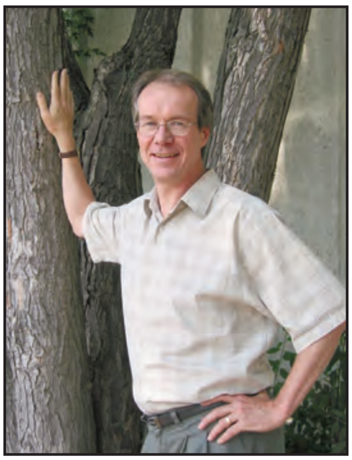
Department of Physics and Astronomy

WINTER 2012

Message from the Chair



David Venus

The Department of Physics and Astronomy is always an active place, but from time to time some of our longer term projects crystallize simultaneously in what seems to be a flurry of announcements. This edition of the Newsletter highlights a series of newly created opportunities and ventures of the department.

The department is introducing some new academic programs that will offer the wider, interdisciplinary opportunities that students are seeking and that better represent the expertise of our faculty members. The first of these is an independent Honours Biophysics B.Sc. that allows the flexibility to fine tune the emphasis of "bio" and "physics" within the curriculum, and includes crucial new courses that serve to integrate the interdisciplinary themes. The second is an Honours Astrophysics B.Sc. This stand alone program has evolved from our successful specialization and has just received Senate approval. This program will first accept registration in September 2013, and will be highlighted in the next Newsletter. Of course, we continue to offer our highly regarded core Honours Physics B.Sc. program.

Combine Biophysics and Astrophysics, and what do you get? Why Astrobiology, of course. McMaster's Origins Institute is offering the first Astrobiology graduate program in Canada, and the Department of Physics and Astronomy is proud to be one of six departments participating in this interdisciplinary program that focuses on life in extreme environments on Earth or other planets.

Among other important developments, I would particularly like to mention that Caroline Burgess, the departmental Outreach Co-ordinator, has decided to pursue her passion for helping students using an entrepreneurial model. Best wishes and sincerest thanks to Caroline for the tremendous work she has done creating our outreach programs that involve more than 2000 high school students every year. You can still access our outreach programs via outreach@physics.mcmaster.ca ; we are currently putting a new Outreach Co-ordinator in place.

Please get in touch if you are interested in any of these new opportunities, or if you have some ideas about how we can create new opportunities together.

In this issue...

Alumni - Where are they now?

Kate Harding (B.Sc. 2010) graduated from the Master of Library and Information Science program at University of Western Ontario and is now a Liaison Librarian at the University of Saskatchewan Health Sciences Library, responsible for library services to students, staff and faculty in nursing and biomedical sciences.

Ian Rowe (B.Sc. 2011) is working as a Health Physicist at Bruce Power, the world's largest nuclear power site.

Nathan Leigh (PhD 2011) holds a Postdoctoral Fellowship at the European Space Agency in the Netherlands.

Undergraduate Profile

Alison Kinross

I grew up not far from McMaster, in Toronto's Greek town. I was lucky enough to be surrounded by a very supportive family, which led to early encounters with math and physics. My early memories include: my sister and I graphing the depth of fallen snow as a function of time, optimizing the lay-out of our bedrooms using 1/20th scale replicas, and testing homemade parachutes by launching beanie babies off of our third floor deck. I'm currently in my final year of undergrad physics, and I seem to be conducting similar home experiments as part of Dr. Dalnoki-Veress' soft condensed matter class. Clearly, I chose the right school for studying physics. My experience in the physics and astronomy department has been much more rewarding than I could have possibly imagined when I started university.

Physics appeals to me due to the fact that it is focused on reality. Originally enrolled in mathematics, I quickly realized that math at the university level doesn't necessarily share this focus, making it difficult for me to maintain interest. This realization, along with an excellent experience in my first year physics course and an offer to conduct research in the department, led me to switch into physics after my first year. I am very grateful to both Caroline Burgess, for helping me to secure this initial summer research position, and to Dr. Karen Hughes for being such a fantastic professor!

