training in a residency program.

Daniel Paramo, B.S. Physics and Mechanical Engineering '98

Like many freshmen, I arrived at SCU "undeclared" and wasn't entirely sure what I wanted to pursue. It was

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during the shared engineering and science curriculum that I discovered how the derivation of the equation was just as important to me as the practical application. Dr. Betty Young was pivotal in my undergraduate Physics and Mechanical Engineering degrees.

I started at Etec Systems after graduation and was responsible for making their electron beam (e-beam) lithography tool easier and faster to manufacture. I used this experience at KLA-Tencor for their e-beam metrology and next generation optical thin-film instruments, and at Genus/Aixtron for their pioneering Atomic Layer Deposition tool. Next I left the semiconductor industry and went to a medical device company that manufactures digital x-ray sensors. Currently I am at a hybrid bio-tech/medical-device startup setting up production lines and establishing necessary processes to meet regulatory requirements.

The foundation from my Physics education has enabled me to work across engineering disciplines and allows me to approach challenges from a systems-level perspective. In my free time, I enjoy barbecuing for my family and competing in an amateur car race series held throughout California with my RX7.

Bonnie Valant-Spaight, B.S. Physics '94

After graduating with a BS in Physics in 1994, Bonnie went directly to Cornell University to study experimental particle physics. Ah, the joys of Jackson and Sakurai! The change of weather from sunny California was a huge shock to her system. She worked with the CLEO collaboration, an experiment right on the Cornell campus, and produced a thesis on the decay of B mesons produced from electron-positron collisions. In her spare time, she also danced with and choreographed for the Ithaca Ballet. An excerpt from her "Sentimental Journey" was recently featured in their 50th anniversary gala, and they frequently revive "Jupiter," which was inspired by Holst's music and astronomical imagery.

Bonnie's husband, Tracy Spaight (SCU '93), got a job in Houston, TX, before she had finished her thesis, so they moved in 2000, and she finished her degree remotely. In 2001 she joined PathFinder Energy Services as a nuclear physicist. She was in the awl bidness! She worked in what's known as "logging while drilling," in which instruments become part of the drill string and measure earth formations shortly after they've been penetrated by the drill bit. Bonnie enjoyed working with mechanical and electrical engineers to make tools that could produce precision measurements while being baked, pounded, and squeezed within an inch of their life.

In 2006 Tracy was offered his dream job designing video games, so they moved to Marietta, GA, a suburb of Atlanta. Bonnie found a job at Propagation Research Associates, a company of about 10 people, where she is the Principal Investigator for several Small Business Innovation Research projects involving mitigating tropospheric and ionospheric effects on radar and infrared signals. She has learned a great deal about weather modeling, the ionosphere, GPS systems, and atmospheric turbulence. In 2008, Bonnie and Tracy welcomed a daughter, Josephine, into their lives.

ALUMNI-WE WANT TO HEAR FROM YOU!

We would love to hear how you are doing. Please email us your information including name and year of graduation, what you did after school, what you are doing now, and/or how your SCU degree contributed to your current activities. We would love a picture as well! With your permission, we may feature you in an upcoming newsletter. E-mail us at physics@scu.edu.

STUDENTS

2012 PHYSICS AWARDS DINNER

Andrew Hodun received the Drahmann Prize, which is presented to the graduating senior physics major who best exemplifies the hardworking and earnest values of Dr. Drahmann, long time Dean of Sciences and Professor of Physics. Mrs. Jean Drahmann is pictured above, with Andrew.

The Blockus Award, in memory of Dr. David L. Blockus, Ph.D., is presented each year to the outstanding senior student(s) in the Physics Department. Dr. Marilyn Blockus is pictured here with the 2012 recipients, Theodore Mefford and Austin Jones.

The Carl H. Hayn Prize is awarded each year to the most outstanding student in the Physics for Scientists and Engineers I, II, and III sequence. Richard Schulte was this year's recipient, and he was joined by Fr. Hayn and William Duffy, professors emeriti, to receive his award.

CONGRATULATIONS CLASS OF 2012

Joseph Brenninkmeijer—Engineering Physics
Aaron Melgar—Engineering Physics
Andrew Hodun—Engineering Physics
Theodore Mefford—Physics
Austin Jones—Physics
Alex Curry—Physics
Stony Strickland— Engineering Physics

STUDENT RESEARCH SYMPOSIUM

On November 5, 2011, several of our juniors and seniors presented some of their faculty-sponsored research. Titles of their talks are listed below.

