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Physics in Canada
La Physique au Canada
Volume 74, Nos. 3-4
2018

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Physics in Mining
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La physique dans l'exploitation minière
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Volume 74 Nos. 3-4 (2018)

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Reflections of modern physics. A physicist in clean-room gear walks through a pristine drift of SNOLAB, located at the 2070 m level of the Creighton mine. SNOLAB is a permanent clean lab expansion built around the cavity of the original Nobel Prize winning SNO experiment.

Réflexions sur la physique moderne. Un physicien dans un survêtement de salle blanche dans une galerie impeccable de SNOLAB à 2070m sous la surface de la terre dans la mine de Creighton. SNOLAB est une salle blanche permanente, une expansion construite autour de l'expérience originale de SNO gagnante du Prix Nobel.

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DEPARTMENTS
DÉPARTEMENTS

Canadian Association of Physicists (CAP)
Association canadienne des physiciens et physiciennes (ACP)

The Canadian Association of Physicists was founded in 1945 as a non-profit association representing the interests of Canadian physicists. The CAP is a broadly-based national network of physicists working in Canadian educational, industrial, and research settings. We are a strong and effective advocacy group for support of, and excellence in, physics research and education. We represent the voice of Canadian physicists to government, granting agencies, and many international scientific societies. We are an enthusiastic sponsor of events and activities promoting Canadian physics and physicists, including the CAP's annual congress and national physics journal. We are proud to offer and continually enhance our web site as a key resource for individuals pursuing careers in physics and physics education. Details of the many activities of the Association can be found at http://www.cap.ca. Membership application forms are also available in the membership section of that website.

L'Association canadienne des physiciens et physiciennes a été fondée en 1946 comme une association à but non-lucratif représentant les intérêts des physicien(ne)s canadien(ne)s. L'ACP est un vaste regroupement de physiciens oeuvrant dans les milieux canadiens de l'éducation, de l'industrie et de la recherche. Nous constituons un groupe de pression solide et efficace, ayant pour objectif le soutien de la recherche et de l'éducation en physique, et leur excellence. Nous sommes le porte-parole des physiciens canadiens face au gouvernement, aux organismes subventionnaires et à plusieurs sociétés scientifiques internationales. Nous nous faisons le promoteur enthousiaste d'événements et d'activités mettant à l'avant-scène la physique et les physiciens canadiens, en particulier le congrès annuel et la revue de l'Association. Nous sommes fiers d'offrir et de développer continuellement notre site Web pour en faire une ressource clé pour ceux qui poursuivent leur carrière en physique et dans l'enseignement de la physique. Vous pouvez trouver les renseignements concernant les nombreuses activités de l'ACP à http://www.cap.ca. Les formulaires d'adhésion sont aussi disponibles dans la rubrique «Adhésion» sur ce site.

PHYSICS IN CANADA LA PHYSIQUE AU CANADA

The Journal of the Canadian Association of Physicists
La revue de l'Association canadienne des physiciens et physiciennes

ISSN 0031-9147

ANNUAL SUBSCRIPTION / ABONNEMENT ANNUEL:
$46.00 Cdn + GST or HST (Cdn addresses),
$46.00 US (US addresses); $51.00 US (other/foreign addresses)

Advertising, Subscriptions, Change of Address/
Publicité, abonnement, changement d'adresse:
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Association canadienne des physiciens et physiciennes,
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THE PHYSICS IN MINING

The articles selected for this issue are representative of the SME's and academics rather than from any large corporations. The intent is to showcase ventures that illustrate the connection of physics to the research and development projects being done externally to the mining companies.

In the first article *Meeting Future Mineral Resource Demand by Ultra-Deep Mining,* Doug Morrison provides a cross section of projects funded through the Centre for Excellence in Mining Innovation (CEMI) and the Ultra Deep Mining Network (UDMN). The UDMN has a $35 million network of 76 active members from large corporate benefactors to small research and development start-ups with 25 projects underway, the $35 million funding is comprised of a $15 million government grant coupled with the cash and in-kind contributions of the industrial network, a contribution from industry partners is essential for the project to be approved by the UDMN board. Even though there is the imperative for industrial contributions and a focus on developing a commercial product the program offers flexibility, because not all monies contributed from a given industry partner are earmarked to a specific project; the network partners share the results. This article provides an excellent introduction to the variety of projects that are underway and expected to continue moving forward.

The second article *Exploring New Frontiers in Deep Underground Science* by Samantha Kuula and Blaire Flynn briefly discusses the history and current experiments underway at the SNOLAB, a physics-based research facility at the 2000 meter level of Creighton Mine near Sudbury, Ontario. This is where the Nobel Prize winning SNO experiment was achieved and was also my first job as a physicist. The third article by Naeem S. Ahmed, *3D Scanning and Mapping of Underground Mine Workings Using Aerial Drones* brings physics, aerial drones and mining together. Naeem initially worked at SNO and upon completion of the project he struck out to form his own company to develop drones to integrate LIDAR, point cloud data and Simultaneous Localization and Mapping technology. This is a very important method of data collection from zones where personnel are not permitted.

In the fourth article *Electromagnetic Radiation from Coal Rock Failure in Underground Coalmines* by Dazhao S., Xueqiu H., Enyuan W., Zhenlei L., and Cai M., the problem of stress in the underground environment is discussed. The mining industry refers to seismic events as rockbursts and this is quite literal; when the stress is redistributed due to mining activity and the excavation of an underground opening creates a void for the rock to enter there are circumstances when the rock literally explodes into the opening. If these events can not be controlled or mitigated they present a significant problem to the safety of the personnel and economic viability of a mining project. Understanding the underground stresses, developing ground control methods and monitoring these events is a vibrant ongoing area of physics-based research in both the industry and academic community. This article suggests that the technique of monitoring electromagnetic radiation from coal mines is a promising technique that may enable a more definitive prediction of rockbursts.

In the final article, *The Impact of Cryogenics on Deep Mines*, I discuss the idea that cryogenics is a viable solution to chilling in deeper or hotter mines. Cryogenics offers an opportunity to manage the energy profile of a mine by using cryogenic energy storage in conjunction with renewable energy sources. The combining of an energy storage project with the supply of ancillary services provides the scale of plant needed to supply the cryogenic liquid economically. The delivery of a cryogenic fluid to the underground environment provides an opportunity to produce compressed air, electricity and power for vehicles while simultaneously providing chilling and as an added benefit the surplus liquids are in demand and can be sold to the open market.

These articles are intended to inform you of the physics that is going on in the mining industry; perhaps with all the very cool physics that we hear of like dark matter searches and the detection of gravitational waves some of the every day variety might be slightly overlooked. There certainly is physics in mining; it is a lot of fun,

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provides excellent pay packets and is an indication of the physics that is happening all around us everyday and everywhere.

Dr. Daniel L. Cluff, C.Eng., P.Phys.
Guest Editor, *Physics in Canada*

Comments of readers on this Editorial are more than welcome.

LA PHYSIQUE EN EXPLOITATION MINIÈRE

Les articles retenus pour le présent numéro représentent davantage les PME et le milieu universitaire que n'importe quelle grande société. L'idée est de mettre en valeur les entreprises qui illustrent le lien entre la physique et les projets de recherche-développement qui se font à l'extérieur des entreprises minières.

Dans le premier article intitulé *Meeting Future Mineral Resource Demand by Ultra-Deep Mining,* Doug Morrison énonce un éventail de projets financés par le Centre d'excellence en innovation minière (CEIM) et l'Ultra Deep Mining Network (UDMN). L'UDMN a un réseau de 35 millions de dollars regroupant 76 membres actifs allant de grandes sociétés bienfaitrices à de petites entreprises de recherche-développement en démarrage qui ont 25 projets en cours, ces fonds de 35 millions de dollars se composant d'une subvention gouvernementale de 15 millions ainsi que de l'apport en espèces et en nature du réseau industriel, une contribution des partenaires industriels est essentielle à l'approbation du projet par le conseil de l'UDMN. En dépit de la nécessité de l'apport de l'industrie et de l'accent placé sur la mise au point d'un produit commercial, le programme est souple parce que tous les fonds offerts à un partenaire industriel donné sont destinés à un projet particulier, les partenaires du réseau partagent les résultats. Cet article présente une excellente introduction à la diversité des projets en cours que l'on s'attend à voir continuer de progresser.

Dans le deuxième article, intitulé *Exploring New Frontiers in Deep Underground Science,* Samantha Kuula et Blaire Flynn examinent brièvement l'histoire et les expériences en cours à l'installation de recherche, SNOLAB, fondée sur la physique au niveau de 2000 mètres de la mine Creighton, près de Sudbury, Ontario. C'est là qu'a été réalisée l'expérience de l'Observatoire de neutrinos de Sudbury (ONS), couronnée du Prix Nobel, et que j'ai eu mon premier emploi à titre de physicien. Le troisième article intitulé *3D Scanning and Mapping of Underground Mine Workings Using Aerial Drones*, de Naeem S. Ahmed, réunit physique, drones aériens et exploitation minière. Naeem a d'abord travaillé à l'ONS et, après avoir terminé le projet, il a formé sa propre entreprise pour mettre au point des drones comprenant LIDAR, données en nuages de points et technologie de localisation et cartographie simultanées. Voilà une méthode fort importante de collecte de données dans des zones interdites au personnel.

Le quatrième article, *Electromagnetic Radiation from Coal Rock Failure in Underground Coalmines*, Dazhao S., Xueqiu H., Enyuan W., Zhenlei L. et Cai M. examinent le problème du stress en milieu souterrain. L'industrie minière qualifie les coups de charge de secousses sismiques, ce qui est très littéral; quand le stress est redistribué en raison d'activités minières et que l'excavation d'une cavité souterraine crée un vide que le roc peut combler, il y a des cas où le roc explose littéralement et la comble. Si l'on ne peut contrôler ou atténuer ces cas, il se pose un grave problème de sécurité pour le personnel et la viabilité économique d'un projet minier. Comprendre le stress souterrain, élaborer des méthodes de contrôle des sols et surveiller ces événements est un secteur dynamique de recherche fondée sur la physique tant dans l'industrie que dans la collectivité universitaire. Cet article donne à penser que la technique de surveillance de la radiation électromagnétique des mines de charbon est prometteuse et permettrait de prévoir les coups de charge avec plus de certitude.

Le dernier article, intitulé *The Impact of Cryogenics on Deep Mines*, examine l'idée que la cryogénie est une solution préférable à la réfrigération dans les mines plus profondes ou plus chaudes. La cryogénie permet de gérer le profil énergétique d'une mine en recourant au stockage d'énergie cryogénique de concert avec ces sources d'énergie renouvelable. La combinaison d'un projet de stockage d'énergie avec prestation de services accessoires montre la taille de l'usine requise pour fournir économiquement le liquide cryogénique. La prestation d'un fluide cryogénique au milieu souterrain permet de produire de l'air comprimé, de l'électricité et de l'énergie pour les véhicules tout en assurant simultanément la réfrigération et, en prime, les liquides superflus sont en demande et peuvent se vendre sur le marché ouvert.

Ces articles visent à informer sur la physique existante dans l'industrie minière; en raison de tous les sujets de physique très intéressants dont on parle, comme les recherches sur la matière noire et la détection des ondes gravitationnelles, peut-être en a-t-on un peu négligé certains des plus courants, dont la physique en exploitation minière fait sûrement partie; celle-ci est fort amusante, procure d'excellents revenus et illustre la physique qui entoure notre quotidien et notre milieu.

Dr. Daniel L. Cluff, C.Eng., P.Phys.
Rédacteur honoraire, *La Physique au Canada*

Les commentaires des lecteurs sur cet éditorial sont toujours les bienvenus.

NOTE: Le genre masculin n'a été utilisé que pour alléger le texte.

The Editorial Board welcomes articles from readers suitable for, and understandable to, any practising or student physicist. Review papers and contributions of general interest of up to four journal pages in length are particularly welcome. Suggestions for theme topics and guest editors are also welcome and should be sent to bjoos@uottawa.ca.

Le comité de rédaction invite les lecteurs à soumettre des articles qui intéresseraient et seraient compris par tout physicien, ou physicienne, et étudiant ou étudiante en physique. Les articles de synthèse d'une longueur d'au plus quatre pages de revue sont en particulier bienvenus. Des suggestions de sujets pour des revues à thème sont aussi bienvenues et peuvent être envoyées à bjoos@uottawa.ca.

Physics and Mining are Connected Through the Millennia

by Daniel L. Cluff

The oldest recorded use of stone tools is estimated, using paleomagnetic dating or the characterisation of reversals in Earth's magnetic field over time, to be about 3.3 million years [1]. A chert mining site was discovered at the Nazlet Khater 4, estimated by radiocarbon dating to be 33,000 years old [2]. Chert is a sedimentary rock of mythical hardness that was used by early humans for tool-making and also to strike sparks to start a fire. The oldest known proper mine, that being a traceable activity to extract certain minerals in an organised fashion, is currently held by the Lions Cavern at the Bomvu Ridge in the Ngwenya mountains of Swaziland (now eSwatini). The hematite and specularite were extracted for cosmetics or rituals and is estimated, by radiocarbon dating, to have been active about 43,000 B.C. to 41,000 B.C. and may have been mined until at least 23,000 B.C [3]. Perhaps this honour will be bestowed to an as yet discovered operation because it is presently accepted that the use of cosmetics dates back at least 500,000 years [4]. Mining has been part of the human experience for millennia as determined by the use of dating methodologies based on physical principles.

In the present day, mining is a complex industry. The five basic elements of the mining cycle are: exploration, from a lone prospector in the wilderness to large scale geophysical surveys using seismic, gravitational, magnetic, electrical and electromagnetic methodologies; discovery, the stage where the deposits found by exploration are confirmed to a higher level of accuracy and the permits or environmental surveys needed to further the project are sought; development, is the point where feasibility, geoscience and engineering studies are advanced to the point where financing decisions are able to be made; production, is the culmination of the previous activities that have led to an operating mine where the primary activities are extraction, milling and processing of minerals and finally closure, the environmental renovation and ongoing land reclamation, which often starts at the onset of the project and may continue long after the completion of mining activities. This brief description of the mining cycle demonstrates the need for high quality science and engineering from beginning to end of a mining project; a mining project can typically take about seven to ten years from discovery to an operating mine and cost from hundreds of millions to billions of dollars to build. Taking into account the risk factor it is estimated that about 500 to 1,000 exploration projects are undertaken to produce 100 possible advanced exploration projects leading to 10 development projects capable of attracting financing, but of these typically one delivers a profitable mine [5]. The amount of time and expenditure required to create a producing mine is substantial; thus, opportunities abound.

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Summary

Mining, as a human activity, is connected with the first demand for a stone of a special type that would have to have been "found" by searching the surface. In the present day, mining is a complex industry with advancements enabling it to be a part of our clean future.

The intent of this issue is to inform everybody of the connection between modern mining and physics already illustrated to some extent in the introductory paragraphs. The typical impression that comes to mind of a mining operation is a dirty place with a crew of ragged workers carrying picks and shovels, but today that is no longer the case, mines are getting cleaner due to ongoing changes in health and safety legislation and the increased presence of advanced technology such as autonomous or remotely operated equipment. Another impression is that mines are built and operated by mining engineers, which is still true for the most part, but the engineers' teams are increasingly comprised of multidisciplinary groups of scientists, specialised engineers and technologists. A wide array of mining engineering consultancy firms have long been in existence and are growing, but over the last few decades increasing numbers of specialist consultancies and mine service companies have successfully launched. In this climate physicists are becoming progressively more sought after especially as the mines get deeper, the thermodynamics and seismic susceptibility, two of the most intractable problems associated with deep mining, are both strongly connected to physicists and the technology needed to meet the demands is becoming increasingly more complex.

Mining corporations have been increasingly closing their research departments in favour of contracting out these services. In response to this challenge small companies have assembled the expertise to supply these services. In the 2017 budget, the federal government announced an Innovation Supercluster Initiative (ISI) to provide $950 million for business led consortia. The purpose of the ISI is to accelerate the growth and development of business-led innovation superclusters in Canada. The CLEER supercluster (**C**lean, **L**ow-energy, **E**ffective, **E**ngaged and **R**emediated) cultivated a consortium commitment upwards of $700 million, cash plus in-kind from 162 members across Canada, with a full 70% coming from Small and Medium-sized Enterprises (SME) and although the request from the federal government was only about $200 to move forward with a $900 million program the supercluster did not make the final cut. This pan-Canadian "cluster of clusters" would have created an estimated 140,000 new direct and indirect jobs and contributed $26 billion to Canada's GDP after five years [6]. The failure of the federal government to approve the mining supercluster demonstrates their lack of understanding of the vast support industry that has grown across Canada to provide research and support services to the mining industry and the impact that this support network has had on the Canadian industry and on the mining industry globally.

The recent Carbon tax introduced by the Federal budget brings to mind the connection between mining and environmental stewardship. Although mining corporations have made great progress and continue to strive to extract minerals in cleaner operations the connection between mining and climate change is not often at the forefront of public awareness. The simple equation expresses as follows: carbon reduction requires an increase in metals. The increase in electric vehicles and new advanced technologies not only requires much more of the basic metals such as copper and nickel, but also more of the exotic minerals such as the rare earth elements. So the mining activity is not just itself getting cleaner, but is a significant part of our clean future.

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MEETING FUTURE MINERAL RESOURCE DEMAND BY ULTRA-DEEP MINING

BY DOUGLAS MORRISON

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Deep underground mines, more than 2500 m below surface, are challenged to develop the technologies required to deliver the metals that the industrial economy requires to support a growing global population. A population of nine billion will certainly strain our agricultural and transportation capacity, but it is the total resource demand of the first-world life that threatens to out-strip the resources of the entire planet. The problems that mining face are increasingly complex requiring an in-depth understanding of topics like thermodynamics, tensor analysis and advanced computation consequently, to get much better at moving millions of tonnes of ore every day in thousands of mines around the world, mining needs a lot more physics and the involvement of many more physicists.

THE CEMI AND UDMN ADVANTAGE

CEMI is a Canadian not-for-profit organization, mandated to lead step-change innovation by introducing new practices, procedures, tools, techniques and technologies to help generate a significant improvement in the performance of mines. CEMI focuses on innovation in four strategic technical mining categories: exploration, deep mining, improving mine productivity or operational performance and reducing the environmental impact to improve sustainability. Market acceptance is essential to successful innovation and CEMI diligently works to ensure that these mining innovations are commercially viable and achieve a level of operational integration into day-to-day mining activities. Our approach is purposeful, to ensure innovations are sustainable and economically feasible for the mining industry. The UDMN is a $35 million national network hosted at CEMI consisting of 76 active members from large mining companies to small to medium research and development companies with a total of 25 projects underway that address challenges of mining at depth and are commercially viable for adoption into mining operations.

SUMMARY

This article showcases some of the projects completed by the Centre for Excellence in Mining Innovation that focus on the development of new, commercially viable Canadian technologies. The Ultra Deep Mining Network is a Business Lead Network with matching funding from the federal government comprised of large corporations, small to medium sized enterprises and academic institutions tasked with the selection and supervision of projects relevant to the future of deep mining. In virtually every project the concepts and research is based on the fundamentals of physics and employ physicists as part of a multidisciplinary team.

The UDMN focuses on four distinct areas of research and development that are considered vital to the future success of deep mining: improved human health and effectiveness to enhance the human environment in deep mines; material transportation and productivity to increase the rates of development and production in mines; rock stress risk reduction to improve the stability of deep underground excavations and energy reduction to reduce the energy consumption of mining projects.