I held my first research position in Dr. Tom Timusk's lab, where we used optical spectroscopy to investigate a phase transition of unknown order. The following summer I held an NSERC USRA with Dr. Graeme Luke in the crystal growth lab under the supervision of Dr. Hanna Dabkowska, where I grew single crystals by the optical floating zone method. At the end of the summer, I was lucky enough to be sent to TRIUMF to conduct mu-SR measurements on one of the crystals that we had grown. This past summer I held another USRA at Queen's University with Dr. James Fraser, where I investigated laser-welding dynamics using a new in-situ imaging technique. Finally, I'm currently working on my thesis project in Dr. Takashi Imai's lab, conducting NMR measurements on another piece of the very same single crystal (in fact, our temperature is stabilizing as I type).

Not only has this department provided me with the opportunity to participate in a variety of research projects, but I have also been able to present my work at four conferences, including three Canadian Undergraduate Physics Conferences! I have no idea what I plan on doing next, but I am sure that my time here will have prepared me well.

Alumni - Where are they now?

Sean Matt- a CITA National Fellow here in the mid 2000s with Ralph Pudritz and Hugh Couchman - has accepted a tenure stream Lecturer position at the University of Exeter in the U.K.

Graduate Profile

Aaron Maxwell

Having grown up in Toronto's East end, I wasn't familiar with the depth and breadth of the night sky as a child. But I wanted to be an astronaut. As it turns out, becoming an astronaut is ridiculously hard. So I decided to study astronomy, which seemed like the next best thing. To that end, I chose to attend York University because they offered the chance to work at the observatory there, and I wanted to be an Observational Astronomer. I learned two things: research is cool, and observing in the winter is cold. So I decided to pack my bags and head across the country to beautiful Victoria to study the theory of how stars form under the supervision of Dr. Doug Johnstone for my Master's thesis. This only stoked my interest even more in the larger scales of star formation in the universe, so I packed my bags yet again and headed back across the country to study galaxy formation. When I thought of all the places in Canada to do that, there was only one logical choice - McMaster University.

I now work on the formation of stars in dwarf galaxies with Dr. James Wadsley and Dr. Hugh Couchman. Dwarf galaxies are essentially scaled down versions of the large beautiful galaxies we're used to thinking about. Dwarfs are the perfect laboratory to study how star formation and other processes affect galaxy evolution, as the various physical scales start to overlap. My focus is on simulating these dwarf galaxies - putting all of the physics we know and understand into a program and letting supercomputers do the nasty bits. Getting the chance to work with these two world renowned astronomers is an amazing opportunity, especially given their extensive background in computational astrophysics! What puts the icing on the cake is that the research that I do flows so easily into collaborations with other astronomers in the department, as well as around the world! I've benefited from the chance to travel around the world to present my research, and to have been awarded a research grant from the National Sciences and Engineering Research Council (NSERC). Being at McMaster has helped me grow my passion about all aspects of science research, outreach, and communication, as well as fielding a superb softball team!

Alumni - Where are they now?

Nidal Abu-Libdeh (PhD 2010) is an Assistant Professor at Prince Mohammad University (PMU).

Sara Haravifard (PhD 2010) holds a joint Post-Doctoral position at Argonne National Laboratory and University of Chicago.

Issei Nakamura (PhD 2010), is a Postdoctoral Scholar in Chemical Engineering at California Institute of Technology.

Nathan Leigh (PhD 2011) holds a Postdoctoral Fellowship at the European Space Agency in the Netherlands.

Postdoc Profile

Oliver Bäumchen

I was born and raised in a town named Illingen very close to the city of Saarbrücken in Germany. Saarbrücken is the capital of Saarland, a small German state close to border with France. My passion for physics started with gazing at the stars during summer and winter nights in the countryside. In fact, setting up my 10-inch telescope together with my friends back home and doing some amateur astronomy is still a great source of personal enjoyment for me. I am very grateful that my natural curiosity about physics was fostered by my family and also by two excellent high school physics teachers. Looking back to those days, I still find it amazing how much effort and passion these teachers put into communicating their personal excitement about physics, from demonstration experiments to developing a solid theoretical and mathematical background.