Nuclear Spin-flips in the Pure Quantum Dephasing of a Solid State Electron Spin Qubit
Teddy Mefford (Faculty advisor: Guy Ramon)

Modeling the Electrostatic Properties of a Double Quantum Dot
Tor Johnson (Faculty advisor: Hong-Wen Jiang, UCLA)

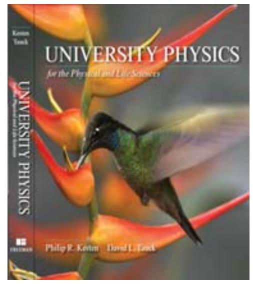
Transient-Grating Study of Electron and Hole Diffusion in (Ga,Mn)As
Eric Kittlaus and Chris Waight (Faculty advisor: Chris Weber)

Naturally-Occuring Activity and Spike-Spike Train Decoding in a Nervous System in the Crab
Alex Curry and Aaron Melgar (Faculty advisor: John Birmingham)

Please check our website for information about the upcoming student research symposium that will be held on campus this October 27th and is open to the public.

IN THE DEPARTMENT

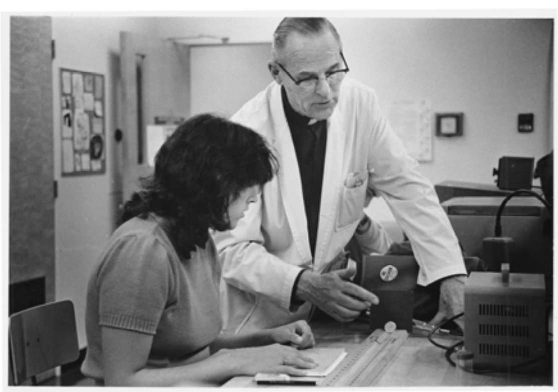
On July 13th, the physics department and friends celebrated Fr. Hayn's 96th birthday, at the Adobe Lodge. It was a wonderful party and Fr. Jim Felt brought a copy of his high school yearbook. Fr. Hayn had been his high school physics teacher during World War II.



"University Physics", written by Professors Kesten and Tauck (Biology), was published in 2012 and has already been adopted at institutions including Harvard, Brown, and Smith College.

Gary Sloan joined the department as our laboratory manager. He is a native of Santa Clara and, prior to coming to SCU, Gary was the lead machinist at the Wall Street Journal in Palo Alto. In his spare time, Gary enjoys restoring classic vehicles.

FROM THE ARCHIVES

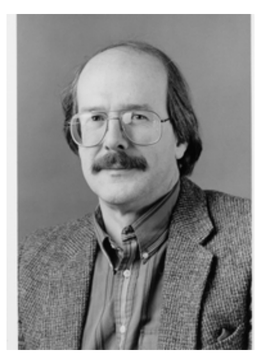


Fr. Hayn and a student, circa early 80's, from the SCU Archives

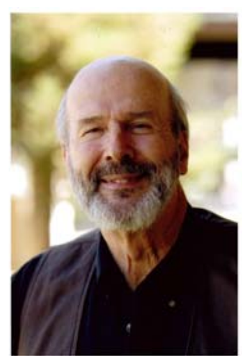
Professor Duffy and a student. Photo credit: Charles Barry, 1989

The Department of Physics brochure, from the 1960-1961 academic year. There were 1325 students enrolled at the University, approximately 45 of whom were physics majors. Do you recognize the student working with Professor Duffy? If so, please let us know!

Then and Now



1980's. From the SCU Archives



Today

Mr. William (Bill) DeHart, is the most senior member of our department. He first came to Santa Clara in 1973, and has taught thousands of students during his career in the labs associated with the introductory physics sequence.

STUDENT RESEARCH SPOTLIGHT : POLYMER PHOTOVOLTAICS

David Oparko (Physics '14) and Max Giamonna (Chemistry and Biochemistry '12) use an Atomic Force Microscope to image the surface of a polymer-based solar cell. This work is part of a collaboration between Prof. Rich Barber (Physics) and Department of Chemistry and Biochemistry faculty members Prof. Brian McNelis and Prof. Thorsteinn Adalsteinsson. They are studying the effect of varying C_{60} additive molecules on device stability and extending that work to include structural studies. The most recent journal article from this project can be found in *Solar Energy Materials & Solar Cells*, ***100***, 192, (2012).

Santa Clara University

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