IMPROVED HUMAN HEALTH AND EFFECTIVENESS

As the working environments become more extreme there is a measurable decrease in worker productivity. Physical stressors are a commonly encountered impediment experienced by workers in mining environments, but especially increases as the mines get deeper and even more so within the ultra-deep mine setting. There is a need for an enhanced solution to develop more effective personal protective gear that will help keep people working within appropriate occupational conditions. Normalizing temperature and environmental conditions in the extremes of hot and cold air flows including fluctuating oxygen levels and high concentrations of diverse contaminants are essential. One must meet ambient air quality standards so as to not alter or impact human health or performance. Developing systems and technologies that improve communication, navigation and the overall well-being of the ultra-deep workforce is a priority for a workforce that is expected to be productive under these extreme conditions. The current research of interest on improving human health in ultra-deep mining environments are: workplace ergonomics and human Factors for Ultra-Deep Mines; workplace safety and industrial hygiene; thermal Control — to design novel systems and technologies that regulate the temperatures to which workers will be exposed and communication and navigation — to improve systems of communication and navigation to effectively communicate with workers over a wide geographical area underground.

Jannatec Technologies managed two projects: thermal garment adaptive wearable mining technology to normalize the environmental conditions in which a worker is asked to perform his job duties and wearable communications to mitigate occupational health and safety risks as our operations move to ultra-deep mining. Maestro Digital Mine has commercialised environmental air quality stations for deep mining. Maestro has evolved from a research and development start-up to a successful manufacturer of gas sensors with the unique ability to be able to be calibrated on the surface with reference gases and then brought to depth without the requirement to re-calibrate at depth. Vigilante AQS™ environmental stations are being installed in some of the deepest mines around the world. These projects are heavily dependant on applied physics and the use of advanced sensors which we understand is one of the divisions of the Canadian Association of Physicists.

Resource extraction in Canada is occurring at ever greater depths and geotechnical risks are increasing significantly, particularly as they relate to stress within the rockmass. The challenges associated with this, in both the mining and oil and gas sectors; need to be addressed as failing to do so will foster unacceptable project risks. This in turn will impact investment and will jeopardize Canada's competitiveness.

INDUCED SEISMIC HAZARD MITIGATION IN ULTRA-DEEP MINES

The in-situ stress due to the overburden increases as depth increases and the redistribution of stress that is a manifestation of mining is more complex at depth. For the safe extraction of minerals from deep mines it is absolutely critical to minimize geomechanics-related risks, which can impact on operational productivity, cost management and safety. The incidence of stress related ground failures increases and are more energetic as the stresses increase due to the depth, these rock burst events can render entire sections of the mines inaccessible. These events are dangerous to the personnel and may have serious negative economic impacts and potentially mine closures due to the so called sterilization of ore reserves. Mine sequencing and de-stress blasting are currently used to modify the stress field and reduce the seismic hazard in deep mines but these techniques are often insufficient to adequately reduce rockburst potential and related risks in mines, in particular near vulnerable underground excavations. Thus, further complementary and innovative research into stress management methods is required. Projects in this theme that will explore ways to better measure, anticipate, mitigate and manage and even modify built up stresses in the rockmass, resulting in more intelligent rock mechanics design protocols and advanced approaches. Cross-sectoral research proposals are looking at ways to make mines safer by reducing geotechnical risks through a broader understanding of the stress management in ultra-deep mining sectors in the next ten years.

There are six current projects underway or near completion in this research area a brief description of a few are as follows. Seismic stress inversion undertaken by ESG Solutions to apply a newly developed method for characterising the direction and stress magnitude ratio stress tensor from microseismic source mechanism results, leading to advanced analysis and interpretive capability. Symboticware developed the open geotechnical data network and data analysis system, which uses appropriately equipped mobile equipment to transfer data from ultra-deep geotechnical networks into a centralized data handling system and thereby enable real-time decision-making, which has just been selected for a multimillion dollar contract to install symbots by Vale an international multifaceted resource corporation with nickel and copper assets in Sudbury, Ontario. Geoscience Integrator, a 4D real time geotechnical hazard assessment and reporting system for ultra deep mining has been commercialised by Mira Geoscience. It is a true 4D multi-disciplinary geoscience data management solution, interfacing with visualization, modelling, query, and expert system applications to drive exploration and mining success. It enables the management of multi-disciplinary time-based data (primary data that is a function of time and the time-evolution of both data and models) in a flexible and easily extensible relational data model. Standard data import, ad hoc reporting, customized standard reporting, and report scheduling are all easily controlled from a web interface. The Institute of Mine Seismology (IMS) embarked on a project to provide active seismic monitoring for seismic risk reduction by turning sensitive velocity measurements from an active seismic source into an in-situ measurement of stress changes in a volume of rock. These geotechnical based projects for the most part involve a deep understanding of the wave nature of seismicity and tensor analysis which naturally lies within the purview of physicists.

IMPROVED MINE PRODUCTIVITY AND NOVEL TRANSPORTATION METHODS

Mining companies are continuously striving to improve the economics and efficiencies of each of the processes involved in getting their product to market. Typically the mine operates with a single shaft, although there may be separate compartments for personnel and materials this is a bottle neck, which becomes increasingly tight as their operations expand further underground; thus, it becomes critical to find innovative materials handling improvements, because it will take longer to transport workers and materials into the mine and to the work place. Similarly, the transportation of ore, waste and fill material into and out of an ultra deep mine present an ever-increasing challenge as mines go deeper.

The main research areas of interest focus on improving mine productivity and introducing novel transportation methods are about improving the individual steps involved in the basic mining activities such as the development process to create the access tunnels or 'drifts' needed to mine the ore. This means improving the cycle of removing the newly blasted rock at the face of the drift, installing ground support to stabilize the new section of drift, drilling the face-holes in the end of the drift and charging them with explosives ready for blasting. Other aspects that are targeted for cost reduction efficiencies include the supply ventilation, pumping water and other fluids, installing services such as power and water, communications, mine planning and surveying (without GPS).

There are seven projects currently supported by the UDMN in improved mine productivity with a few outlined below. The rapid lateral development canopy Phase II is a CEMI project to enable increased development rates by maximizing the utilization of the advancing face. The canopy is a structure that protects equipment and people in the drift heading and allows face activities and ground support installation to be done concurrently, so reducing the critical path cycle-time. Advancing more rapidly access ore sooner and generates revenue sooner, providing a better return on investment. The Hydraulic Air Compressor (HAC) Demonstrator is an Electrale Innovation, MIRARCO and Laurentian University supported project and has grown to a pilot scale project located at Dynamic Earth supported by the UDMN, IESO, NOHFC and Reasbeck Construction to name a few. A hydraulic air compressor exploits the pressure head of water falling in a cylinder to create bubbles of compressed air — as was the case at the Taylor plant in Cobalt, Ontario in 1910. The plant had no moving parts and produced enough compressed air to operate all the pneumatic equipment in all the mines of Cobalt until the last one finally closed in the 1980s. The new hydraulic air compressor plant is intended to determine efficiencies of a system using pumps rather than the natural waterfall of the original.

Finally, the MIRARCO schedule optimization software tool called SOT-plus is a computational method that employs numerical solvers to establish the impact on the NPV and productivity of variations in the long term planning of mining deep ore bodies, allowing profitable and successful mining at depth in the presence of geotechnical, ventilation and asset allocation challenges.

IMPROVING THE ENERGY CONSUMPTION PROFILE OF DEEP MINES

This initiative is intended to develop energy saving methods and technologies to reduce the energy consumed by mines and specifically for Ultra Deep Mines. The energy required to power underground mine operations is significant and is comparable with that used for a city of a few thousand people. The goal of this focus area is to be realized by innovative measurement, auditing, benchmarking and optimization of energy systems for ultra deep mines and innovations in the fields of energy measurement systems, audit methodologies and consumption metrics, realized in hardware, firmware or software that specifically address the needs of ultra deep mines. The target is to reduce the energy demand of the underground ventilation system and the ore transportation equipment. Some targets are to examine alternatives to diesel powered haulage systems, the development of more efficient vertical transportation of ore and rock, and the implementation of energy storage technology in combination with renewable energy systems and novel air-cooling systems. The Cryofan© project for ultra-deep mine chilling is being prototyped by CanMIND Associates and is the topic of a separated article in this edition.

There are seven projects currently funded by the UDMN in collaboration with various industry and academic partners several of which are outlined below. McGill University has studied large scale freezing-on-demand with a closed loop geothermal system. Two projects concern the development of prototype electric powered vehicles, one for personnel transport and a second large-scale battery-powered vehicle in the 150 to 250 hp range; an industry-first. To learn more about these projects visit www.miningdeep.ca.

The projects outlined in this article employ the fundamentals of physics including mechanics, thermodynamics, energy, seismicity and tensor analysis. The mining industry has traditionally employed engineers and accountants to develop projects once the ore deposit has been prospected and delineated by prospectors and geologists. The advances in the technologies required for the mining projects of the future are expected to make possible mining projects that are environmentally energy efficient and environmentally benign. These objectives will require multi-disciplinary teams of engineers and scientists from several fields and the value of physicists in this increasingly complex industry is growing.

EXPLORING NEW FRONTIERS IN DEEP UNDERGROUND SCIENCE

BY SAMANTHA KUULA AND BLAIRE FLYNN

Establishing a clean lab two kilometers underground in an active mine may seem unusual, but it is essential to the experiments underway at SNOLAB, Canada's underground research laboratory specializing in particle astrophysics. Particle physics has a rich history underground and it has been long-known that overcoming the dirty, hot environment present in a mine is well worth the extremely quiet conditions that can be achieved by going deep underground [1]. By the mid 1960s, neutrino experiments were underway in Kolar Gold Mine in India, East Rand Property Gold Mine in South Africa and in Homesake Gold Mine in South Dakota, USA. As the field of astroparticle physics developed, experiments required more sensitive detection systems and by the late 1960s full fledged laboratories were coming on board in locations across the globe [2].

DEEP UNDERGROUND LABORATORIES

There are a number of underground physics labs in the world (Table 1). These facilities are generally established in mines or in cavities excavated for transportation or power generation initiatives. SNOLAB is situated on the 6800 level of Vale Creighton Mine, an active nickel mine in Sudbury, ON and consists of a network of caverns and hallways with a total volume of over 37,000 m^3 [3]. Each underground laboratory has its own advantages and SNOLAB is the deepest clean lab with the entire space maintained as a Class 2000 clean room (less than 2000 particulates over 0.5 µm in each cubic foot of air).

SUMMARY

SNOLAB is an underground laboratory that began as the Sudbury Neutrino Observatory and subsequently expanded not only physics experiments such as searches for dark matter and supernovae, but fruit fly genetics and the Presence or Absence of Ionizing Radiation. The laboratory is an ultra clean facility located at the 6800 level of Vale's Creighton mine near Sudbury, Ontario.

The flat overburden of 2070 m of norite rock results in a cosmic-ray muon flux of 0.27 μm^{-2} day^{-1} at SNOLAB (see Fig. 1) resulting in a 50 million times reduction in muons from surface [4]. Since the rock itself is a source of natural radioactive backgrounds, the lab relies on an extensive ventilation system of 13 air handlers and strict cleanliness protocols to minimize the presence of uranium and thorium in the lab air.

SNOLAB was constructed using standard mining techniques with ground support in all areas of the lab. The development of the lab took place in two phases between 2004 and 2011 with the official opening taking place in 2012. The excavation was a meticulous 4.5 year process lead by the J.S. Redpath Group that saw 87 000 t of rock excavated [5] and required 8300 tonnes of shotcrete,

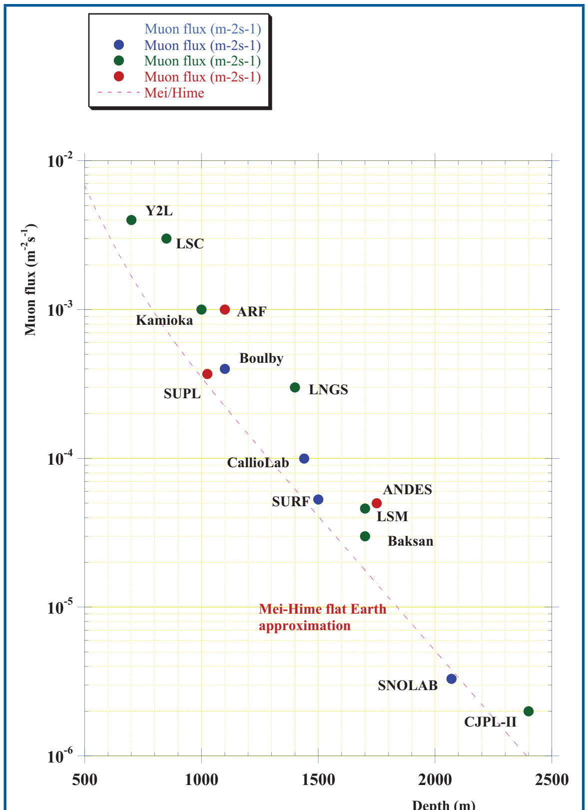

Fig. 1 Muon Flux as a function of depth.

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TABLE 1
A GLOBAL SUMMARY OF DEEP UNDERGROUND SCIENCE LABS

SITE	DEPTH (M)	ACCESS	MUON FLUX ($m/m^2/s$)	RADON (Bq/m^3)	CLEANLINESS CLASS
Kamioka	1000	Horizontal	10^{-3}	80	Only in sectors
SNOLAB	2070	Vertical	$3.1\ 10^{-6}$	130	2000 or better
LSC	850	Horizontal	$3\ 10^{-3}$	100	Only in sectors
CJPL	2400	Horizontal	$2\ 10^{-6}$	40	Only in sectors
SURF	1480	Vertical	$5.3\ 10^{-5}$	300	3000
Gran Sasso	1400	Horizontal	$3\ 10^{-4}$	80	Only in sectors
CJPL-II	2400	Horizontal	$2\ 10^{-6}$	40	Only in sectors
Boulby	1100	Vertical	In Construction	<3	10000
LSM	1400	Horizontal	Planned	15	ISO9
LSC-CUNA	850	Horizontal	Planned	100	Only in sectors
LBNF/SURF	1480	Vertical	Planned	300	3000
ANDES	1750	Horizontal	Planned	-	-
Baksan	1550	Horizontal	Planned	40	Only in sectors

30 000 rock bolts, 8500 sheets of ground support screen and 2000 cable bolts [6].

EXPLORING NEW FRONTIERS

SNOLAB is a world-class facility with a broad science program focused on neutrino experiments (SNO+ and HALO) and dark matter experiments (SuperCDMS, DEAP-3600, MiniCLEAN, PICO, DAMIC, NEWS-G, and CUTE). While the lab continues to be the location of choice for particle physics, new innovative partnerships have been established that are pushing developments in other fields such as mining innovation, bioinformatics and subsurface biology.

The creation of the MODCC (Mining Observatory and Data Control Centre) [8] capitalizes on existing data integration and sharing expertise at SNOLAB as well as the significant investments already made in the deep underground facility. The MODCC represents a powerful user — and data-interpretation interface that searches, collects, filters and analyzes mining/exploration related datasets. The result will be a data processing facility with accessibility and capability unlike anything currently available to mining/exploration companies and researchers anywhere in the world. This project will address the mineral and related R&D industry's data access and integration needs by creating a service that collects, integrates and securely stores and then distributes data. Streaming data that will originate from sensor arrays in operating mines will eventually be assessed in real-time, thereby making the MODCC a "living data centre" [9].

Fruit flies may not be the first thing that comes to mind when you think of a lab focused on sub-atomic particles, but recent work from Dr. Thomas Merritt (Laurentian University) may change that. Merritt's research group, FLAME (Flies in a Mine), uses flies to study genetics and metabolism and has recently turned their attention to the effects of working in a mine, specifically working deep underground. The unique features that make SNOLAB an ideal location for studying subatomic particles, a controlled environment deep underground, also make it an ideal location for studying the biological response to pressure. Working underground means working under higher atmospheric pressure and the deeper we mine, the higher the pressure — and mines are going deeper and deeper in search of resources. Mining companies are interested in understanding physical responses to working under higher pressure in order to address the effects and support a healthier workforce. In SNOLAB, the atmospheric pressure is approximately 20% greater than on the surface; using techniques they developed for studying metabolic responses in flies, they are measuring the response to mining pressures across thousands of individual metabolites (sugars, amino acids, lipids, etc.). The work is in the early stages, but suggests that at least 10% of metabolites change with even a single trip down to mining depths. The long-term effects of this change aren't known, and are a central question in Merritt's work. Ultimately, Merritt and his students hope that through understanding this response in flies they can help to develop strategies to address the changes observed to make mining, and any work done under high atmospheric pressure, safer and healthier [10].

The REPAIR (Researching the Effects of the Presence and Absence of Ionizing Radiation) project [7], run by the Northern Ontario School of Medicine and Laurentian University, is currently examining the biological effects of prolonged growth and development in SNOLAB. It is hypothesized that organisms have adapted to oxidative stress produced by natural background radiation, which promotes and maintains DNA stability, and that removal of background radiation will be detrimental to living systems. Several different model systems are being utilized to test this hypothesis. Human cell cultures grown in SNOLAB will be examined for cancer risk, oxidative stress, and genomic damage such as DNA double strand breaks. Lake whitefish embryos raised in SNOLAB will be examined for whole-organism survival, growth and development [7].

SNOLAB enables research that will accrue benefits in the future; these include technology developments in high-efficiency photon sensors that are expected to have an application in medical imaging, national security, public safety solutions and are also expected to facilitate the development of low background techniques. SNOLAB supported initiatives such as the MODCC will deliver direct benefits to the Canadian mining industry by enhancing productivity and supporting job creation. SNOLAB continues to strengthen its position as one of the premier underground laboratories in the world, increasing scientific leadership and contributions across many areas of Canadian science.

ACKNOWLEDGEMENT

SNOLAB acknowledges its organizational partners; Carleton University, Laurentian University, Queen's University, University of Alberta, Université de Montréal, our mining host Vale, and our funding agencies; CFI, NSERC, NOHFC, FedNor, the Province of Ontario and the City of Sudbury. Your investment makes our work possible.

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3D Scanning and Mapping of Underground Mine Workings Using Aerial Drones

by Syed Naeem Ahmed

Laser scanning and mapping of underground mine workings have become a norm in the majority of underground mines. There are many operational benefits of scanning underground mine cavities including accurate excavation audits, geological assessments ground support assessments and generally mine scanning that is performed remotely, which allows for scanning areas where the risk to personnel is too great in areas that may be less stable than allowable for entry. Even though the scanning technology is fairly advanced, a number of challenges are still posed in underground mine environments including the possibility of equipment damage from falling rocks, narrow openings and cavities, limited time availability due to production schedules etc. These challenges have been addressed with systems that offer faster data acquisition and mobile scanning.

It is worth noting that with the recent push towards the concepts of "the digital mine" and Internet-of-Things (IoT), laser scanning and mapping have assumed central importance. More and more mines are now looking for autonomous vehicles that can minimize human presence in underground operations; thus, making the mine much safer and more productive. One of the main issues with autonomous vehicle operation in an underground mine is the unavailability of GPS-like positioning information. An efficient way to handle this issue is by employing a Simultaneous Localization and Mapping (SLAM) algorithm to simultaneously determine the position and create the map while the laser scanner is in motion. This paper presents a case study to determine the feasibility of SLAM-based scanning from aerial drones in underground mines.

Summary

The underground environment requires various levels of ground control depending on the intended use of the excavation. In places where personnel will be attending, the ground control must have a factor of safety, which is costly unless the work can be carried out by remotely operated equipment. Arial drones are highly flexible in terms of navigating difficult terrain, can be fitted with various payloads and when LIDAR with Simultaneous Localization and Mapping software is employed the unit is a very cost effective tool for monitoring and decision making.

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CASE STUDY

We mounted a LiDAR (V-SCAN3D) capable of mobile scanning using a SLAM algorithm onto a drone (Tilt Ranger) and flew it in two different underground mines (see Fig. 1).

For this study we chose two different types of stopes typically inaccessible by personnel: one that was only excavated from the top and the other with both top and bottom excavations.