While finishing my physics studies at Saarland University, my research interests had already started focusing more and more on problems in the field of soft condensed matter physics. I realized that this was an exciting, fast growing field including fascinating questions related to polymeric and biological systems that are highly relevant in everyday life. For that reason it was a natural decision to continue my research activities in the soft matter physics group of Prof. Karin Jacobs at Saarland University for my PhD (from 2006 to 2010). My PhD involved studying the dynamics of liquids at interfaces by means of experimental techniques such as atomic force microscopy, optical microscopy, reflectivity methods and ellipsometry and relating the experimental results to hydrodynamic theories and molecular models.

During the summer of 2009 I jumped over the pond to North America to participate in a Gordon Conference in New Hampshire. Aside from this conference, my motivation was also to look for interesting places in the US and Canada for my time as a postdoc. The large overlap of common research interests and an invitation from Prof. Kari Dalnoki-Veress also lead my way to Hamilton. Discussing research with Kari and his students at McMaster made me realize in a short period of time that we share many common viewpoints and excitement for soft matter physics. Being rewarded a postdoctoral fellowship by the German Research Foundation finally allowed me to start working with Kari and to become a member of the Physics and Astronomy Department at McMaster University.

Music, sports and discovering the beauty of nature and wildlife while hiking and climbing rocks are further important parts of my life, which made moving to Canada seem like a perfect choice for me. Immediately after arriving on Canada Day in the summer of 2011, I realized that the Physics and Astronomy Department is not only an excellent academic environment for research and teaching, but also represents a great community of students and teachers exhibiting an amazing positive spirit that made it easy for me to make new friends. While the major part of my current work comprises studies on the glass transition of polymer films and capillary-driven liquid flows, the latter in close collaboration with the theory group of Elie Raphael at the ESPCI in Paris, I am also looking forward to extending my research activities from polymeric liquids to very exciting biological systems in the near future.

New Honours Biophysics Program

Starting in 2012 the Department of Physics and Astronomy is excited to offer a new honours program in Biophysics. The program has been designed to give a strong foundation in mathematics and the physical sciences with the addition of key life sciences courses. The program is flexible, allowing students to choose electives to specialize in a particular direction, such as molecular biology or microbiology, in later years.

In addition to the existing courses in physics, mathematics, chemistry, biochemistry and biology, four new courses have been created for the program, one in each year. The new level I course (Biophysics of Movement and Senses: From Microbes to Moose) will apply grade 12 physics ideas to biological systems. The topics covered include Sound, Hearing and Echolocation, Optics of Vision, Animal Locomotion, Thermal Motion of Molecules, Heat and Heat Flow in biological systems and Fluid Dynamics including principles of Swimming and Flying.

The level II course (Explorations in Biophysics) is an inquiry based presentation of selected current topics in biophysics. As part of this course students will work in small groups and carry out several short projects involving a literature review and experimental or computational research. The level III course (Soft Condensed Matter Physics) includes topics in polymers, liquid crystals, surfactants and colloids. The course covers structure, dynamics, phase transitions and self-assembly, and discusses applications and links to the life sciences. The level IV course (Introduction to Molecular Biophysics) presents recent contributions made to the fields of molecular and cell biology, including the physical properties of biomolecules, protein folding, molecular motors, cell motion and cell adhesion.

Sidewalk Astronomy

Recently several astronomy graduate students have started a new outreach initiative they're calling sidewalk astronomy. The students host weekly observing sessions, weather permitting, with the Department of Physics and Astronomy's 30cm Meade telescope. The observing location outside of the Mary Keyes Residence was chosen to maximize both the amount of the sky visible and the amount of local foot traffic. The public observing nights are scheduled to coincide with the planetarium public shows allowing the patrons of the planetarium to view objects in Hamilton's night sky after the shows. Despite the fact that this is a new initiative with relatively little advertising, the average number of people at each observing night is 150. Members of the McMaster and greater Hamilton community are able to look through the eyepiece and see planets, stars and even our neighbour, the Andromeda Galaxy. Future plans include implementing solar observing during the day, allowing anyone to take a quick peek at sunspots. The students welcome anyone interested to join them on observing nights. More information can be found at: www.physics.mcmaster.ca/sidewalkastronomy/home.html

Alumni - Where are they now?

Pat Clancy (PhD 2011) joined the Department of Physics at the University of Toronto as an NSERC Banting Postdoctoral Fellow.