For the latter we flew the drone twice, once with the scanner mounted on top of the drone and followed by a run through with the scanner mounted at the bottom. The two maps obtained from these separate runs were then digitally merged together to create the complete mine map.

The stopes we scanned are shown in Fig. 2, registration in the mine coordinate system was done by placing reflective crosses on known control points and then performing a stationary scan (see Fig. 3). The stationary scan was then merged with the mobile scan and then registered in the mine coordinate system using the control points visible in the point cloud.

The top two images in Fig. 2 show the scan results from the traditional scanning equipment (left) and drone scanner (right). The two scans, when merged together, were found to match very closely and within their margin of errors. This established that the system can be used in place of a traditional cavity scanning system. The bottom two images show the scans of two stopes from the drone. The left image has scan from the traditional scanner merged with the one from the drone.

The point clouds obtained from the scanner are in x,y,z position format with intensity of reflected light as the fourth column. The value of reflected light intensity can provide useful information on rock face geology

Fig. 1 Tilt Ranger drone (Inkonova AB) with V-SCAN3D scanner (Clickmox Solutions).

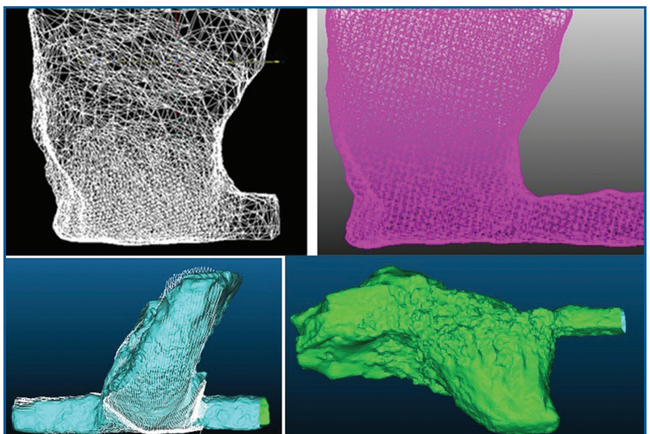

Fig. 2 (top left) Scan from traditional scanning system, (top right) scan from drone, (bottom) scan of two large open stopes.

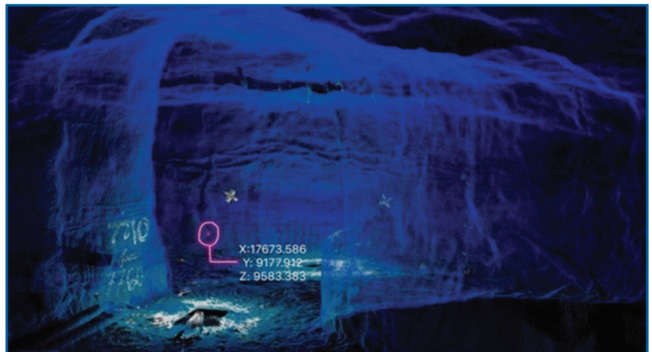

Fig. 3 Point cloud registration with reflective markers.

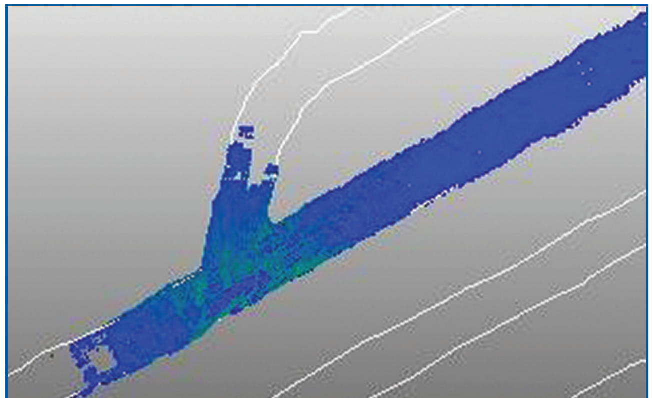

Fig. 4 Point cloud to measure convergence in underground mine drift.

including identification of large cracks and faults. Such information is highly important to design ground support structures as well to plan further lateral drift developments.

3D laser scanning also provides a means of convergence monitoring. High lateral pressures in an underground rock mass can induce slow convergence leading to eventual collapse of walls and pillars. Regular scanning of underground cavities and comparing them with previously captured data can be used to determine the extent and rate of convergence. This is possible by overlaying the new point cloud onto the previous one with both registered in the mine coordinate system. The point cloud of the section of a drift overlaid on a previous 2D profile is shown in Fig. 4. Note that the scan shows changes in the profile at several locations along the drift. In order to derive meaningful results from this exercise, it is important to understand the noise level, accuracy and precision of the system. Different scanning systems provide different levels of accuracy and precision and the choice depends on the monitoring requirements. Generally, accuracy of 3-5 mm is considered adequate for measuring convergence in underground mine cavities.

OUTCOME OF CASE STUDY

We conclude that mobile scanning provides an efficient and safer means of scanning and mapping underground mine cavities. The areas that were previously not possible to scan, can now be scanned using aerial drone-based scanners. This method not only provides time savings but also has huge advantages in terms of safety.

ELECTROMAGNETIC RADIATION FROM COAL ROCK FAILURE IN UNDERGROUND COALMINES

BY DAZHAO SONG, XUEQIU HE, ENYUAN WANG, ZHENLEI LI, AND MING CAI

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In recent years, many coalmines in China have migrated to deep levels at a speed of 10 to 25 m per year. Currently, 47 coal mines in China are mining below 1000 m depth [1,2]. As the depth and the mining rate increase, coupled with the complex geological structures in some mining areas, the risk of coal rock dynamic disasters, such as rockburst and coal and gas outburst, increases significantly. Exploring effective methods to provide early warning of a coal rock dynamic disaster is important, but also a challenging task.

Traditional methods of investigating coal rock dynamic disasters include drilling bits, stress measurement, and geophysical methods such as microseismic, acoustic emission (AE), and electromagnetic radiation (EMR) monitoring [3]. EMR monitoring is a new method developed in recent years. Research shows that fracturing of solid materials like coal rock can emit EMR. It is seen from theoretical simulations [4-6], lab experiments [7-9], and field measurements [10-12] that small-scale fracturing in coal rock is the source of EMR.

Frid *et al.* [13-15] considered that EMR is a very useful method for predicting ejection hazards in coalmines. Based on the electromagnetic (EM) pulses induced by coal rock fracturing, they proposed EMR methods for coal and gas outburst and rockburst prediction. Rabinovitch *et al.* [6,16] and Frid *et al.* [10] presented an EMR model showing that during crack propagation, the surface vibration wave excited by ionic motion on both sides of the crack walls causes dipole oscillations and thus emits EMR. In addition, they discussed the directionality of EMR from fractures. Some researchers [17, 18] investigated the mechanical behavior of concrete and rock loaded to failure and analyzed AE and EMR. The AE signals were always observed during the damage process, whereas the magnetic signals increased abruptly near the final collapse of the specimens. Lichtenberger [19,20] measured EMR in a cross section and along the long axis of a tunnel. From the correlation of EMR and shear stresses, orientations and magnitudes of the horizontal principal stresses were determined, indicating that measuring EMR can be a valuable tool for determining field stresses. Krumbholz *et al.* [12] proposed an EMR method to determine stress orientations within the crust in Northern Europe.

SUMMARY

Electromagnetic radiation (EMR) has been noted to occur in conjunction with the deformation and fracturing of coal on scales from local failure to overall collapse. The EMR signals are recorded during coal rock deformation and fracturing. When monitored, these signals can be used to qualitatively evaluate the stress state of coal rock and become part of the tool box used to estimate coal rock dynamic disasters in underground coalmines.

In this paper, we first analyze the rheology and mutation phenomenon as well as the electromagnetic (EM) response in the deformation and failure process of coal rock, followed by several field applications of the EMR monitoring method for rockburst warning. The prospect of the EMR method for CCDD warning is also discussed.

RHEOLOGY AND MUTATION PHENOMENON OF COAL ROCK DURING DEFORMATION AND FRACTURING

Through experiments on hundreds of coal rock samples from different mining areas with different pore gases, gas pressures, and confining pressures, it is found that coal rock containing gas is an elasto-plastic material with strong rheological failure characteristics, and its mechanical behavior is a dynamic rheological process related to time, as shown in Fig. 1. From the figure, we can also find that the applied stress, the adsorption property of pore gas, and the pore pressure are positively correlated with this rheology, and the adsorbed gas makes the coal rock behave in a more rheological manner.

Based on the rheological mechanics theory and the experimental results, a three-dimensional rheological constitutive model of coal rock is established as follows:

$$\frac{G_2}{H_3}(\bar{T}_{ij}-\sigma_y)+(1+\frac{H_2}{H_3}+\frac{G_2}{G_1})\dot{\bar{T}}_{ij}+\frac{H_2}{G_1}\ddot{\bar{T}}_{ij}=2G_2\dot{S}_{ij}+2H_2\ddot{S}_{ij},\bar{T}_{ij}\geq\sigma_y \quad (1)$$

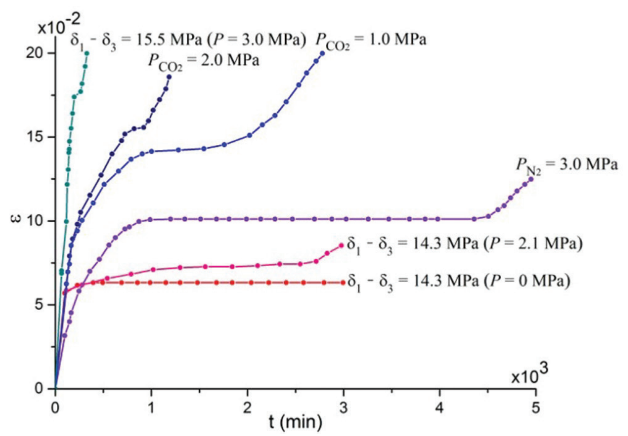

Fig. 1 Rheological-mutation process of coal rock containing gas under different loading conditions (δ_1 is the axial pressure, δ_3 is the confining pressure, and P is the gas pressure).

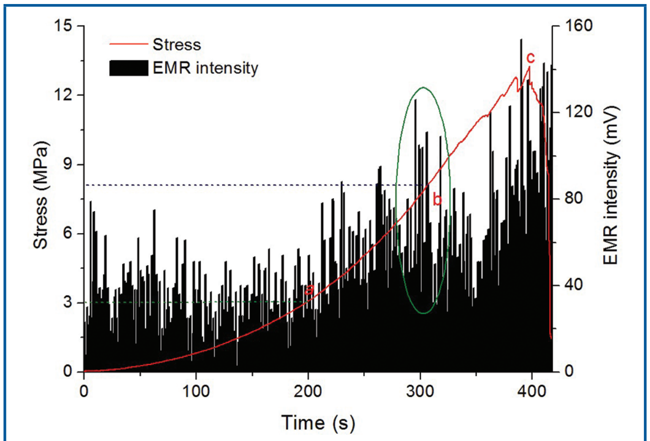

Fig. 2 EMR intensity and stress–time curve during uniaxial compression of a coal specimen (EMR intensity shown in the histogram is the accumulative value of various EM signal bands in one second).

where T_{ij} is the effective deviatoric stress tensor, $\dot{T}_{ij}$ and $\ddot{T}_{ij}$ are the first and the second derivatives of the effective deviatoric stress tensor over time, respectively, $\dot{S}_{ij}$ and $\ddot{S}_{ij}$ are the first and the second derivatives of the stress tensor over time, respectively, $G1$ and $G2$ are shear moduli of coal rock, $H2$ and $H3$ are viscosity coefficients of coal rock, σ_y is the equivalent effective yield stress, and $\overline{T}_{ij}$ is the equivalent effective deviatoric stress tensor.

According to Eq. (1), we explain the rheological-mutation mechanism of coal and gas outburst, revealing that the essence of gas outburst is a nonlinear rheological-mutation failure evolution process of coal rock containing gas under the action of the four factors — stress, gas pressure, mechanical properties of coal rock, and time.

This process can be spatially divided into three regions of rheological damage zones: relaxation, strong and weak rheological zones, and temporally four phases: preparation, occurrence, development, and ending phases. During the preparation phase, only the rheological destruction of coal rock containing gas in the three regions is accelerating, and outburst can enter the occurrence phase and eventually evolve into a disaster. Hence, it is important to find a method to monitor continuously in real-time the rheological-mutation process of coal rock in underground coalmines.

EMR EFFECT ON RHEOLOGICAL-MUTATION PROCESS OF COAL ROCK CONTAINING GAS

Under the influence of stress and pore fluid (e.g., gas), coal rock containing gas will deform and fracture, which in essence is the initiation and propagation of microcracks. In this process, due to piezoelectric effect, electrification, non-equilibrium stress diffusion caused by charged defects (such as hole, linear dislocation, edge dislocation), covalent bond breaking, EDA (electron donor acceptor)-bond rupture, intermolecular force fluctuations, etc., charge on the microcrack wall separates, which can generate EMR [21]. EM waves generated by mechanisms such as dipole transient in stress-induced electric fields, variable motion of separated charges with cracks expanding on the walls of the microcrack edges, relaxation of separated charges on the crack walls, are some forms of EMR [22-24].

Figure 2 shows a typical evolution of EMR of coal containing gas during uniaxial compressive loading. From the initial loading to 150 s, pores and cracks are closed, causing deformation and microcracking of the coal near the crack walls and EMRs are generated in the process. After the complete pore closure, as shown at Point-a in Fig. 2, the stress–time relation shows roughly a linear behavior as the load increases, indicating that under a relatively small load, the coal specimen undergoes stable microcracking and EM signals increase continuously at a relatively constant rate, until the stress reaches about 60% of its peak. After Point-b in Fig. 2, EM signals reduce for about 50 s, which may be attributed to the complete failure of small structural units with lower strength and insufficient failure of large structural units (the so-called skeleton structures) with higher strength [25]. At this point, the coal specimen is under a quasi-static equilibrium under the applied stress; in other words, the external energy applied to the specimen is fully absorbed or stored as the strain energy in the skeleton structures. This leads to a reduced microcracking of the coal, resulting in decreased EM emission. When the stress continues to increase and reaches about 90% of the peak, the above-mentioned equilibrium is broken; the skeleton strength is not sufficient to resist the external stress, macrocracks undergo fusion coalescence, resulting in the failure of the coal specimen and emission of a large amount of EMRs.

Based on the above experimental data, constitutive relations of coal rock represented by electromagnetic signal parameters in one-dimensional and three-dimensional cases are established according to the statistical damage theory, which are expressed as

$$\sigma = E\varepsilon\left(1-\frac{\sum N}{N_{\mathrm{m}}}\right) \quad (2)$$

where σ is the stress, E is elastic modulus, ε is the strain, N is the number of EMR pulses, N_m is the cumulative number of EMR pulses when the specimen is completely destroyed.

It is seen from Eq. (2) that in the coal rock loading and destruction process, statistically there is a positive correlation between EMR and stress. The higher the applied stress is, the stronger are the EM signals. As a result, EMR intensity, pulse numbers, and other parameters can effectively reflect the stress state of coal rock.

EMR is a phenomenon of energy radiation in the process of rheological-mutation of coal rock, which can dynamically reflect the deformation process of coal rock and thus can be used to provide early warning of coal rock dynamic disasters in underground mines.

APPLICATION OF COAL ROCK EMR MONITORING TO STRESS ASSESSMENT AND ROCKBURST WARNING

Mining Area Stress State Assessment

The use of the EMR monitoring technology to assess the stress state of a haulage roadway at the 11702 working face at Nuodong coalmine in China is illustrated in Fig. 3(a). In the strike direction, 10 monitoring points with an interval of 10 m were selected beginning from the working face. The EMR monitor was installed at each testing point, with its antenna oriented to the coal wall and fixed at a position of 1 m to the floor and 0.5 m from the face wall. EM signals at each testing point were monitored for 120 s. We repeated the test three times every 24 hours . We also tested the drilling bits at a 20 m depth with a diameter of 42 mm from the collar of the horizontal boreholes.

In the dip direction, three 14 m long, 42 mm diameter boreholes were drilled in front of the face at 110 m, 120 m, and 130 m (Fig. 3(a) A, B, and C, respectively), and drilling bits of every meter were tested. After the drilling bits test, EM signals were monitored. The testing points were laid out every 1 m inwardly along the borehole. Stress-induced EM signals at each point were measured with the antenna probe from the inner to orifice for 120 s.

Figures 3(b) and (c) show the typical EMR monitoring results. As shown in Fig. 3(b), the average EMR intensity for the three boreholes in the 0 to 8 m range shows an increasing trend, and the maximum average signal intensity is observed at about 9 m, and then gradually decreases after 10 m. The depth of loose zone of the haulage roadway at the 11702 working face is about 7 m, and the stress concentration zone is in the range of 8 to 10 m. The assessment of the stress state using the EMR monitoring method agrees well with that of the drilling bits method, a traditional method of assessing stress in the field. Therefore, when driving adjacent coal seam roadways and implementing

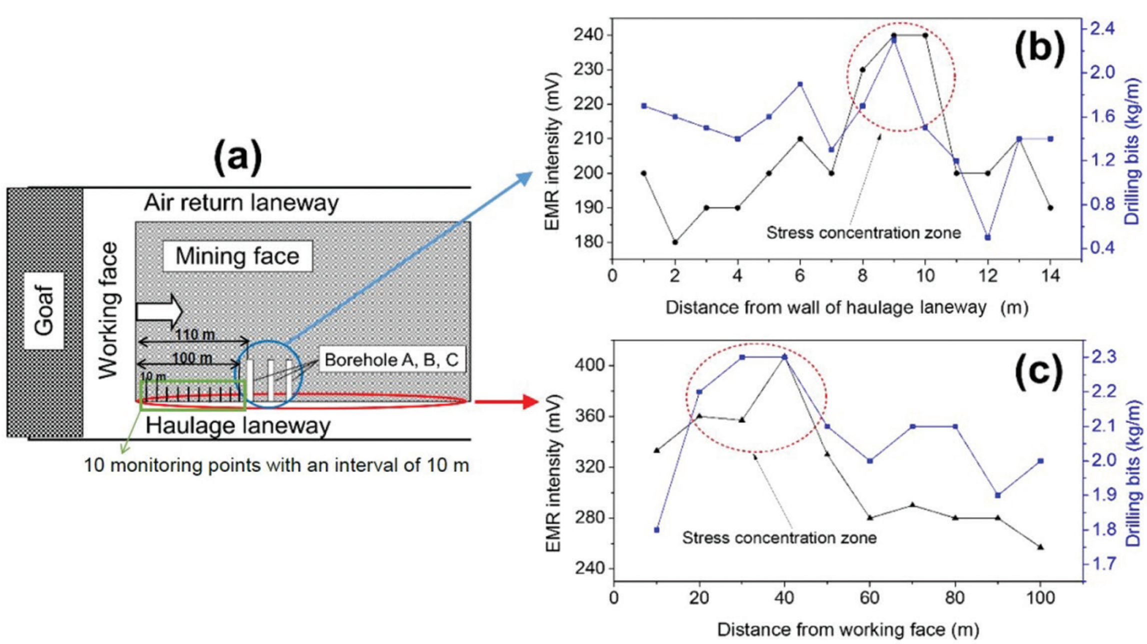

Fig. 3 Mining area stress state assessment by the EMR monitoring method at Nuodong coalmine: (a) measurement point layout in the strike and dip directions of a working face; (b) average value of three boreholes of EM intensity and drilling bits in the dip direction; (c) drilling bits and the average of EM intensity for three days in the strike direction.

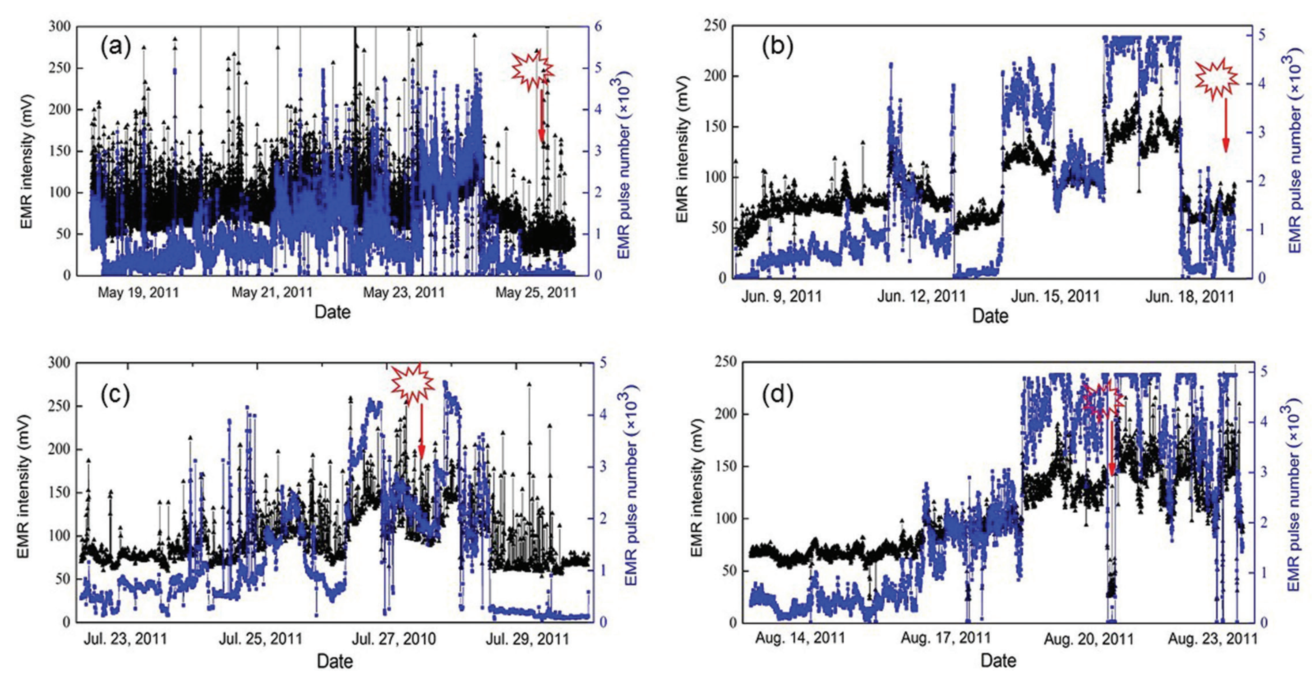

Fig. 4 Evolutions of EMR intensity and pulse number over four time windows: (a) 5.25 rockburst; (b) 6.18 rockburst; (c) 7.27 rockburst; (d) 8.21 rockburst.

the nearby No.17 coal gob-side entry, the stress concentration zones should be avoided; thus, reducing roadway support and maintenance costs.

Figure 3(c), with the increase of the distance from the working face, EMR intensity increases first then decreases. In the range of 20 to 40 m in the strike direction, the EMR intensity is higher than the average, indicating that this area is the stress concentration zone caused by mining. The stress relief zone is about 10 m from the wall of the working face, and the original stress zone is 50 m further from the wall of the working face. Therefore, the influence range of the working face in the strike direction is about 50 m. For safe mining at the 11702 working face, advanced support for haulage roadways and return airways should be provided in the range of 0 to 60 m.

Monitoring and Warning of Rockburst using the EMR Monitoring Method

Qianqiu Coalmine in Henan Province, China, has a long history of dynamic hazards. Rockbursts at the 21141 face occurred frequently from May to August in 2011. Among them, four events, occurred that affected the coal production on May 25, June 18, July 27, and August 21.

Figure 4 shows the evolutions of EMR intensities and pulse numbers over time in the monitoring period. The times of the four rockburst occurrences are also shown in the figure. It is seen from the figure that before the rockburst occurrence, the intensity and pulse number of the EMR signals increase for more than five consecutive days and a good positive correlation between the two parameters can be seen. Figure 4(a) shows a gentle increase trend while Figs. 4(b) to (d) show fluctuations in the monitoring data. The rockbursts did not occur at the time when the maximum intensity and pulse number of EMR signals were recorded, but rather delayed in a window within 48 h after the EMR signals passed the peak and reached at a lower intensity level.

Although a rockburst occurs suddenly, its development generally undergoes four stages including breeding, development, initiation, and termination. In other words, before a coal rock suddenly destabilizes, it will undergo a complex self-organizing rheological-mutation process internally. This process is always accompanied by the generation of a large amount of fractures in the coal rock with associated emission of EMR signals. Hence, monitoring of EMR can be used as a means of providing warning of dynamic disasters such as rockburst in underground mines. Due to complex geological and stress conditions in underground mines, there is a large uncertainty in the warning of rockburst using this method. Research is currently conducted to study the patterns of EMR signals to increase the confidence of providing warning of dynamic disasters.

CONCLUSIONS

The deformation and fracturing of coal rock is a rheological-mutation process from local failure to overall collapse. EMR is a phenomenon of energy radiation accompanied with this deformation process. EMR signals can be recorded during coal rock deformation and fracturing. The monitored EMR data can be used to qualitatively evaluate the stress state of coal rock and potentially forecast coal rock dynamic disasters in underground coalmines.

ACKNOWLEDGEMENTS

This work is supported by the National Natural Science Foundation of China (51774023, 51634001) and the Fundamental Research Funds for the Central Universities (FRF-TP-16-071A1).

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The Impact of Cryogenics on Deep Mines

by Daniel L. Cluff

Cryogenic Energy Storage is an emerging technology that, when installed at a mine site, provides the economies of scale to create the availability of cryogenic liquids which are also capable of delivering several ancillary services to the project. Mining projects are large energy consumers and are not often conveniently located near thriving metropolises with a high voltage grid connection. Energy supply and cost are a significant variable in the viability of a project. Projects are usually remote or as is often the case located in a geo-political jurisdiction where they would consume upwards of 20% of the available energy produced for the grid; thus, a source of reliable energy is key to success of these projects and the comparability of the size of a mining project to a small community suggests that the scale of the energy project would be conducive to remote communities. The use of renewable energy has been embraced by two Canadian mining projects, Raglan Mine in Quebec and Diavik in the North West Territories have both installed wind turbine projects.

> *"Combined with an efficient storage system, renewable energy proved to significantly reduce operating costs, green house gas emissions, and dependence on diesel fuel, in mining operations and communities of the Canadian North. Furthermore, experience indicated that energy storage is a necessary enabler towards persistent penetration higher than 40% of diesel micro-grid capacity."*[1]

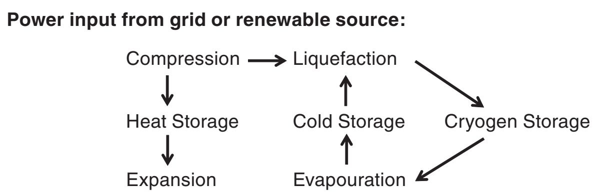
Diavik has no energy storage capacity, but the 9.2 MW turbines produced 17 GWh/yr in 2013 or 8.5 % of the total power produced for the mine, reducing the Diesel consumption by 3.8 million litres or $5 million for the year. This on-site renewable energy production cut back on the winter ice road fuel haulage by approximately 75 loads [2].

Summary

Deep mining is a challenging undertaking. As the project gets deeper, the geotechnical and thermodynamic aspects are the two most difficult aspects to control. In this article, the innovative concepts of chilling deep mines via cryogenics and the added services that are potentially available are explored.

The use of storage at Raglan has demonstrated the import of an energy storage system for increased penetration.

Although cryogenic energy storage is an emerging technology, indications are that in comparison to other storage modalities of an appropriate size, it is cost competitive, nontoxic, has no barriers to location and is scalable to very large grid sized systems. The source of the cryogenic liquids is a surface liquefaction plant. The basics of the system are outlined in the following diagram.



DISCHARGE INFRASTRUCTURE FOR POWER OUTPUT

The hot and cold storage increase the round trip efficiency of the system, the heat rejected from the compression stage in the liquefaction process is used during the expansion stage to generate electricity and the cold created during the evapourative cooling is stored for use in the liquefaction process [3]. Using heat from industrial processes can significantly increase the efficiency of the power generation and similarly cold from the expansion of liquid natural gas will increase efficiency of the liquefaction, both of which increase the round trip overall efficiency of the system. The attainment of much higher round trip efficiencies is due to the purchase of the cold in the form of the LNG or the use of heat from industrial processes that has also been purchased, but would otherwise be lost to the environment. In the grid connected case, an opportunity for the mining project to perform energy arbitrage forms a substantial part of the argument for the larger plant size. When such an energy project is located at the site of a mining project the concept of global adjustment manipulation is a noteworthy possibility. The global adjustment factor is determined by the power utilities measurement of the project consumption during selected peak power periods over the course of the year. Companies often attempt to anticipate these peak power periods and reduce consumption by ramping down

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large power draws, but this is a statistically difficult endeavour. Having a behind the grid power storage and/or production facility provides the flexibility of being able to produce power during the peak periods, increasing the probability that the power draw is reduced during the peak, during which a measurement has can be taken by the power authority.

CHILLING THE MINE AT DEPTH

There are a few typical approaches to chilling mines: the first tactic is to introduce more air flow for removing excess heat; another approach is to pump cold water or an ice slurry to an underground holding facility with heat exchangers to interact with the ventilation flow, and finally the construction of an underground refrigeration plant to cool the air on a bulk basis. As the mines get deeper there are increasing drawbacks to these solutions. Firstly, the air heats up as it descends, commonly referred to as autocompression in the industry, but physicists would recognise the meteorological term “lapse rate”, in simple terms the dry air temperature increases by about 9.8 °C/km but, depending on the shaft conditions and relative humidity, the lapse rate is often about 6.5 °C/km; thus, the air arriving at 2500 m depth drawn from the surface at 25 °C will be about 35 °C to 50 °C, which is clearly an unacceptable working environment.

Cryogenic chilling is a remarkably straight forward concept. A liquid cryogen comprised of oxygen and nitrogen is pumped underground, where it absorbs a substantial amount of heat upon expansion. Of great interest to the mining project designers is that there is no return circuit required, because the liquid cryogen expands to air at ambient temperature and simply exits the mine via the normal ventilation raise. After more than a century of engineering, cryogenic technologies are safe, advanced, reliable and typically available off-the-shelf. The cryogenic liquid has certain advantages compared to the other chilling systems due to the basic physical properties of cryogenic liquids. For use in a mine, the cryogen will have to contain a certain oxygen fraction such that, upon expansion and mixing with the ambient air, the minimum oxygen content in the air is maintained at 19.5%; therefore, due to the variability of the O_2/N_2 ratio, these are approximate properties. The latent heat of vapourisation is about 205 kJ/kg and the specific heat capacity of air varies with temperature over the range from cryogenic temperatures from about 78 K to ambient temperature, say 300 K, but an average value of 1.05 kJ/kg-K can be used for convenience, so for 1 kg of cryogenic liquid the heat absorbed is:

$$1\text{ kg}(205\text{ kJ/kg} + 1.05\text{ kJ/kg-K} \times (300 - 78)\text{K}) = 438\text{ kJ}$$

The expansion factor depends on the ambient temperatures and density at a given depth, but a typical value is that about 720 litres of air is produced for each litre of liquid; additional heat added during the expansion phase causes increased final volume leading to more power extracted by the turbines and increased efficiency of power production. The elegance of cryogenic chilling for deep mines becomes immediately apparent due to the amount of heat absorbed per kilogram of liquid and the one-way trip that the liquid takes, but there are more implications that even strengthen the argument [4].

The placement of a power generation unit underground requires that the cryogenic liquid be piped to that depth to supply the evaporative cooling and expansion sections, see diagram 1, which allows for the simultaneous production of electricity and chilling. The heat from the mine is converted to electricity creating an electricity/chilling cogeneration system. Unlike any other underground chilling system where the heat is simply moved around consequently a hot discharge to the surface is required, which creates many complications such as a no-go area for mine personnel.

The availability of the cryogen underground leads to a concept of chilling on demand, which is achievable by additional strategically placed cryofans™ to provide consistent temperatures given varying heat loads. This is an exciting possibility given the introduction of electric vehicles to deep mining, which may allow for a reduction of the ventilation flow by up to 50% of that legislated when using Diesel equipment. The reduction in airflow increases the susceptibility to larger air temperature changes for lesser amounts of heat introduced. This can be problematic if the flow cannot be increased to carry the heat away the temperatures may increase beyond the allowable working limits rather quickly. A cryogenic system has the capability of delivering chilling on demand, able to respond rapidly by simply increasing the liquid flow. Not only does the liquid air provide chilling, it actually replaces some of the air that would be drawn from the surface, a 10% airflow reduction can translate to upwards of a 25% power saving.

A Computational Fluid Dynamics model was created to simulate Chilling by a Cryofan™ vapouriser [5]. The model is comprised of a concentric tube heat exchanger, to allow the latent heat of vapourisation to be absorbed by the liquid flow. Converting the liquid to a gas occurs at ultralow temperatures, which results in very cold gaseous air with a density of about 4.2 kg/m^3. The gaseous flow then continues to absorb heat causing increases in volume and pressure. The air is confined to increasing diameter pipes until it exits to the ventilation airflow through venting outlets. At the exit to the normal ventilation flow the air sourced by the cryogenic liquid is still very cold so expands somewhat upon exhausting to the airflow in the downcast shaft. The heat exchanger and gaseous flow tubing are all located in the normal ventilation air flow so all of the heat absorbed by the cryogen is taken from the ventilation air. This ensures that the temperature of the flow is reduced to reasonable values rather than introducing ultra cold flows at any point in the system, as this would present a hazard to workers in the immediate vicinity.

The model is used to study the interaction of a cryogenic chilling system given the assumed conditions in a shaft at various depths and initial conditions. The ambient inlet conditions for a given model considered as typical were a pressure of 125 kPa and temperature of about 46 °C, which were set to simulate the conditions of the air at a depth of 1900 m, after the effect of auto-compression, which are derived from the surface conditions of 28 °C dry bulb, 19 °C wet bulb at 43% relative humidity. The chilling power, 8.87 MWr is required to achieve 12 °C dry bulb, 12 °C wet bulb at 100% relative humidity at that depth, was selected to compare to the expected chilling delivered by a bulk air chiller installed at that depth. The liquid air mass flow is 19.8 kg/s, which introduces 13.9 m^3/s of air into the ventilation system. The impact on the ventilation system is chilling and replacement of some of the required ventilation flow at that depth. In order to provide the required 180 m^3/s flow at the 1900 level depth requires 211 m^3/s be drawn from the surface rather than the 228.25 m^3/s that would have been drawn from the surface had the cryogen not introduced 19.77 kg/s, or 13.59 m^3/s, keeping in mind that the differences between the required flow from the surface 16.43 m^3/s and that at depth are due to the air density at depth is 1.42 kg/m^3 whereas that at the surface is about 1.2 kg/m^3. The power saving due to the reduced flow from the surface to the 1900 m level is that the main fans are now operating at 78.5% of full power. Ventilation power costs can be upwards of 60% of the total required by the mine, so this power saving is significant and there is 19.77 kg/s less air that must be chilled. These details are significant because they add up to a substantial saving when calculated over the lifetime of the mine, in this case the expected life of mine was twenty years.

COMPRESSED AIR SOURCED FROM CRYOGENIC LIQUIDS

Should a scheme using cryogenic energy storage and an underground electricity generation/chilling cogeneration system be adopted by a mining project, then the existence of cryogenic liquids underground provides an opportunity to produce compressed air not only at the typical 120 psi required by a mining project, but also any elevated pressure as required for any special purposes. A typical compressed air system for underground use would be about 5000 cfm. The current method of providing this amount of compressed air to the mine is to use a surface plant with supplemental compressors and storage underground at strategic locations. This type of system requires about a 1300 hp compressor, storage tanks and piping from surface to the levels underground. The industry standard costs of such systems are modelled over a ten year expected life as follows 76% energy, 12% capitol costs and 12% maintenance on a yearly basis. The energy costs for this size system are about $1 million per year so the total cost of the system is about $1.24 million per year. The cost of piping for a 2500 m deep mine is estimated to be about $5 million at start up with ongoing maintenance. If the cryogenic systems are already installed, then it is a simple case of using some of the liquefied air to produce compressed air at underground storage tanks. The 5000 cfm compressed air requirement can be met by about 125 to 140 tpd of cryogenic liquid, this is somewhat less than the actual 5000 cfm, but it is quite typical and expected in the mining industry that compressed air suffers significant losses of 30% to 50% of the system capacity, so the estimated amount of compressed air delivered by a 5000 cfm system would be in the 2500 cfm range at about 90 psi. The cryogenically sourced compressed air would be created underground and proximal to the working area where it is needed so these losses incurred during delivery would not be expected. The additional benefit is that a 2500 cfm system would produce 600 kW of chilling so the compressed air production is also a cogeneration concept that provides compressed air and chilling simultaneously.

A comparison was created of the costs associated with installing the cryogenic liquefaction plant with storage and piping to a bulk air chiller installed underground at about 1900 m depth as the capitol expenditure and using the energy costs and yearly maintenance costs as the operating expenditures with a discount rate of 10% over a life of mine of 20 years, see Table 1. The options 1, 2 and 3 are a straight comparison of: the bulk air

TABLE 1

COST COMPARISON OF CRYOGENIC SYSTEMS TO TYPICAL MINE SYSTEMS.

	Option 1 Chiller only		Option 2 5 MWe generation		Option 3 5 MWe and compressed air	
($M)	CAPEX	OPEX	CAPEX	OPEX	CAPEX	OPEX
BAC	$31.4	$3.22/yr	$31.4	$3.22/yr	$37.5	$4.37/yr
CRYO	$31.9	$3.48/yr	$44.7	$1.74/yr	$45.9	$2.47/yr
20 year NPV Calculated at a discount rate of 10% ($M)						
BAC	$58.80		$58.80		$75.78	
CRYO	$61.60		$59.52		$66.90	
Percent of Plant Capacity Required for Mine Chilling						
Mine	31%		55%		61%	
Surplus	69%		45%		39%	

chiller and the cryogenic liquids, both creating 12 °C DB and 12 °C WB at the 1900′ level; 5 MW underground electricity generation with supplemental chilling and the former, plus compressed air supply respectively [6].

EXTRACTING CHILLING OR ENERGY FROM THE PRESSURE IN DEEP MINE DELIVERY SYSTEMS

Deep mining is generally considered to begin at about 2500 m depth, which can create pressures in the liquid delivery piping of 21,315 kPa (3091 psi), for a density of 870 kg/m^3. The pressure would not reach those levels because the piping system would include reservoirs and pressure reducer systems on the way down, but 1000 psi is required for the 5 MWe electricity generation system, which can be achieved by a head of about 800 m. This is advantageous as the design can incorporate the pressure head, which will allow for elimination of the compressors, required if the same system had been placed on the surface. This is a substantial price reduction of the electrical generation system. Another quite interesting aspect is the use of the pressure to create chilling via the Joule Thompson effect. Temperatures of gaseous flow of −150 °C are possible at the 1000 psi pressure needed by the electrical generation system. This has not been prototyped, but the same concept is applied to create the cryogen in the liquefier and is also the reason why more chilling is available from in the expansion turbines during the creation of the electricity.

CONCLUSIONS

Cryogenics offers the opportunity for cogeneration of electricity/chilling, compressed air/chilling and motive force/chilling. The ability to extract chilling simultaneously while providing another service has been shown to be possible and is attractive to mining projects as they descend beyond 2500 m. The use of cryogenics as an energy storage vector is an emerging technology, but is based on systems that have been engineered for over a century; thus, the safety aspects are well developed and the equipment is readily available and reliable.