The First Astrobiology Graduate Program in Canada

Starting in 2013 the Origins Institute (OI) is proud to host the first graduate program in Canada in the field of Astrobiology. Astrobiology is the search for evidence of life beyond the Earth (eg. Mars, Titan, SuperEarths,..) and is a rapidly growing area of research.The OI program is a "Collaborative Graduate Program in Astrobiology" in which students register and are based in a "home" department - one of five collaborating departments - and complete their normal degree requirements under those auspices. The astrobiological component of the program (which is a specialization of the student's degree), involves taking a one term Survey of Astrobiology course, an ongoing biweekly research seminar/ journal club, at the M.Sc. level, as well as a one-term Astrobiology related course from outside of their normal home department at the Ph.D. level. Students will carry out Astrobiology related research and complete a thesis in a variety of possible areas. Students will benefit enormously from broad contact with program students and faculty from our participating departments. In many instances, their research will involve interdisciplinary collaborations with members and students in other "home" departments. Research topics have a broad range; from astrophysical aspects of Astrobiology (eg. habitability of exoplanets, origin of water and biomolecules on young planets, etc.) to topics in geochemistry and pre-biotic chemistry, and on to RNA world and early evolutionary biology and biochemistry

The program launched in Jan. 2013 and joins just a handful of graduate programs in the U.S. and Europe. The Origins Institute has a strong track record in Astrobiological Research and provides students with a superb set of laboratory and computer facilities across the university. Participating home departments are Biology, Biochemistry and Biomedical Sciences, Chemistry and Chemical Biology, Physics and Astronomy, and the School of Geography and Earth Sciences. More information can be found at: http://origins.mcmaster.ca/education.php

Department Awards:

Helen Kirk (Origins Institute) was one of 4 McMaster researchers awarded a Banting Postdoctoral Fellowship, the most prestigious postdoctoral award in Canada. After earning her PhD in physics at the University of Victoria, Kirk went to work as a post-doctoral researcher at the Harvard-Smithsonian Center for Astrophysics. She is considered a world leader in the observational study of star formation in molecular clouds, and her research is expected to bring new capabilities to McMaster's Origins Institute and its study of how star clusters form.

Student Awards:

Rob D'Ortenzio has been awarded the Carl Westcott Memorial Fellowship. This is given annually to an outstanding graduate student who does most of their thesis research at TRIUMF.

Alumni - Where are they now?

Erik Sandqvist (B.Sc. 2010) is now Head of Physics and lead mentor of First Robotics Canada team 4519 at King's Christian Collegiate.

Canadian Astronomical Society Student Prizes

At the annual meeting of the Canadian Astronomical Society (CASCA), our department graduate students received the following awards:

Anne Hou - Best Student Talk "The impact of group dynamics and substructure on galaxy evolution" Supervised by Laura Parker and Bill Harris

Yasuhiro Hasegawa - Best Student Paper "The origin of planetary system architectures - I. Multiple planet traps in gaseous discs" Supervised by Ralph Pudritz

Canadian Undergraduate Physics Conference (CUPC)

The Department of Physics and Astronomy sent eighteen undergraduate students who did summer research projects at McMaster to the CUPC 2012 held at the University of British Columbia. Seven of these students won the following awards:

Richard Parg - 1st place for talk in Condensed Matter Physics
Michael Birch - 1st place for talk in Particle and Nuclear Physics
Darren Fernandes - 1st place for talk in Astronomy and Astrophysics
Alison Kinross - 3rd place for talk in Atomic, Molecular and Optical Physics
Miles Couchman - 3rd place for talk in Condensed Matter Physics
Piotr Roztocki - 3rd place for talk in Biological and Medical physics
Randy Belanger - 3rd place poster

Congratulations to all participants for a great showing.

In addition, the bid put together by the McMaster team for the conference next year was successful so that CUPC will be held at McMaster University in 2013.

Faculty Awards

John Berlinsky is this year's recipient of the MUFA (McMaster University Faculty Association) award for outstanding service and was honoured with a reception in the Great Hall of the University Club. The award is presented annually to faculty and professional librarians who have made an outstanding contribution to the University through the provision of exceptional service to faculty, librarians, staff, students or alumni.