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Gravitational Wave Detections Usher in a New Era of Astronomy

by Jonathan Ziprick and Gabor Kunstatter

We live in an exciting time for research in gravity. Gravitational waves (GWs), the ripples in the fabric of spacetime predicted by Einstein a hundred years ago, have finally been detected experimentally. The first detection of GWs, emitted by the merger of two massive black holes, was made by LIGO (Laser Interferometer Gravitational-wave Observatory) in 2015 [1], and there have been six detections in total. The most recent two, one of which provides the first signal from the merger of two neutron stars, were confirmed by the Virgo interferometer [2]. These observations are amazing feats of modern technology that mark the advent of gravitational-wave astronomy, a new way of looking out into the cosmos by observing gravitational rather than electromagnetic radiation. They therefore raise the possibility of discovering new phenomena that have until now remained hidden. This monumental achievement earned the 2017 Nobel prize in physics for Rainer Weiss, Barry Barish and Kip Thorne, the three main contributors to this research.

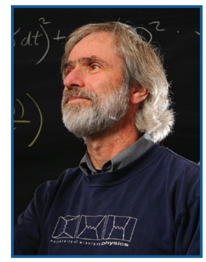
Summary

Since this article was submitted there have been further exciting developments in the field of observational black hole physics:

- **At this point LIGO has at least ten solid gravitational wave observations of compact object mergers https://www.ligo.org/news/index.php#O3resumes**
- **Upgraded LIGO, with 40% increase in sensitivity started runs on April 1 https://www.ligo.org/news/pr-O3resumes.pdf**
- **In February, 2019, LIGO received funding for a $35 million upgrade, called "Advanced LIGO Plus", due to be completed by 2024 https://www.ligo.caltech.edu/news/ligo20190214**
- **The international Event Horizon Telescope revealed an image of the event horizon of the supermassive black hole at the center of a galaxy (Messier 87) 55 million light-years from Earth. https://eventhorizontelescope.org**

It is important to highlight the important contributions to the success of the GW experiments made by Canadian physicists. Interpretation of GW measurements requires many precise numerical simulations of dynamical, three dimensional solutions to the full Einstein equations that describe the merger of heavy compact objects such as black holes and neutron stars. These simulations provide templates to which observed signals are compared in order to determine the values of the physical parameters in a given event and search for potential deviations from Einstein's theory. Such calculations are notoriously difficult and were in fact impossible until a breakthrough in numerical relativity by South African and Canadian physicist Frans Pretorius [3], currently at Princeton. Dr. Pretorius received his MSc at the University of Victoria under Werner Israel, who can arguably be credited with establishing the strong general relativity community that exists in Canada today. Dr. Pretorius' PhD was obtained at the University of British Columbia under Matt Choptuik, another world leader in numerical relativity. In addition, substantial numbers of the required templates for black hole mergers were first obtained [4] by the numerical relativity group of Harald Pfeiffer (Max Planck Institute) while he was at the Canadian Institute for Theoretical Physics (CITA) at the University of Toronto. Luis Lehner's group at the Perimeter Institute of Theoretical Physics (PI), while not formally part of the LIGO collaboration, provided simulations of neutron star mergers that are important for the interpretation of this class of events. During his first years in Canada Dr. Lehner was also associated with the University of Guelph. At the time of writing, CITA is the only Canadian institution that belongs to the eighty (institutional) member LIGO collaboration. Given the strength of the Canadian relativity community as a whole and its considerable contributions to the field, direct involvement in LIGO by Canadian institutions will hopefully grow substantially in the near future.

The GW detections provide remarkable confirmation of the theory of general relativity, which treats space and time on an equal footing, merged together into a four-dimensional geometry called *spacetime*. In this view



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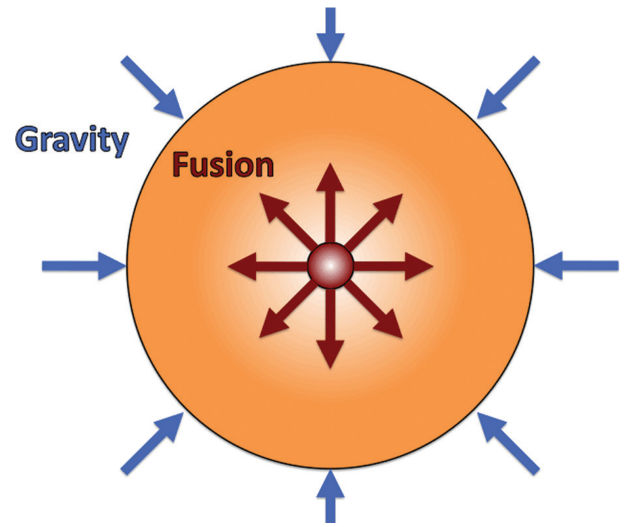

Fig. 1 The balance between gravity pushing inward, and fusion pushing outward, keeping a star radius at equilibrium. Credit: Britton Olson

gravity is seen not as a force, but as the effect of curvature in the spacetime geometry. Objects with mass create curvature, and this curvature in turn affects how these objects move. In the famous words of physicist John Wheeler: "Spacetime tells matter how to move; matter tells spacetime how to curve."

In general relativity, it is the geometry of spacetime that provides the field analogous to the electromagnetic field in Maxwell's theory. Just as charges moving up and down in a radio antenna generate electromagnetic waves, accelerating masses generate GWs in the spacetime geometry. More concretely, as these waves travel they alter the local spacetime curvature causing physical changes in length and the rate of time flow, both very counterintuitive phenomena. This is happening all around us, but the effect is unimaginably small for ordinary objects. In order to have GWs large enough for detection, incredibly massive objects such as black holes or neutron stars must orbit each other at speeds comparable to that of light. These are fascinating objects which are not fully understood and GWs provide invaluable insight into their nature.

Black holes and neutron stars are the end state of the ordinary stars which light up the night sky. Stars are born in stellar nurseries, massive clouds of mostly hydrogen gas. Some regions of the gas start by chance with a higher density and increased gravitational attraction, drawing in more gas and increasing the density even further. Eventually gravity becomes strong enough to fuse hydrogen into helium giving off massive amounts of energy, and a star is born. Fusion in the star core generates an outward pressure that keeps the star from collapsing in on itself, illustrated in Fig. 1.

Eventually all of the fuel is used up and a star reaches the end of its lifecycle, with the end state dependent on the initial mass of the star. Much of the stellar mass is ejected in a supernova as the core collapses. Stars that begin with 10 to 29 solar masses leave behind a core of 1.4 to 3 solar masses that collapses into a neutron star, with quantum mechanical *neutron degeneracy pressure* balancing against gravity to prevent further collapse. For stars having more than 29 solar masses before the end stage, it is generally believed that nothing can stop gravitational collapse, and the end state is a black hole.

Neutron stars are incredibly dense: a one teaspoon sample of neutron star material would weigh one billion tonnes on earth! Some neutron stars, known as *pulsars*, have a very strong magnetic field and rotate rapidly (up to 1000 times per second). As observed from earth, pulsars send a beam (or pulse) of electromagnetic radiation in very precise intervals. The first (indirect) evidence of GWs came in 1971 when R. Hulse and J. Taylor observed a binary system of a pulsar orbiting around a neutron star. Because of the precision of the pulsar period data, Hulse and Taylor were able to accurately calculate the period of orbit. According to general relativity, two stars in orbit will spiral closer together at increasing speed as gravitational energy is radiated away in GWs. Observations continue to this day, and the calculated change in period fits incredibly well with theory (see Fig. 2).

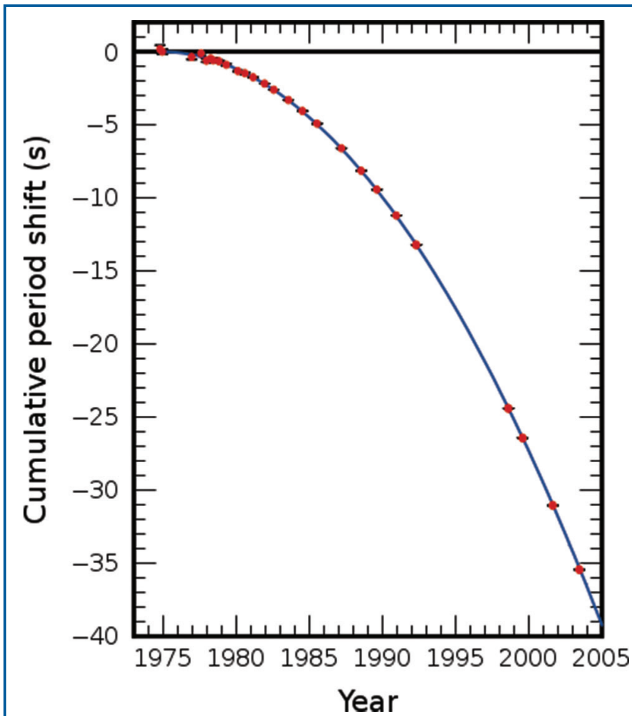

Fig. 2 Observed data points (in red) and the prediction according to general relativity (solid line) of the Hulse-Taylor binary pulsar system orbital period. Source: Weisberg, J.M.; Taylor, J.H. (July 2005). "The Relativistic Binary Pulsar B1913+16: Thirty Years of Observations and Analysis".

For this contribution Taylor and Hulse were awarded the 1993 Nobel prize in Physics.

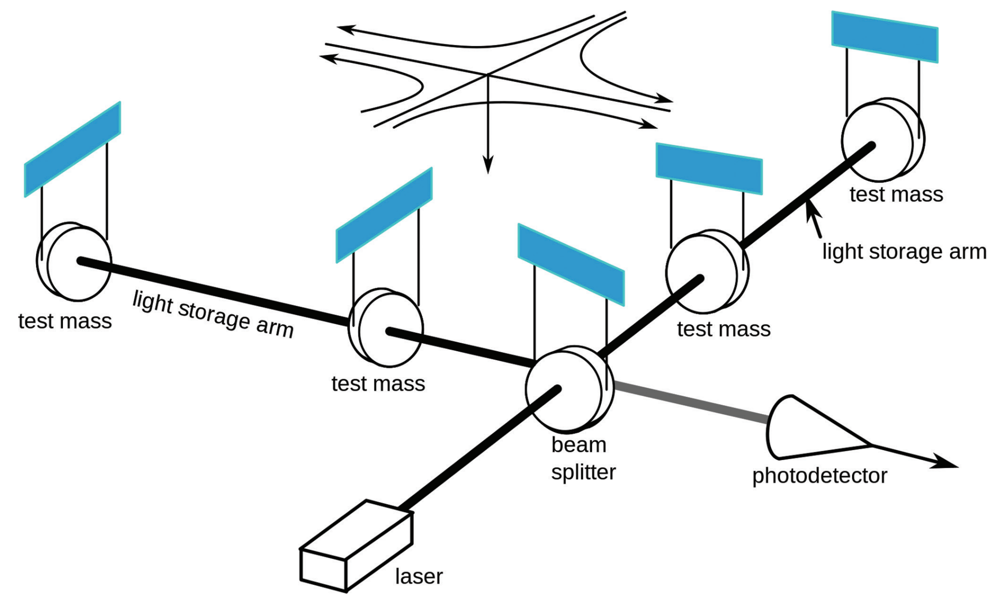

Fig. 3 Diagram of a LIGO interferometer. Source: LIGO-Caltech

Black holes form from stars so massive that gravity overcomes all other forces. General relativity predicts that the collapse process continues until a single point of infinite density forms at the centre, causing a divergence in the spacetime curvature (i.e. a *singularity*) at the centre. Surrounding the singularity is a region known as the event horizon, which represents the point of no return. Within the bounds of the event horizon even light moving 'outward' gets pulled back toward the centre, like a fish trying to swim up a waterfall. Generally in physics, we assume that nothing that can be measured locally should be infinite, so the singularity implies that Einstein's theory must no longer be valid near the black hole core. In this sense, GR predicts its own demise. The resolution is thought to be that when curvature becomes very large, gravity should follow the rules of quantum rather than classical mechanics. However, *there is no established quantum theory of gravity.* This is an active field of research and one can hope that gravitational waves coming from black holes will offer some experimental signatures to give insight for developing such a theory.

Currently there are three observatories working together to detect gravitational waves: two LIGO detectors in Hanford, WA and Livingston, LA, each with 4km arms, and the Virgo detector in Pisa, Italy with 3km arms. Having multiple interferometers gives more confidence in results since they are obtained independently at each location, and also helps to pinpoint where the signal originated. These measurement devices can detect a change in length between the mirrors of 10^{-19}m, or about 1/10000 the width of a proton. LIGO is planning to add a third detector in western India by 2023, and other organizations around the globe are planning future detectors and getting funding in place.

Modern gravitational wave detectors are giant laser interferometers that use the interference of light as a measurement tool. A simple sketch of the main components is given in Fig. 3. The components include a laser source, beam splitter, two long arms with mirrors at the end and a photodetector. This video explains how a laser beam is sent down the two different arms, reflects off the mirrors at either end, and recombines before reaching the photodetector. When the mirrors are at equilibrium the two beams exhibit destructive interference and no signal is observed. If the mirrors are displaced, the two beams no longer cancel each other, and the displacement can be measured by the intensity of light hitting the photodetector.

LIGO initially ran from 2002 to 2010 at a lower sensitivity than it has now, but did not find any detections. While this was disappointing, it was not entirely unexpected since the volume of space within detection range had a low probability of neutron star or black hole mergers over that time span. After the initial run, modifications were made over the next several years to increase sensitivity. The improvements included a more powerful laser capable of producing photons with shorter wavelength (increasing the measurement precision), and a seismic isolation system to better isolate the mirrors from vibrations in the surrounding area (eliminating experimental noise). This improved the sensitivity by a factor of 10, increasing the volume of space which could be observed by a factor of 10^3. Detections were now 1000 times more likely to be found. Advanced LIGO began running in September, 2015, and as luck would have it, the first gravitational wave was detected just a few days later! Further improvements are still in progress, and at full sensitivity, LIGO expects about 40 detections per year from neutron star sources alone.

The first detection by LIGO in September 14, 2015 obtained signals from the merger of two black holes of 29 and 36 solar masses to form a final black hole of 62 solar masses. The process ejected three solar masses worth of energy in GWs. A video illustrating the merger of two black holes and resulting GWs can be found here. The merger took place in a galaxy 1.3 billion light years away, but since only two detectors were operational at the time, the location of the source could not be triangulated with high precision. The form of the observed waves confirmed that general relativity accurately describes the black hole merger, and also provided evidence that these observations were indeed achievable: GW astronomy had arrived! Interestingly, the frequency of the observed GWs is within the audible range for humans; an audio file along with images of the data can be found here.

On August 17, 2017, GWs from the merger of a binary neutron star system were observed by Virgo and both LIGO detectors. Remarkably, 1.7 ms later the Fermi Gamma-ray Space Telescope detected a gamma ray burst emanating from the merger. With these four separate detections, the direction of the source was determined accurately and 70 observatories around the globe were notified so that they could search this location in the sky for further signals. A great deal was learned about neutron star mergers from this event alone. Physicists confirmed the theoretical prediction that neutron star mergers are a source for short gamma ray bursts, and that such events produce gold, lead and other heavy elements. It also provided confirmation that general relativity accurately describes the merger of neutron stars.

As of the date this article was written, there have been six GW observations by LIGO in total, with the last two being detected by Virgo as well. A list of these detections and the resulting publications is available on the LIGO website. This is only the beginning. GW astronomy is an exciting new field that will develop and mature over the coming years and decades. As technology improves and more detectors are built, we will be able to see farther out into space, observing signals that originated further back in time. If we can look back far enough, we can hope to uncover some insight into the Big Bang. More accurate data might show deviations from the predictions of general relativity, revealing clues to the quantum nature of gravity. We may even observe exotic phenomena such as cosmic strings, or something completely unforeseen! It is a rare occurrence in physics for an entirely new field of observational science to emerge, and GW astronomy is sure to play an important role in our efforts to learn more about gravitation and the mysterious objects that lurk in the universe.

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2018 STUDENT COMPETITIONS / *COMPÉTITIONS ÉTUDIANTES 2018*

(SEE EXTENDED ABSTRACTS OF THE WINNERS ON PAGES 119-130 PLUS PHOTOS ON PAGE 118 / *VOIR LES RÉSUMÉS DES GAGNANTS AUX PAGES 119-130 ET PHOTOGRAPHIES A LA PAGE 118*)

The Canadian Association of Physicists has established these awards to recognize student members giving the best oral and poster research presentations at the annual CAP Congress. Up to three awards in each category, each consisting of a certificate of recognition and a cash prize, are made each year. in addition, a number of CAP Divisions offer prizes for the best student presentations at the divisional level. Eligibility, selection procedure, and selection criteria for the competitions are available through the Congress website each year.

L'Association canadienne des physiciens et physiciennes a créé ces prix afin de récompenser les membres étudiants auteurs des meilleures communications au congrès annuel. Elle décerne tous les ans un maximum de trois prix dans chaque catégorie, chacun consistant d'un certificat de mérite et d'une somme. De plus, plusieurs divisions offrent des prix pour leurs meilleures présentations étudiantes. Admissibilité, modalités et critères de sélection pour les prix sont sur le site web de l'ACP.

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3rd Place	Candice Quinn, University of Calgary

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CONDENSED MATTER AND MATERIALS PHYSICS	
Placement	**Name / Affiliation**
1st Place	Carmen Lee, McMaster University
2nd Place	John Niven, McMaster University
3rd Place	Daniel Korchinski, University of Calgary

PHYSICS EDUCATION AND APPLIED PHYSICS AND INSTRUMENTATION	
Placement	**Name / Affiliation**
1st Place	Amy-Rae Gauthier, University of New Brunswick

PHYSICS IN MEDICINE AND BIOLOGY	
Placement	**Name / Affiliation**
1st Place	Kyla Marie Smith, University of Manitoba

NUCLEAR PHYSICS	
Placement	**Name / Affiliation**
1st Place	Eleanor Dunling, University of York
2nd Place (tie)	Ryan Ambrose, University of Regina
2nd Place (tie)	Satbir Kaur, Dalhousie University

PARTICLE PHYSICS	
Placement	**Name / Affiliation**
1st Place	Eleanor Fascione, Queen's University
2nd Place	Savino Longo, University of Victoria
3rd Place	Robert Les, University of Toronto

THEORETICAL PHYSICS	
Placement	**Name / Affiliation**
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3rd Place	Wyatt Kirkby, McMaster University

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Placement	**Name / Affiliation**
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2nd Place	Carmen Lee, McMaster University
3rd Place	Melanie Hammer, Dalhousie University

HONOURABLE MENTIONS
Name / Affiliation
Eleanor Duning, University of York/TRIUMF
Andrew Evans, University of Calgary
Eleanor Fascione, Queen's University
Robie Hennigar, University of Waterloo
Kyla Smith, University of Manitoba

The CAP 2018 best student presentation award winners gather for a photograph with CAP Past President, Richard MacKenzie (far left) and CAP President, Bruce Gaulin (far right, back row).

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and to the CAP's Vice-President Elect at that time, Dr. Bruce Gaulin of McMaster University, and all of the judges for their extraordinary efforts in organizing this event. Our thanks are also extended to all competitors.

The winners of the 2018 CAP Best Student Presentation Competition at the CAP Annual Congress, 2018 June 11-15, in Halifax, NS, are posted on the CAP's website at https://www.cap.ca/congress-conference/past-congress/congress-2018/. The extended abstracts of those winners who submitted them for publication are reproduced below. Ed.

Magnetic Resonance Imaging of Fast Turbulent Gas Flow

by Amy-Rae Gauthier[1] and Benedict Newling

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Summary

Turbulent gas flow is quantified using motion-encoded SPRITE magnetic resonance imaging to measure the time-averaged velocity field and eddy self diffusivity.

The problem of turbulence has been called "the last unsolved problem of classical physics". While there is no universally accepted definition of turbulence, most physicists have some intuitive sense of the difference between laminar and turbulent flow. Imagine stirring milk into your coffee: notice the coherent structures that form when you first pour in the milk, then see how those structures become incoherent as you stir until you are left with a homogeneous mixture. This is the effect of turbulence.

In any fluid flow system, the velocity field is one of the most important quantities we can measure. To aid in our discussion, it is convenient to introduce the Reynolds decomposition, which separates the velocity field into a time averaged velocity field, $\bar{v}_t$, and a turbulent fluctuation term, $v'(t)$, i.e.,

$$v(t) = \bar{v}_t + v'(t)$$

In a laminar flow, the turbulent fluctuation term would be zero, and so the time-averaged velocity field would be the total velocity field. In this sense, turbulent flow can be characterized as any flow in which the $v'(t)$ term is non-zero [1].

Measuring turbulent flow is a formidable challenge. The difficulty lies in its sensitivity to geometric differences, that is, invasive measurements will alter the velocity field. For this reason, many common flow measurement techniques are not well-suited to turbulent flows. Magnetic Resonance Imaging (MRI) is a versatile and non-invasive technique which can be modified such that measurements are sensitive to turbulent motion. In this article, two fast-flowing turbulent systems will be introduced as examples of the information that can be gleaned from MRI measurements.

MRI and the Motion-Encoded SPRITE Sequence[1]

MRI is non-invasive, inherently three dimensional, and can measure flows that would otherwise be invisible to optical techniques. The trade-off is that the fluid must be magnetically susceptible, which is why sulfur hexafluoride gas is used in these experiments rather than air. In SF_6, the fluorine nuclei have spin magnetic moments which align with the magnetic field. The sample space is divided into voxels, and each voxel contains on the order of 10^{41} nuclei. The spin magnetic moments are summed to create a bulk magnetization vector which precesses about the magnetic field at a frequency given by Larmor's equation:

$$\omega = \gamma B$$

where ω is the frequency of precession, γ is the gyromagnetic ratio which is unique to each magnetically susceptible nucleus, and B is the magnetic field. The versatility of MRI lies in the manipulation of B; i.e., different combinations of spatial magnetic field gradients can be applied to sensitize ω to various physical phenomena, including motion.

The particular combination of sample excitations and magnetic field gradients, collectively known as a pulse sequence, used in these measurements is the motion-encoded SPRITE sequence (Single Point Ramped Imaging with T_1 Enhancement) [2]. A plot of the magnetic field gradients applied over time for a single data point acquisition is pictured in Fig. 1. To achieve motion-sensitization, two

1. Amy-Rae Gauthier received 1st place in the CAP Best Student Oral Presentation competition at the 2018 CAP Congress at Dalhousie U.

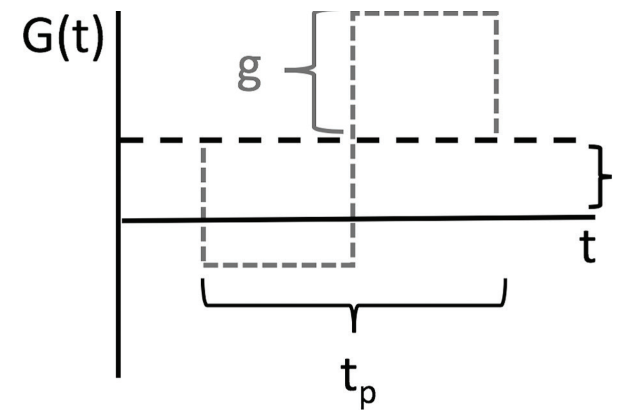

Fig. 1 The spatial magnetic field gradient applied for one data point acquisition in the motion-encoded SPRITE pulse sequence. Two gradients are superimposed: the imaging gradient with magnitude G, and the motion-encoding gradient with magnitude g. The time between excitation and detection of the signal is t_p.

magnetic field gradients are superimposed. The constant gradient is known as the imaging gradient, and the bipolar gradient is known as the motion-encoding gradient. The time t_p represents the time between excitation of the sample via a radio-frequency pulse, and detection of the resulting signal.

The motion-encoded SPRITE sequence introduces a Larmor frequency in the sample space that is dependent on both position and velocity. Integrating the Larmor frequencies over the time t_p results in an expression for the phase accumulation of the magnetization vector:

$$\phi = r\left(\gamma t_p G\right) + \overline{v}_t\left(\frac{\gamma t_p^2}{4} g\right) + \ldots$$

The first term contains information on the position and depends only on the imaging gradient G. The second term contains the time-averaged velocity field $\overline{v}_t$ and depends only on the motion-encoding gradient g. This expression is a Taylor series expansion of the position, so higher order terms would depend on acceleration, jerk, etc. and these terms are assumed to be negligible. This expression is also the equation of a line for a plot of phase $ø$ vs. g, and the slope of this line is proportional to $\overline{v}_t$. In this way, motion-encoded SPRITE can be used to directly measure the time-averaged velocity field of a turbulent flow, i.e., the first term in the Reynolds decomposition.

The signal amplitude also contains information relevant to turbulence. Signal amplitude is proportional to the length of the bulk magnetization vector, so if there is a wide distribution of accumulated phase in a voxel, the signal is attenuated. In laminar flow, all particles of gas from a particular voxel take approximately the same trajectory through the magnetic field gradients,

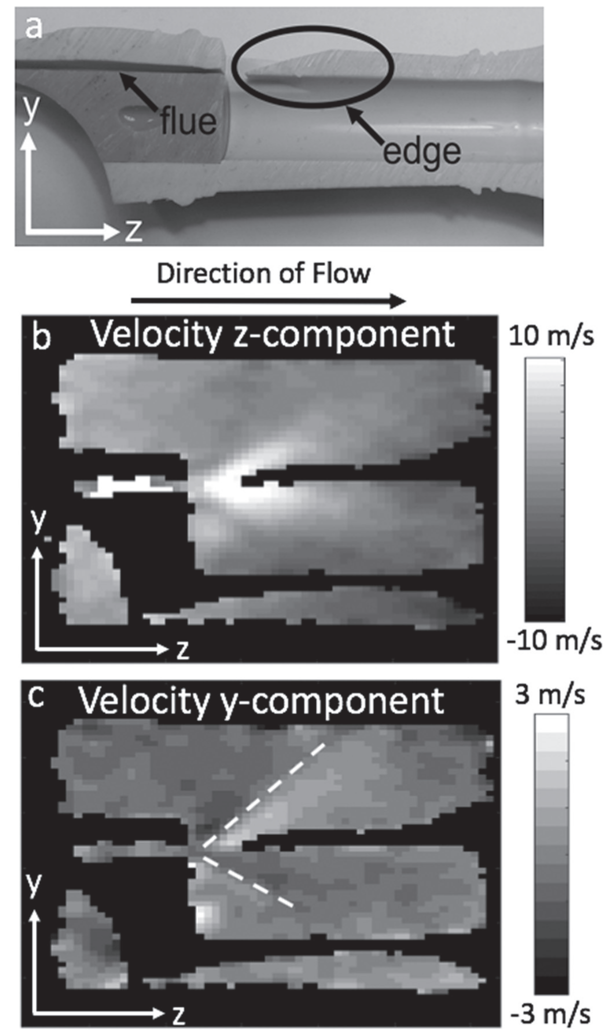

Fig. 2 (a) The cross-section of a recorder nominally identical to the recorder used in the measurements. The important geometric features are the flue and the edge. (b) The central slice of the *z*-component of the time-averaged velocity. (c) The central slice of the *y*-component of the time-averaged velocity.

so the phase distribution is narrow. In turbulent flow, gas particles take different trajectories through the magnetic field gradients, so the voxel contains a much wider phase distribution and the signal is attenuated. The attenuated signal is modelled using a tensor quantity we call the *eddy self diffusivity*, as follows

$$\boldsymbol{D} \cdot \boldsymbol{b} = -\ln\left(\frac{S_o}{S}\right)$$

$\frac{S_o}{S}$ represents the ratio between signal attenuated due to the presence of motion-encoding gradients and signal acquired with

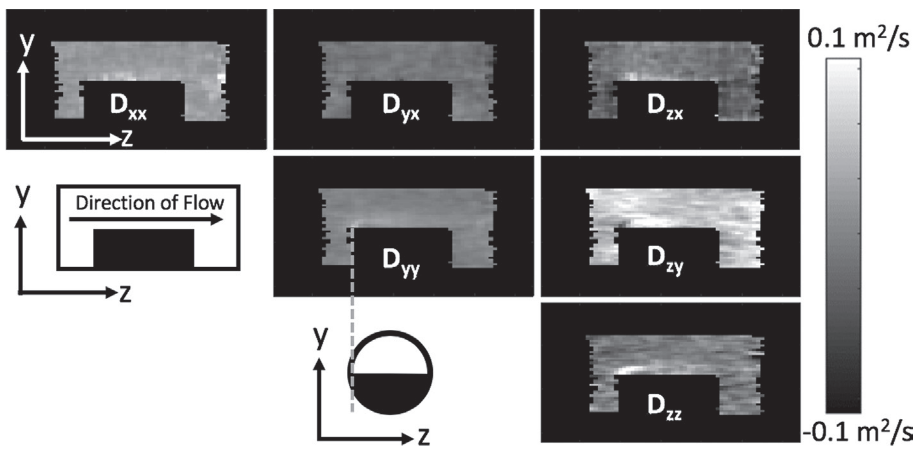

Fig. 3 The central slice of the eddy self diffusivity tensor with sketches of the pipe geometry.

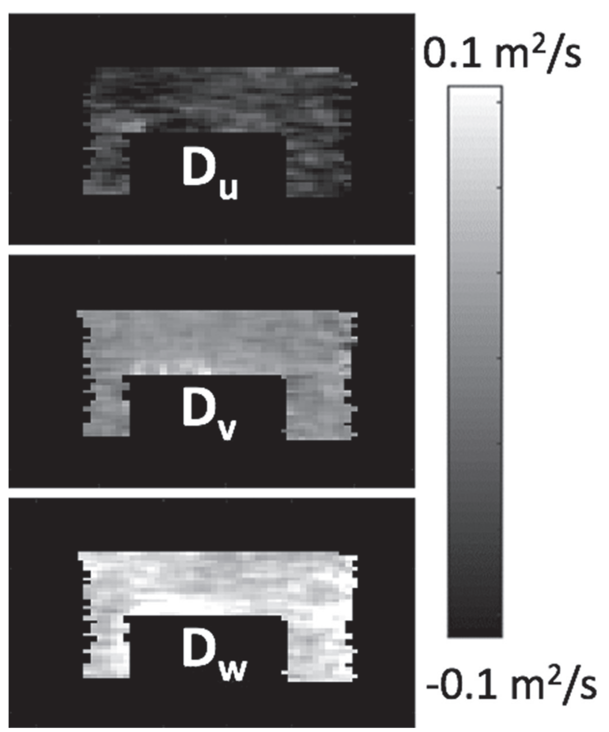

Fig. 4 The three eigenvalues of the eddy self diffusivity tensor in Fig. 3.

only imaging gradients. ***D*** is the eddy self diffusivity tensor, which contains six independent components. ***b*** is called the "b-factor" and is a tensor quantity which describes how sensitive the measurement is to diffusivity. Taking measurements with six different b-factors creates a system of six equations and six unknowns, so all components of the eddy self diffusivity tensor can be calculated. The greater the value of the eddy self diffusivity, the greater effect the turbulent fluctuation term, $v'(t)$, has in that region of the sample space [3]. This is how motion-encoded SPRITE can provide information about the turbulent fluctuation term in the Reynolds decomposition.

EXAMPLES OF TURBULENT FLOW

To demonstrate the effectiveness of the time-averaged velocity field measurements, we use the example of gas flow through a recorder. The recorder has two main geometric features: the flue, which is a narrow channel in the mouthpiece that generates a jet, and the edge, which is a sharp obstruction that generates the oscillations needed to produce sound (see Fig. 2a). According to simulation studies of the recorder (e.g., [4]) the fastest speeds should appear in the flue and the gas should oscillate above and below the edge.

The time-averaged velocity field measurements are consistent with these expectations. The *z*-component of the velocity, pictured in Fig. 2b, shows that the speed is greatest in the flue at 20 m/s. Adjacent to the edge, the speed is reduced to around 10 m/s, and the bulk of the fluid is moving in the positive *z*-direction. The *y*-component of velocity, pictured in Fig. 2c, shows that the speed is positive immediately above the edge, and negative immediately below the edge in the space contained by the dashed white lines. This suggests that the gas is oscillating above and below the edge as expected. Furthermore, the maps suggest that recirculation is present, as evidenced by the change in sign of the speed outside the space enclosed by the dashed white lines. These results are broadly consistent with simulations and theoretical models of the recorder, and details regarding these results can be found in [5].

To demonstrate the measurement of the eddy self diffusivity, we use a much simpler geometry: a cylindrical pipe with a hemi-cylindrical obstruction, drawn in Fig. 3. Gas is moved through the pipe at speeds on the order of 10 m/s. Intuitively, we expect the region where the gas encounters the edge of the obstruction to be where the turbulent fluctuations have the greatest effect. For the central cross-section of the pipe, all six components of the eddy self diffusivity tensor are mapped in Fig. 3. The *ZZ* and *ZY* components of the tensor show a bright spot adjacent to the edge of the obstruction, so these results are consistent with our expectations.

The eddy self diffusivity tensor can be manipulated further to answer a bigger question: is turbulence in this system isotropic? Typically, in computational fluid dynamics simulations, the turbulence is assumed isotropic to simplify the already complex calculations required. Also, turbulence is often thought of as a completely random phenomenon, so the assumption of isotropy is natural. If turbulence were isotropic in this system, the eddy self diffusivity tensor would have no off-diagonal elements, and all the diagonal elements would be the same. However, the tensor in Fig. 3 has as its principal axes the x, y, and z axes of the MRI system. To test isotropy, the eddy self diffusivity tensor is diagonalized, and if the eigenvalues come out the same, then turbulence is isotropic. Figure 4 shows maps of the three eigenvalues for each voxel in the sample space. They are not the same, and therefore turbulence in this system is anisotropic. Further investigations of this system are currently underway to see if the turbulent anisotropy can be further quantified.

CONCLUSION

The two turbulent systems explored here are examples of how MRI is well-suited to the problem of turbulence because it is non-invasive and naturally three dimensional. In particular, the motion-encoded SPRITE pulse sequence continues to be a robust tool for the measurement of gas flow. The phase accumulation offers a direct measurement of the time-averaged velocity field, which is the first term in the Reynolds decomposition. The signal amplitude contains information about the turbulent fluctuation term, and by modelling the turbulence as an eddy self diffusivity tensor, the turbulent anisotropy can be measured. These two quantities are helpful in quantifying and characterizing turbulence, which can help inform computational and theoretical work in the field.

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Interpreting Satellite Observations of the Ultraviolet Aerosol Index to Understand Aerosol Scattering and Absorption

by Melanie S. Hammer[a,1], Randall V. Martin[a,b], Aaron van Donkelaar[a], Chi Li[a], Virginie Buchard[c,d], Omar Torres[c], Brian L. Boys[a], David A. Ridley[e,f], Robert J.D. Spurr[g], and Max Manning[a]

Aerosols are particles suspended in Earth's atmosphere. They are emitted from a variety of sources, such as motor vehicles, industry, biomass burning, uplifted desert dust, and ocean spray. These particles impact climate through their interactions with solar radiation. Aerosols with scattering properties have a cooling effect on climate as they reflect incoming solar radiation back to outerspace, while aerosols with absorbing properties absorb the incoming solar radiation, which warms the atmosphere and cools the surface. The climate impacts of aerosols are known to be significant; it is estimated that the cooling effect of aerosols has masked approximately one third of the warming due to greenhouse gases [1], while aerosol absorption is estimated to possibly be the second largest source of atmospheric warming after carbon dioxide [2,3]. However, the overall magnitude of the climate effects of aerosols remains highly uncertain, due to the large uncertainties associated with the aerosol particles themselves. Global observations of aerosol scattering and absorption would improve our understanding of how aerosols interact with solar radiation and therefore also improve our understanding of their climate impacts.

We used NASA's Ultraviolet Aerosol Index (UVAI) dataset, which is a product of the Ozone Monitoring Instrument (OMI), to improve understanding of changes in aerosol scattering and absorption over time and space. Satellite remote sensing is a valuable tool which provides atmospheric composition information on a global scale. The UVAI is a method of detecting aerosol optical effects from satellite measurements in the ultraviolet. The UVAI is calculated as the ratio of the radiance measured by the satellite with the radiance that would be measured by the satellite if the atmosphere were completely free of aerosol. Positive UVAI values indicate aerosol absorption, and the sources of positive UVAI values are biomass burning and desert dust aerosol. Negative UVAI values indicate aerosol scattering, and the sources of negative UVAI values are inorganic and scattering organic aerosol. We examined trends in the UVAI for 2005-2015 to learn about changes in aerosol scattering and absorption over time.

Summary

We use the Ultraviolet Aerosol Index, a method of detecting aerosol optical properties from satellite measurements, to understand changes in aerosol scattering and absorption over time and space.

To interpret the observed UVAI trends, we developed a simulation of the UVAI using the global chemical transport model GEOS-Chem coupled with the radiative transfer model VLIDORT. We used GEOS-Chem to split the atmosphere into about a million grid boxes, then in each grid box the meteorological and emissions inputs are given to the physical and chemical equations necessary to simulate the chemical composition of the atmosphere. From this simulation, we provided the aerosol information to VLIDORT necessary for the calculation of the atmospheric radiances used in the calculation of the simulated UVAI. We then used this simulation with known aerosol composition to interpret the trends in the satellite observed UVAI values.

We found that compared to the OMI UVAI, the UVAI simulation captured the aerosol absorption over desert regions, but failed to capture the absorption over biomass burning regions [4]. This was because chemical transport models, including GEOS-Chem, typically treat black carbon as the sole absorbing carbonaceous aerosol. However, over the past number of years there has been a growing amount of evidence for the existence of an additional absorbing carbonaceous aerosol species known as brown carbon, which absorbs strongly in the ultraviolet and is emitted through low-temperature, incomplete combustion of biomass and biofuel. By adding brown carbon to the

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GEOS-Chem simulation, the UVAI simulation was then able to reproduce the absorption over biomass burning regions compared to OMI.

We then used this improved simulation with known aerosol composition to interpret the 2005-2015 trends in observed UVAI values to learn about changes in aerosol scattering and absorption over time [5]. We found that decreasing levels of scattering aerosols, due to pollution controls, explained positive trends in the UVAI over the south-eastern U.S. A decline in absorbing biomass burning aerosol due to cropland expansion explained negative trends in the UVAI over West Africa. An increase in scattering aerosol due to industrial activity explained negative trends in the UVAI over India. Over the Middle-East there was a small region of positive trends in the OMI UVAI values that was not captured by the simulation. This feature was located near the Aral Sea, which has been drying up for several years due to land use changes. As the sea bed becomes more exposed, there would be increased emissions of absorbing desert dust and the surface reflectance would increase, which are both factors that would increase the UVAI. Therefore the satellite UVAI is capturing these effects as they happen, but they are not yet modeled in GEOS-Chem, which is why the feature is not captured in our UVAI simulation. This indicates an area for future model development.

CONCLUSION

In summary, interpretation of satellite UVAI observations with the GEOS-Chem chemical transport model is yielding new insight into scattering and absorption by atmospheric aerosols.

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IMPROVING RECONSTRUCTION OF GeV-SCALE NEUTRINOS IN ICECUBE-DEEPCORE BY DIRECT EVENT SIMULATION

BY SARAH NOWICKI[1]

NEUTRINOS AND THE ICECUBE OBSERVATORY

Detection of the weakly interacting neutrino is a challenging area of study that has emerged as one of the most exciting in modern particle physics. The discovery of a non zero neutrino mass through measurements of neutrino oscillations [1,2] has provided a truly intriguing scenario for particle physicists where extensions to the existing Standard Model [3] are necessary.