Maikel Rheinstädter, Assistant Professor in the Department of Physics and Astronomy, won an Early Research Award (ERA) from the Ontario Ministry of Economic Development and Innovation. The ERA program helps to attract and retain research talent by assisting new researchers with building their research teams. Maikel Rheinstädter will create healthy artificial brain membranes, then mimic Alzheimer's disease under controlled lab conditions by varying cholesterol and peptide concentrations – the substances that make up the plaque that interferes with the brain's normal function – to determine precise risk factors such as high cholesterol level to aid in the early diagnosis and treatment of dementia. In Ontario alone, approximately 200,000 people – plus their loved ones – cope with the disease, and it is estimated that by 2038 more than one million Canadians will be living with dementia. Rheinstadter's research program will help understand the molecular mechanisms behind Alzheimer's Disease and will train almost a dozen undergraduates, two Master's and two PhD students in the preparation of biological tissue and the use of x-ray scattering in membrane research.

Nobel Prize 2012

Duncan O'Dell

The 2012 Nobel Prize in Physics was awarded to Serge Haroche of the Ecole Normale Supérieure in Paris and David Wineland of the National Institute of Standards and Technology in Boulder, Colorado, "for ground-breaking experimental methods that enable measuring and manipulation of individual quantum systems". The work of the two recipients is in many ways complementary: the quantum system Haroche manipulates and measures comprises of individual photons trapped inside a 3cm cavity between two extremely reflective superconducting mirrors, but he uses atoms fired through the cavity to do the manipulation and measurement of the number and phase of the photons. Meanwhile, Wineland's quantum system is made up of individual ions (atoms with one or more electron knocked off) trapped in space by electric fields, but he controls and measures their quantum state using photons from lasers. A key word in the Nobel citation is "individual": this prize recognizes the control of nature at the finest level achieved so far, namely single photons and atoms.

One of the weirdest predictions of quantum mechanics is that a particle can be in a superposition of different states at the same time. This behavior is counter-intuitive because we do not observe it in every day life, leading the quantum pioneer Erwin Schrödinger to pose his famous paradox where the unfortunate feline is in a precarious superposition of being alive and dead. In 1952 Schrödinger wrote: "We never experiment with just one electron or atom or (small) molecule. In thought-experiments we sometimes assume that we do; this invariably entails ridiculous consequences...". By controlling quantum systems at the single particle level, Haroche and Wineland's groups have been able to verify that these ridiculous consequences are realizable in the laboratory if you are careful enough and if you can isolate your system from decoherence (an interaction with the environment that collapses the quantum state). Although not full-blown cats, the groups were able to make and test exquisitely delicate quantum states that are considered macroscopically distinguishable, such as superpositions of different microwave field states combined with different states a Rydberg atom (in Haroche's case) and superpositions of different internal states of the ion combined with its motional state (in Wineland's case). Note that both of these states also display so-called entanglement between their subparts, another strange quantum property that Einstein dubbed "spooky action at a distance", but was crucial for their measurement protocol which did not measure the target system directly. Indeed, in order to monitor the time evolution of their respective systems, both groups implemented the first ever non-demolition measurements (contrast this to, e.g., a detector that counts photons by absorbing them) and so allowed repeated measurements to be performed. In this way they were able to see a wave function collapse actually taking place!

The experiments are also of great technological significance. Decoherence is the Himalayan-sized barrier that stands between us and a working quantum computer. In fact, Wineland was the first to realize CNOT quantum logic gates, the building block for such a device. Readers may be interested to know that making these CNOT gates was actually the Ph.D. project of Brian King, a professor at McMaster between 2001 and 2009. Any bets on next year's prize?? (Hint: it's a boson).

Outreach Initiatives - Some Tried and True and Some Brand New

Sara Cormier

I took over the position of Outreach Coordinator for the Department of Physics & Astronomy at the beginning of September. In the few months since I started things have been a bit of a whirlwind. Caroline Burgess, the previous Outreach Coordinator left a tremendous legacy. My goal was to continue the wonderful outreach program Caroline implemented and maybe add a few of my own touches. The goal of our outreach program is to promote physics and astronomy to students of all levels and to try to debug the stigma that "physics is hard and therefore I don't like it" and to promote the overwhelming benefits that a physics degree holds. To achieve these goals we have a variety of different outreach events, some new and some old, aimed predominantly at high school students to increase interest in physics.