The IceCube Neutrino Observatory (see Fig. 1) is a cubic-kilometre-scale Cherenkov detector, instrumenting the deep glacial ice sheet near South Pole Station, Antarctica [4]. More than 5000 sensitive light detectors, known as photomultiplier tubes (PMTs), are deployed in a nearly hexagonal 3D array in some of the most optically pristine ice in the world [5]. Each of the PMTs is integrated into a digital optical module (DOM) comprising a glass pressure housing with on-board autonomous power and data acquisition [7]. The DOMs are distributed vertically along a cable or 'string', with 60 DOMs per string.

The detector is designed with DOM spacing according to specifically targeted physics goals. To detect cosmic neutrinos from high-energy astrophysical processes, the primary IceCube array of 78 strings has an average inter-string spacing of 125 m and 17 m vertically between DOMs, optimizing the sensitivity to energies beyond the TeV-scale. At the centre of IceCube a denser infill array (DeepCore) has been deployed [8], optimized to detect atmospheric neutrinos between ~5 and 100 GeV. DeepCore largely facilitates IceCube's particle physics program, in particular measurements of atmospheric neutrino oscillations.

SUMMARY

Real-time event simulation, to include a full description of the natural ice, holds the potential to improve event reconstruction in the IceCube Neutrino Observatory.

ICECUBE EVENTS AND RECONSTRUCTION

When a neutrino undergoes a charged-current interaction with an atom in the ice within or near the IceCube detector array, a charged lepton of the same flavour is produced. These leptons will then emit their energy, including production of Cherenkov photons, as they traverse the detector. The topology of the particle's charge deposition is characteristic of the flavour and interaction type. As shown in Fig. 2, the detected neutrino interactions have two distinct types: 'cascades', related to electron-type, most tau-type and neutral-current interactions where an approximate spherical charge-deposition is observed; and 'tracks', related to muon-type charged-current interactions. The light generated in the energy deposition is then detected by the IceCube DOMs. At high energies, beyond the TeV scale, where many thousands of photons are detected, the event characteristics are largely evident by eye. Energies relevant for studies of neutrino oscillations however, 0 (10 GeV), result in only tens of detected photons on average. In either case, reconstruction of the event characteristics is crucial to extracting the physics of interest.

IceCube event reconstruction is in general concerned with the extraction of two key parameters of the neutrino: its energy and direction. The existing standard IceCube reconstructions predict the amount and timing of the deposited charge in the detector for a given event hypothesis. This expectation for the photon distribution relies on a tool known as 'photon look-up tables' [9]. These tables consist of pre-generated templates describing photon detection probabilities for a fixed event type in a given location of the detector.

Scaling and/or a superposition of these templates is used to predict the charge amplitudes for any event hypothesis. The glacial ice that makes up the detector medium is modelled in discrete, horizontal layers, each with its own scattering and absorption coefficients. The photon look-up tables are therefore specific to the assumed ice model. Advanced study of the ice has demonstrated the

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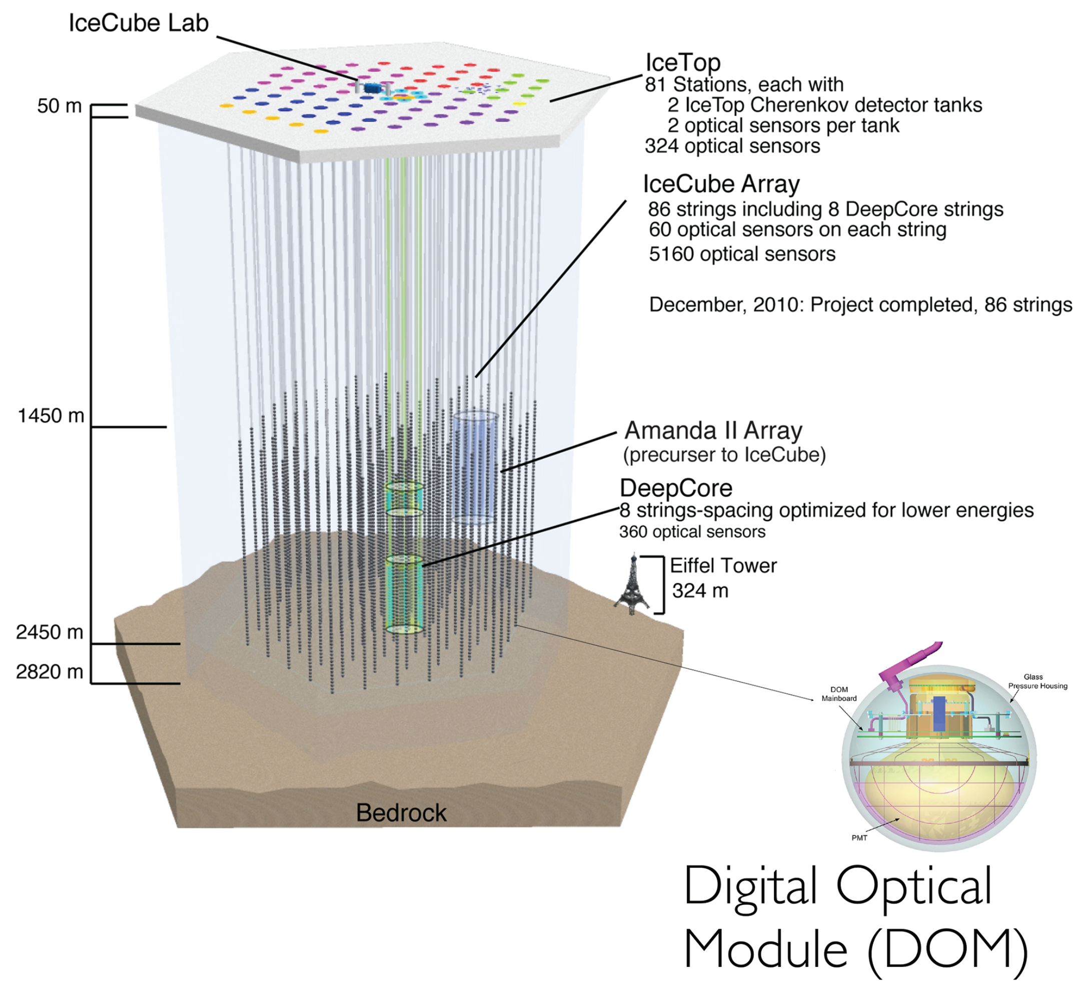

Fig. 1 Artist's concept of the IceCube Neutrino Observatory [6]. IceCube is composed of three primary detector arrays. The primary in-ice array, targeting astrophysical neutrino measurements, instruments more than a cubic-kilometre of the glacial ice sheet 1.5 km below the surface at South Pole Station. The DeepCore array extends the scientific reach of IceCube to neutrinos near 5 GeV. IceTop, deployed at the surface above the IceCube array, operates as a large-scale cosmic-ray air shower detector for the facility. Credit: IceCube Collaboration.

complexity of this natural medium [10], including calibration measurements that have identified a tilt in the modelled layers across the detector volume and a directional anisotropy in the scattering and absorption properties [11]. Describing these ice model elements in the photon look-up tables requires increasing their dimensionality, limiting both the ability to produce and utilize the tables on large-scale computing clusters. In addition, the optical properties of the re-frozen ice near the DOMs may differ substantially from the surrounding medium. The characterization of the re-frozen ice and its incorporation into the event reconstruction remains an outstanding challenge.

RECONSTRUCTION BY DIRECT SIMULATION

One path to overcoming the challenges encountered in IceCube event reconstruction is to directly simulate the event hypothesis on the fly utilizing the most advanced ice models. This method, called DirectReco, removes several assumptions built into the predictions obtained using the photon look-up tables and proves particularly useful in evaluating the impact of systematic uncertainties associated with the ice model. The DirectReco algorithm is based on several existing reconstructing tools that compare the expected and observed charges in a given DOM via a maximum likelihood calculation. One of the inherent limitations in this method, however, is the statistical fluctuations that can arise when comparing the DirectReco charge predictions to those from the photon look-up tables, that are derived by averaging the effect of nearly 75 million photons. This limitation is mitigated by re-simulating an event many thousands of times, ultimately producing statistics of similar order to those in the photon look-up tables. At the final stage, a modified Poisson

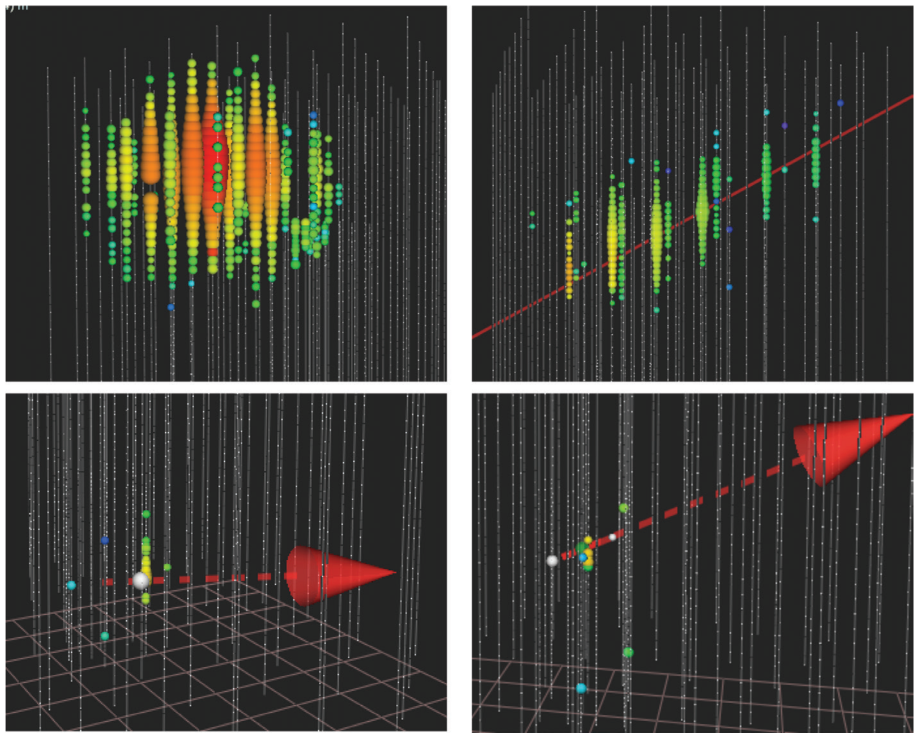

Fig. 2 Examples of IceCube events. (Top) High energy event displays: (Left) an ~1 PeV cascade-type; and (Right) an ~340 TeV muon-type. (Bottom) Low energy event displays: (Left) 30 GeV cascade-type; and (Right) 30 GeV muon-type.

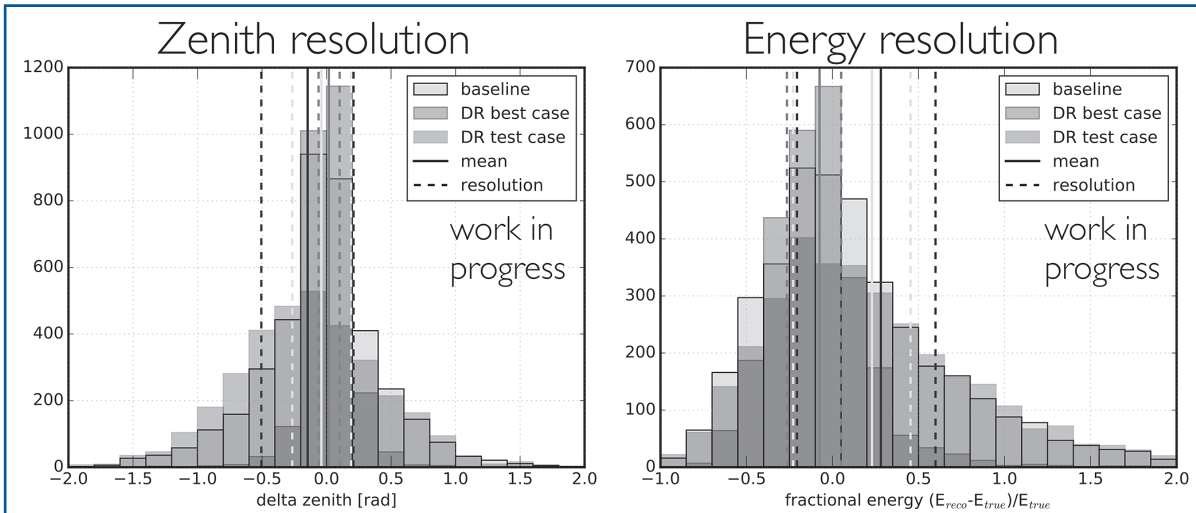

Fig. 3 Initial benchmark test of the DirectReco algorithm for 'low-energy' IceCube DeepCore simulation events. The reconstructed neutrino parameters for the zenith direction (Left) and energy (Right) are evaluated. Note that the current IceCube best reconstruction (baseline) is shown in yellow. DirectReco output, seeded with the event's true information, is shown in blue and represents a 'best case' output of the fitter at this stage of the development. Also shown in purple is the DirectReco result when seeded with the same values as those used in the baseline fit. The mean (solid vertical lines) and the 25 – 75% quantile (dashed vertical lines) for each of the distributions are shown in the related colours.

likelihood [12] is applied to account for any remaining statistical fluctuations in the reconstruction calculation.

To benchmark this method, ~4000 final analysis-level simulated events over the energy range of 1 GeV to 1 TeV were reconstructed with the DirectReco algorithm. Figure 3 shows the substantial improvement in the event reconstruction made possible with DirectReco, in particular for the resolutions of the reconstructed zenith angle and energy of the simulated neutrinos. Since these observables affect the sensitivity of IceCube to neutrino oscillation physics, DirectReco is expected to produce corresponding improvements to the constraints on oscillation parameters. The improvements to IceCube's constraints on neutrino oscillations will be discussed in a future publication.

One of the remaining long-term challenges for the DirectReco fitter in replacing the standard method using photon look-up tables is the time required to propagate sufficient photon statistics for the full event dataset. In particular, as steps are taken to optimize the resolution achieved with the DirectReco fitter through an iterative process, the event reconstruction time may dramatically increase. This remains a work in progress for the study, with the current mean reconstruction time of 0(100) s, similar to that of the current baseline reconstruction for the low-energy events.

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Modeling Polarisation Distortion of Optical Quantum Signals Through A Pressurized Window

Sebastian Slaman[1] and Thomas Jennewein

We study the polarization distortion of optical photons traversing an optical window under mechanical stress due to a pressure differential between both sides of the window. We confirm only a minor effect for light entering the window at normal incidences, as previously established [2]. However, we do find that for non-normal incidences the effect of birefringence on polarization encoded photon signals is noticeable and may no longer be neglected.

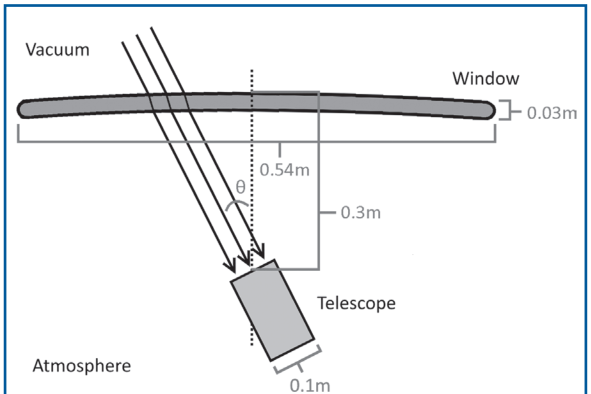

Fig. 1 Diagram of the signal beam that would reach the telescope through the window. The telescope is located inside the pressurized crew compartment.

REAL-WORLD APPLICATION

This research was inspired by the Space QUEST mission proposal that aims to test decoherence of entangled photon pairs due to gravity [3]. The mission proposes to transmit polarization entangled optical signals from ground to a receiver telescope located inside the International Space Station (ISS) (Fig. 1). As the quantum signal beam passes through a pressurized window, it will experience birefringence [4].

FINITE ELEMENT MODELING

The window's birefringence is modeled using finite element modeling (FEM). Each finite element has a different stress tensor and consequently, birefringence [5-7]. We implemented a ray-tracing algorithm that calculates the particular birefringence caused by the individual stress-elements each ray passes. The polarization distortion caused by each optical element of the FEM grid is represented by an individual Jones matrix [8]. The total Jones matrix (J_T) experienced by a particular ray is determined by accounting for the Jones matrices of all the elements it transverses. By combining all the rays across the aperture of the telescope, the overall polarization distortion induced by the window is estimated.

Outline of the Polarization Analysis Algorithm

The quantum optical signals are considered in two different polarization bases. Horizontal (***H***) and vertical (***V***) polarization states define the HV-basis, while diagonal (***D***) and antidiagonal (***A***) polarization states define the DA-basis. We determine the polarization distortion measured as the Quantum Bit Error Ratio (QBER) for each ray, defined as:

$$\mathrm{QBER} = (\boldsymbol{V}' J_T \boldsymbol{H} + \boldsymbol{H}' \mathbf{J}_T \boldsymbol{V} + \boldsymbol{A}' J_T \boldsymbol{D} + \boldsymbol{D}' J_T \boldsymbol{A})/4 \qquad (1)$$

The QBER effectively measures the probability that a photon would switch polarization from H to V, or from D to A, or vice versa, upon passing through an element.

The stress in the window is defined as a 3D mesh of cubic element of the window (201×201×40 cubes), each with a corresponding stress tensor represented as:

$$\sigma = [\sigma_{xx}, \sigma_{yy}, \sigma_{zz}, \sigma_{yz}, \sigma_{xz}, \sigma_{xy}]. \qquad (2)$$

Stress (σ_{PS}) in the principle strain axis of each element is a diagonal matrix of the eigenvalues of the element's stress matrix (σ). The columns of the matrix V correspond to the eigenvectors, such that the following equation holds.

$$\sigma * V = V * \sigma_{PS} \qquad (3)$$

Summary

This article discusses a method for modeling the polarization distortion of a quantum optical beam passing through a pressurized window at arbitrary angles.

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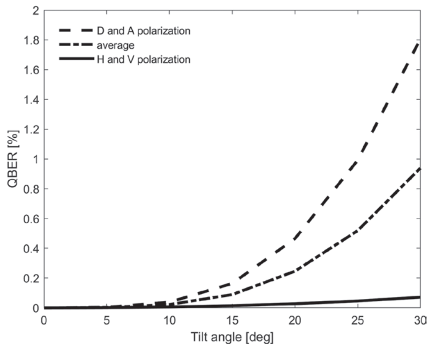

Fig. 2 Overall QBER of the entire beam entering the telescope, as a function of incoming beam tilt angle (0 deg = normal incidence).