Things started to really take off in October beginning with the annual Engineering and Science Olympics. At the Olympics, our department hosts the very popular "physics paper triathlon" event where students build a boat, a bridge and a glider each out of only one sheet of letter paper. It is a difficult task and I am always impressed with the results. The following week we hosted the Community of Physics Teachers meeting. It was extremely useful and illuminating to hear suggestions from teachers on how we can improve things at the university level. One of the suggestions that came up was to provide workshops and presentations for teachers pertaining to current research in the department. This would allow teachers to bring, new, exciting physics into their classrooms. For example, newsworthy events such as the Higgs boson discovery provide the perfect opportunity to elicit enthusiasm about physics.

We are currently looking forward to the Physics@Mac Online Contest. Each year, hundreds of grade 11 and 12 students participate in the contest. Students have the option to participate in partners to promote the idea that physics is not a solitary activity. Directly after the contest, we will be hosting high schools on campus for the annual Physical Sciences@Mac activities. These activities include hands-on physics and chemistry labs, planetarium shows and many exciting demos. All of these activities are only possible with the generosity of our graduate students who donate their time every year.

Lastly, I am very excited to announce a brand new outreach initiative, the Physics Inquiry Workshop for grade 12 students taking physics. This workshop was motivated by the very popular second year "Big Questions" course. The aim is to bring together like-minded, enthusiastic students to engage in discussions at a higher level than what is typically possible in a high school classroom. Students are introduced to a university setting and have the opportunity to experience what university level physics is really like. Each week we start with a mini-lecture on the "big question of the week" and then students break into small groups for discussion. The current set of discussion topics includes special relativity, the arrow of time and quantum mechanics.

When we first began this workshop, community teachers were asked to submit the names of their top grade 12 physics students. We were delighted to receive the names of almost 30 interested registrants. The first workshop was very successful and the students were extremely interested, enthusiastic and inquisitive; it was a ton of fun. The hope is to continue this workshop in the new year with a whole new set of "big questions".

If you have any questions, new ideas for outreach initiatives or are interested in learning more about the current activities we offer please visit our website
www.science.mcmaster.ca/macsci/outreach/physics-astronomy.html
or send me an email at outreach@physics.mcmaster.ca.

Yesterday's Signal: the Higgs Particle and its Discovery

Matthew Williams

This past summer, at 2:55am on July 4th, I awoke to the shrill sound of my alarm to watch the announcement from the International Conference on High Energy Physics on the status of the Higgs search at the LHC. Impatiently, I brewed some coffee while the spokesperson for the CMS experiment presented trigger efficiencies, Monte Carlo simulations, and other evidence that their collaboration's device was in good working order. And then, after what seemed like an eternity, they began to lay out their case for a "Higgs-like particle'". Slide by slide, the evidence accumulated.

The excitement was palpable; when they crossed the threshold for discovery, I partook in a quiet fist-pump as the entire Melbourne audience jumped to their feet and erupted in applause. Many in attendance had devoted decades of their lives to the design, construction, testing, (repair) and, finally, data analysis at the LHC and its experiments. One might reasonably wonder: What would motivate particle physicists to undertake such a large-scale, concerted, multi-national project? What do we stand to gain from this research? How is such a discovery even made?

A discovery using proton-proton collisions at the LHC is far from easy; the strong force (responsible for holding charged quarks within a trillionth of a mm of each other) ensures that any attempt to probe the inner structure of the proton be greeted with an explosive spray of rare and unstable particles, most of which are hadrons. Much of the previous century's early collider studies were aimed at understanding the properties of hadrons and the rules for their decay. This experimental work paved the way for Gell-Mann's quark theory, QCD, and a major pillar in our modern understanding of particle physics. However, to make further progress, it is necessary to filter out this bath of familiar hadrons and look for collisions which may have produced new, unseen particles. Because of the sheer volume of data that would be generated (about one hundred terabytes per second), this task is partly handled by the detection equipment directly, without computation.

LHC Facts

- Circumference: 27 km
- Average Depth: 100 m
- Number of Magnets: 1232
- Personnel: 10 kiloscientists
- Temperature: 1.9 K
- Power Consumption: 800 GWh
- Data rate: 15 Petabytes/yr
- Total Cost: $6.5 billion

Another obstacle to discovery is that the predicted Higgs particle has a ridiculously short lifetime (roughly ten trillionths of a nanosecond), and so is never seen directly in the experiment's detectors. Similarly, the Z boson and the top quark --- other predicted particles discovered in the 1980's and 1990's, respectively --- suffer from the same affliction. In each case, their presence is uncovered by looking for the excess production of particles that can be detected: photons, electrons, muons, protons, neutrons, or a handful of other light hadrons. However, since nothing new is observed directly but only through their observable decay products, a strong emphasis is put on statistical rigour so that false signals do not get oversold.

There is still much to be gleaned from the LHC data; in the coming months, we hope to get a better idea of how the discovered Higgs interacts with other known (and, perhaps, unknown) particles. Nevertheless, the Higgs discovery marks the end of what could be called the ``era of inevitability'' in particle physics. For the last thirty years, every newly-discovered fundamental particle has been found on the left-hand side of the following schematic formula: X = quantum mechanics + (3+1)dimensional space-time + minimum set of fundamental particles consistent with those observed -- previously-identified fundamental particles. It now seems that the list of X's predicted by the above equation is exhausted. Therefore, if anything else is discovered at the LHC, it is almost guaranteed to involve altering the above prescription in some way.

Did you know...

The LHC is tilted underground! The tunnel's depth is 175m near the Jura Mountains, but only 50m near Lake Geneva.

Since thirty years worth of theoretical musings have been compiled in the high energy physics journals, it is possible that future discoveries will fall into a class of well-studied extensions to the canonical lore of particle physics. More importantly, though, new physics may give us a hint towards solving one or more of the many outstanding questions in fundamental physics: Why is there so much more matter than antimatter? What constitutes dark matter? How can the observed vacuum energy be so small? Why does the Higgs particle have the mass we find?

It is the desire for answers to these questions which beckons particle physicists to press forward; to make yesterday's signal tomorrow's background, and to continue in the pursuit of a more complete set of fundamental laws.

Supernova Light Echoes - Once Noise, Now Signal!

Doug Welch

According to the Burma Shave roadsigns of my youth, "Space is Big, Space is Dark". True enough most of the time, but when a supernova occurs, there is a prodigious amount of light released into space for a few weeks. So much light is produced by such an event that it rivals or outshines the combined output of a million, million stars in a galaxy like our Milky Way.

While we detect thousands of supernovae in distant galaxies, the last supernova to be witnessed in our own was back in 1604 (also known as "Kepler's Supernova"). Furthermore, there are only half a dozen records of "guest stars" in historical records that can be definitively associated with the expanding gas and dust supernova remnants now visible at a variety of wavelengths. These closest remnants are the ones we can study in the greatest detail but the lightcurves and spectra were unavailable because that light encountered the Earth centuries ago - before the invention of much of our standard instrumentation such as photometers and spectrographs. The light from the nearest supernovae had been lost for all time - or so itseemed ...

Ironically, we were searching for a form of dark matter when we stumbled onto an unanticipated source of noise in our difference images of fields in the Large Magellanic Cloud (LMC) - noise that turned out to be the scattered light from centuries-old supernovae! Although the features seen in the difference images tended to be dominantly linear, there were locations where the light was concentrated enough to look almost stellar and such brightenings triggered our software pipeline alerts and drew them to the attention of the SuperMACHO Project team. Dozens of such features were detected, all with the shared characteristic that they appeared to move across the sky at a constant rate. When we plotted the locations of these features and their magnitudes and directions of motion, it quickly became clear that they tracked back to the four youngest supernova remnants in the LMC!

We applied for and received time on the Gemini South telescope to acquire spectra of light echo features and confirmed that the scattered light spectra indeed contained supernova outburst light. Our first Nature paper on light echoes reported that the supernova that produced the remnant SNR 0509-67.5 was an overluminous Type Ia.

Our ability to detect outburst light hundreds of year after the outburst itself relies on the fact that outburst light that has scattered off of dust takes a longer path. Since the speed of light is constant, the scattered light will arrive later than the direct light. At a given time, the locus of all places where outburst light could be seen in the sky is an ellipsoid with the supernova remnant at one focus and the Sun/Earth at the other. As time passes, the size of the ellipsoid grows.

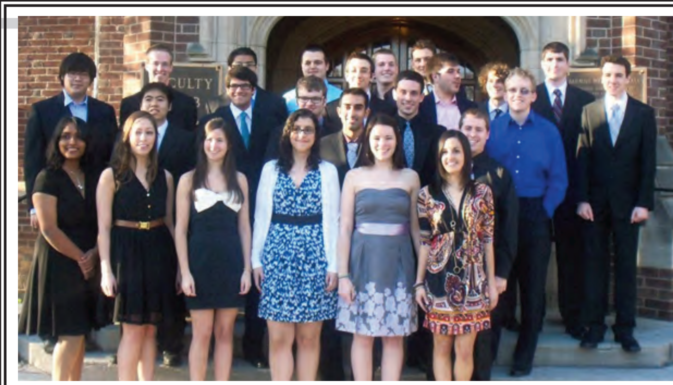
Hidden within that straightforward geometry is a very interesting consequence: if dust exists on the ellipsoid behind the plane of the sky, we can study the light from the opposite hemisphere of the outburst! Outside of the solar system, light echoes are the only way to gain additional perspectives on an object. So they provide us with a way to test the degree of asymmetry of a supernova event.

In 2006, we applied to Kitt Peak National Observatory to begin a survey for light echoes from historical supernovae in the Milky Way. We intended to search in the constellation of Cassiopeia where three such supernovae (1181, 1572, and Cas A) were known to have occurred. Four nights were allocated in October and four in December. Three of the October nights were clear. In December, my M.Sc. student Lindsay Oaster and I went down for the observing run. We had only one clear night and were trapped in Denver in a snowstorm for 55 hours on the way home! But that one night allowed us to discover a large set of light echoes associated with SN 1572 and Cas A! In fact, 5% of the fields contained light echoes - they were abundant and the only reason they hadn't been found before is that no one had differenced images separated by a few months.

Our core supernova light echo team currently consists of Armin Rest (STScI), Brendan Sinnott (Ph.D. in progress), and Brittany McDonald (M.Sc. just conferred). Brendan has developed the theory for interpreting light echo spectroscopy based on dust filament dimensions and orientation, size and positioning of the spectrograph slit on a light echo, and image quality differences between epochs. In one of his thesis papers, he provides detailed new findings regarding the asymmetries of SN 1987A. Brendan has also contributed to the detection of asymmetries in the outburst of the supernova responsible for the remnant Cas A. Brittany completed surveys for light echo systems around the older and less luminous core-collapse supernovae 1054 (a.k.a. "Crab") and 1181. While no light echoes from those events were found in tens of thousands of difference images from the Canada-France-Hawaii Telescope, she was able to show that if either had been a Type II-L, light echoes would have been detected with a high degree of confidence.

The search for light echoes from the remaining historical supernovae continues. But an additional front for light echo research has opened up - we have detected light echoes from the pre-supernova object eta Car, which briefly became one of the brightest stars in the sky in the 1840s. Like the centuries-old supernovae, we were able to study the spectrum from that outburst in the present era! Such rare, luminous, and variable objects may allow us to study centuries worth of activity by mining the light scattered from different regions of dust in their vicinity. If so, we will have excellent templates to identify pre-supernovae candidates in other galaxies and to understand their states before, during, and after supernovae cast their blinding spheres of light into the universe around them.

2012 Graduating Class



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Middle Row: Joshua Lee, Peter Nguyen, Christopher Miranda, Ross Anthony, Babak Karamy, Richard Alsop, Timothy Govey, Tyler Jackson
Front Row: Janini Jeyaraman, Melissa Ferrari, Kathlyn Nelson, Samantha Benincasa, Alison McDonald, Alexandra Terrana
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McMaster University
Downtown Centre, 125
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Contact Information:
Department of Physics and Astronomy, McMaster University
1280 Main Street West, Hamilton, Ontario L8S 4M1
Phone: 905-525-9140, ext. 24559
Fax: 905-546-1252
email: physics@mcmaster.ca
http://www.physics.mcmaster.ca/