The birefringence in the principle strain axis is calculated by multiplying the material's dielectric impermeability tensor (q) by σ_{PS} [9]. The V matrix rotates it back to the window's frame, and R_θ is applied to rotate it according to the tilt of the incoming ray (θ), resulting with the birefringence (ΔB) defined in the rays' reference frame.

$$\Delta B = R_\theta \cdot V \cdot q \cdot \sigma_{PS} \cdot V' \cdot R'_\theta \qquad (4)$$

ΔB is then rotated about the ray's axis by angle γ, such that the birefringence (ΔB_P) is in its own principal reference frame, to simplify the Jones matrix representation.

$$\gamma = \frac{1}{2}\tan^{-1}\left(\frac{2\Delta B_{xy}}{\Delta B_{xx} - \Delta B_{yy}}\right) \qquad (5)$$

$$\Delta B_P = R_{\gamma,3D} \cdot \Delta B \cdot R'_{\gamma,3D} \qquad (6)$$

With ΔB_P, we can calculate the change in refractive index orthogonal components of the polarization would experience giving Δn_x and Δn_y [10].

$$\Delta n_x = -1/2\, n_0^3 \Delta B_{P,x} \quad \Delta n_y = -1/2\, n_0^3 \Delta B_{P,y} \qquad (7)$$

The changes in refractive index cause phase shifts (δ_x, δ_y) in their respective components. The wavelength of light in the window medium is λ_m and the distance it travels in the element is L.

$$\delta_x = 2\pi \Delta n_x L/\lambda_m \; \delta_x = 2\pi \Delta n_y L/\lambda_m \qquad (8)$$

These phase shifts result in a polarization distortion (J_P) in the principal axis. The matrix $R'_{\gamma,2D}$ rotates it back to the beam's reference frame to determine the distortion of one element (J_e).

$$J_{principal} = \begin{bmatrix} e^{i\delta_x} & 0 \\ 0 & e^{i\delta_y} \end{bmatrix} \qquad (9)$$

$$J_e = R'_{\gamma,2D} \cdot J_{principal} \cdot R_{\gamma,2D} \qquad (10)$$

By accounting for the distortions of all the elements a ray passes through, we can determine the total polarization distortion (J_T) that each single ray experiences.

$$J_T = J_e \ldots \cdot J_3 \cdot J_2 \cdot J_1 \qquad (11)$$

RESULTS AND CONCLUSIONS

We calculated the birefringence for an incoming beam at various angles of tilt, θ, with the vertical polarization defined to be in the plane of incidence. The overall QBER of the entire beam is effectively negligible for zero tilt (normal incidence), in agreement with previous work [2]. However, as the incidence angle increases, the impact of mechanical stress causes a significant QBER as seen in Fig. 2. In future work, we plan to model various system parameters such as beam aperture, and study methods to reduce or compensate for the QBER using birefringent elements. The authors would like to thank NSERC, CFI, ORF, and CSA for their funding and support.

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ELEMENTARY SCHOOL EDUCATION AND OUTREACH THROUGH THE EX-ALTA 1 CUBESAT MISSION

BY RUTH E. FERRARI, ASHLEY J. HANSEN, STEFAN DAMKJAR, CALLIE LISSINNA, ANDY KALE, DUNCAN G. ELLIOTT, IAN R. MANN, AND DAVID M. MILES

The University of Alberta (UAlberta) is creating new teaching materials that link active interdisciplinary research to student-accessible discovery learning sessions. In this paper, we present an outreach program run by members of AlbertaSat; a University of Alberta student group focused on the development of cube satellites. Cube satellites are nano-satellites developed to standards defined by a program initially developed by Consulting Professor Robert Twiggs of Stanford's Space Systems Development Laboratory [1]. This outreach program from AlbertaSat adds to teaching materials and programs already available at the University of Alberta which focus on space science and engineering. For example, the Canada/Norway student rocket program [2] uses a week-long, hands-on field course where undergraduate students instrument, launch, and analyze data from a sub-orbital sounding rocket to train them in space science and engineering as well as bridging them into graduate studies or the aerospace industry. In addition, 21 students from multiple departments and programs have worked on senior undergraduate design projects that involved components for AlbertaSat. While these programs focus on undergraduate and graduate study, the three in-school presentations (referred to as sessions) discussed in this paper provide instruction to elementary and secondary students (K-9) regarding fundamental physics concepts, experimental design, as well as project-based and hands-on laboratory skills.

Space is an interdisciplinary research area which spans all areas of science, technology, engineering, and mathematics (STEM) and fascinates people young and old. Space therefore presents an opportunity to attract students to careers in the STEM disciplines while also introducing students in the community to cube satellite development. All three sessions are based on aspects of Experimental Albertan Satellite #1 (Ex-Alta 1) and use this satellite as an anchor and concrete example of work being done in the space science industry. This UAlberta-built cube satellite was designed and built as part of the international QB50 mission (www.qb50.eu) and was launched in 2017 from the International Space Station (ISS). The sessions have been successfully delivered by undergraduate students from the University of Alberta to over 3000 students in schools throughout Edmonton. These sessions are now booked several months in advance.

SUMMARY

We present three successful classroom education and outreach in-school presentations (sessions) for grades K-9 focusing on science, technology, engineering and mathematics (STEM) that are based on the Experimental Albertan Satellite #1 (Ex-Alta 1) cube satellite.

THE EX-ALTA 1 CUBESAT MISSION

A team of UAlberta students, mentored by Faculty members from the Faculties of Engineering and Science, have recently designed, built, tested, and flown the Experimental Albertan #1 (Ex-Alta 1) spacecraft [3]. Ex-Alta 1 is a 3-unit (3U) cube satellite (or CubeSat) as shown in Fig. 1. Its structure adheres to the CubeSat Standard [4] and is designed to study space weather in Low Earth Orbit (LEO). Ex-Alta 1 will demonstrate and test the in-space functionality of new university-built spaceflight hardware, including a miniature magnetic field instrument [5], and it will contribute to the international QB50 CubeSat constellation mission [6] to study the lower thermosphere. Ex-Alta 1 was launched from Cape Canaveral, Florida to the International Space Station (ISS) on April 18th, 2017 and was deployed from the ISS into its own orbit on May 26th, 2017.

The educational outreach sessions created by AlbertaSat members focus on spacecraft design, solar energy and electronics, and the Northern Lights. These concepts are contextualized using short presentations on the Ex-Alta 1 mission which are discussed below.

SESSION 1: DRAW THE NORTHERN LIGHTS

The Northern Lights session is designed for grades K-2 (ages 5-8). In this session, presenters introduce the Earth's magnetic field and describe how it acts like a force field by protecting the Earth from the solar wind which continuously flows from the Sun, especially during extreme

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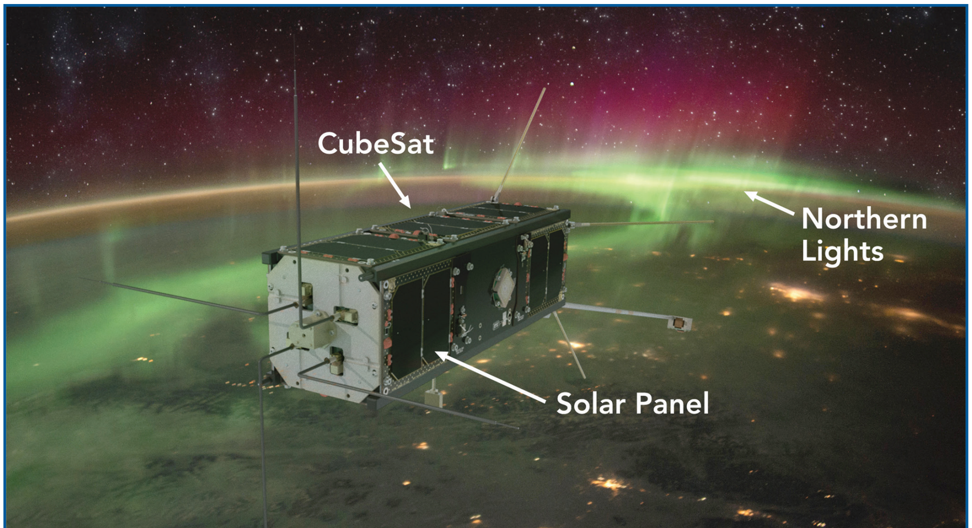

Fig. 1 Artist rendition of Ex-Alta 1 showing the CubeSat, solar panels, and the Northern Lights, the three topics that anchor our classroom activities.

events following strong solar activity such as coronal mass ejections (in which the sun releases a cloud of particles) and solar flares. Students learn how the interaction of the solar wind with the Earth's magnetic field causes disturbances in the field, resulting in particles striking the Earth's atmosphere near the poles, and producing the Northern Lights (Fig. 2, top). Students demonstrate their understanding by painting or drawing their own image of the Northern Lights (Fig. 2, bottom), including the different colours that occur at different altitudes. As part of our efforts to create an interdisciplinary and well-rounded program, students are encouraged to be thoughtful when creating their images and to include more than the minimum requirements. For example, some students choose to include the Sun and solar wind in their painting.

This session has been well-received by teachers, eliciting feedback such as "learning about solar flares hitting the [magnetic] field to make northern lights encouraged deep thinking from our young kindergarten children." [7]

ACTIVITY 2: DESIGN A CUBESAT

The CubeSat design session is aimed at students from grades 3-6 (ages 8-12), however it has been taught from kindergarten to grade 8. The presenters begin by outlining important factors to be considered when planning a space mission and explain typical CubeSat requirements. Students are then asked to sketch their own CubeSat (Fig. 3) using 10 cm × 10 cm × 10 cm cubic units. Their cube satellites may range in size from a single unit (1U) to up to twelve cubic units (12U). Students also consider function and placement of the components and the conditions in space during a discussion of the following components: on-board computer, radio, Global Positioning System (GPS), attitude determination and control system (ADCS), antenna, solar panels, and battery pack. Students must also plan an experiment to test a hypothesis with their spacecraft mission. This session is the most popular of our offerings due to its practical focus on experimental design.

ACTIVITY 3: SOLAR ENERGY AND CIRCUIT DESIGN

The Solar Energy and Circuit Design session is designed for students in grades 6-8 (ages 12-14). Students learn about energy and its forms, conversion, and storage through the use of two photovoltaic cells (solar panels) to power a light emitting diode (LED). The activity implements scaffolding, an instructional method to support learning where complex concepts are built up through simpler examples. Students work through two stages of circuit design with increasing complexity (Fig. 4, top) as they assemble small solder-less breadboard electronics kits (Fig. 4, bottom) that include the required components.

In stage 1, students connect two photovoltaic cells (Fig. 4, PV1 and PV2) in series with an LED (Fig. 4, D1) and a current limiting resistor (Fig. 4, R1, 1000Ω). The LED will shine when the photovoltaic cells are exposed to light, showing how solar energy hitting the cells is converted to electricity in the circuit and back into light emitted by the LED. Students cover the photovoltaic cells and observe that the LED will not shine without its energy source. In stage 2, a few additional components are added to demonstrate energy storage. A capacitor (Fig. 4, C1, 100 μF), and a current limiting resistor (Fig. 4, R2, 100 Ω) are added to store electrical energy, and a switch (S1) is added so that the LED can be turned off, allowing the capacitor to become fully charged. Students store energy by exposing the photovoltaic cells to light with the switch open. After a few seconds, the students cover the photovoltaic cells and close the switch, powering the LED with the energy stored in the capacitor. At the end of the lesson, the students have built a useful circuit with inexpensive components by following a simple progression of steps.

PEDAGOGY & IMPLEMENTATION

All three sessions are designed using principles of inclusive education [8] and are provided free of charge. These sessions use the excitement of space exploration and specifically the Ex-Alta 1 satellite as illustrative examples to motivate students,

Fig. 2 (Top) Reference images and diagrams on the board at a Northern Lights session. (Bottom) Kindergarten students drawing the Northern Lights. The students have selected the order of the colours after discussing how different emissions cause different colours at different heights. Photo provided courtesy of the Roberta MacAdams School in the Edmonton Public Schools district.

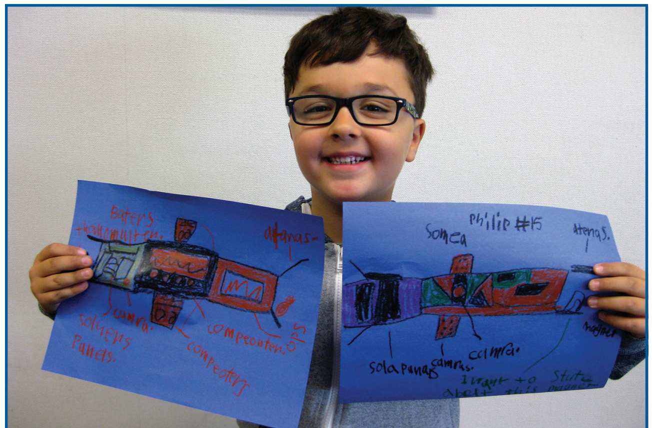

Fig. 3 A Grade 2 student's design of a cube satellite that would take images of the Earth from space. Photo was provided courtesy of Lynwood School in the Edmonton Public Schools district.

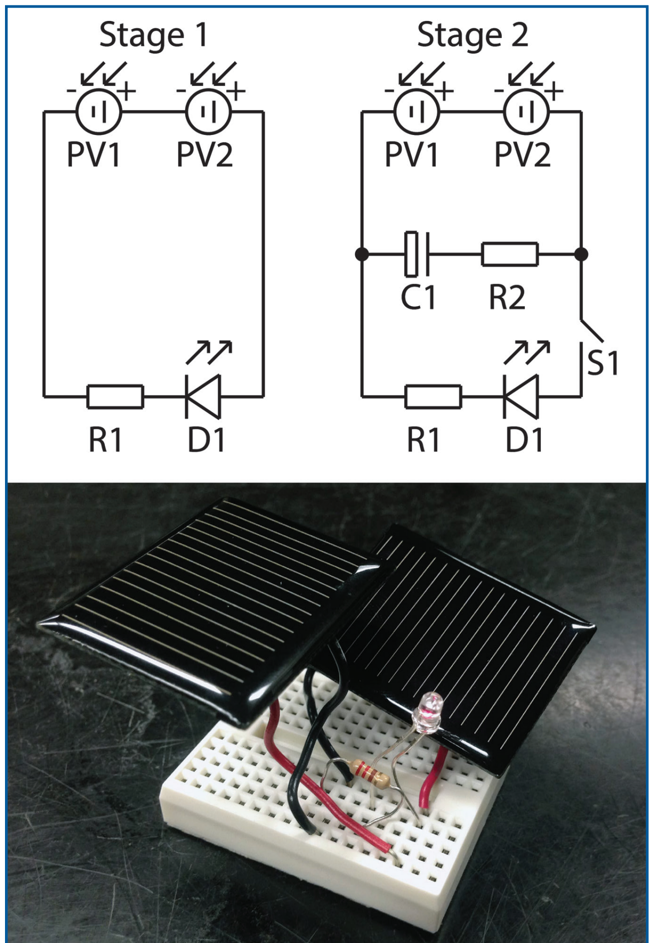

Fig. 4 (Top) Schematic of the simple Stage 1 circuit and the more complex Stage 2 circuit. (Bottom) Completed solar powered LED stage 1 circuit implemented in a small breadboard.

while avoiding the potentially high costs often associated with field trips and in-school presentations. All required supplies (electronics, paper, paint, and paintbrushes) are provided by the AlbertaSat project which is funded by a combination of grants, crowdsourcing, and internal University of Alberta funds. This minimizes the barrier to entry, allowing students from schools in low-income neighbourhoods to be reached. Furthermore, the practises of inclusive education [8] are applied by using multiple methods to teach the material. Each session begins with a short lecture paired with a visual presentation, followed by a kinetic activity (drawing, painting, or assembling) to reinforce the information and fine-tune motor skills. Lecturing and then having students work through an activity helps students understand abstract ideas (such as solar energy or the Northern Lights) by providing them with concrete examples [9] that they can examine. For example, putting together a circuit shows students in a tangible manner how electricity flows from a solar cell to power an LED. These topics are often completely new to students so the sessions implement scaffolding [10] through step-by-step instruction, exemplars, and simple to complex instruction in which students complete one task and the a more complex version of the same task. As an example of scaffolding, in the session on designing CubeSats, students are walked through the requirements and provided an exemplar to help students understand the requirements of this task. The scaffolding in our sessions helps prevent cognitive overload [11] by ensuring students do not get overwhelmed by the new information and level of detail and complexity of each activity.

OUTCOMES

The sessions outlined above are interdisciplinary and give students the opportunity to engage with Alberta's science [12] and art [13] curriculums (Table 1). For example, the Northern Lights activity is aligned with the art curriculum and uses a space science motivation. Spacecraft design is used as an anchor application in the CubeSat design activity to align it with the elementary science curriculum. The session on solar energy encourages further development of students' problem solving skills, as students must work in groups to fix any errors in their circuit. The sessions help students build practical skills such as project planning and group cooperation as "through teamwork they learn that planning, communication, cooperation and flexibility are important to the overall result, even though parts of a task can be worked on individually" [12]. Furthermore, students demonstrate their ability to apply these analysis and design skills while making meaningful connections to their learning as they consider real-world implementation and feasibility in their CubeSat blueprints or circuit designs.

The sessions have been delivered by undergraduate students at the University of Alberta to over 3000 students in the Edmonton area since September 2014 through presentations at elementary schools, junior high schools, and summer camps. In addition, our program has reached over 2000 students and professionals through events such as ScienceFUNday [14], the 7th Annual CubeSat Symposium [15], Science Literacy Week, and the Greater Edmonton Teacher's Conference Association [16]. The program has been exceptionally well-received; teachers who provided feedback via a standardized questionnaire that focused on rating aspects of the program gave it an average overall score of six out of seven. The program received a four out of five regarding overall "effectiveness" and a 4.6 out of five for "would recommend this program".

FUTURE WORK

AlbertaSat's educational outreach program was developed and delivered in parallel with the design and construction of the Ex-Alta 1 spacecraft. Ex-Alta 1 is now operating on-orbit and students and professors have begun work on the development of concepts for the follow-on Ex-Alta 2 mission. We are currently expanding our education outreach program to include sessions

TABLE 1

Mapping of how the three activities meet outcomes and purposes set out by the Alberta art [13] and science [12] curriculums.

NORTHERN LIGHTS (GRADES K-2, AGES 5-8)	CUBESAT DESIGN (GRADES 3-6, AGES 8-12)	SOLAR ENERGY (GRADE 6-8, AGES 12-14)
SCIENCE – GRADE 1, OUTCOME 5:	**SCIENCE – GRADE 3, OUTCOME 3, FOCUS:**	**SCIENCE – GRADE 5, OUTCOME 5-6:**
Identify and evaluate methods for creating colour and for applying colour to different materials. … identify colours in a variety of natural and manufactured objects.	Identify the purpose of the object to be constructed: What is it to be developed? What is it for?	Construct simple circuits, and apply and understanding of circuits to the construction and control of motorized devices.
ART – GRADE 1 AND 2, PURPOSE 5:	**SCIENCE – GRADE 5, OUTCOME 4:**	**SCIENCE – GRADE 5, OUTCOME 5-4:**
Students will create an original composition, object, or space based on a supplied motivation.	Demonstrate positive attitudes for the study of science and for the application of science in a responsible way.	Demonstrate that a continuous loop of conducting material is needed for an uninterrupted flow of current in a circuit
	Science – Grade 6, Outcome 1-3:	Science – Grade 6, Outcome 1-3:
	Construct, with guidance, an object that achieves a given purpose, using materials that are provided.	Construct, with guidance, an object that achieves a given purpose, using materials that are provided.

built around Ex-Alta 2 and creating sessions for high school classes. Due to demand for our sessions, we are developing teaching resources for teachers which will include our session plans, potential assessments, extension activities, and resources. These teaching resources aim to bring our program into schools located outside of the Edmonton area, or into schools whose schedules do not allow for a session to be hosted during class time. We also hope these resources will be of use to teachers who want to use parts of our sessions in lesson plans which address the relevant curricular elements in their classrooms (cf. Table 1). As part of the development of these resources, we recently presented at the Greater Edmonton Teachers' Convention Association (GETCA) [16] on March 2nd, 2017 and hope to attend in 2018. We also intend to present at professional development days for teachers in Edmonton. Teachers interested in utilizing the described teaching materials or having AlbertaSat present at a school should visit https://albertasat.ca/educational-outreach/ or contact the corresponding author.

ACKNOWLEDGEMENTS

Ex-Alta 1 is undertaken with the financial support of the Canadian Space Agency under grant 14SSTQB50. This project has received funding from the European Union's Seventh Framework Programme for Research and Technological Development under grant agreement 284427. This publication reflects the views only of the authors, and the European Union cannot be held responsible for any use which maybe made of the information contained therein. D.M. Miles was supported by a Canadian NSERC PGSD2 graduate scholarship and Faculty Start-up funding from the University of Iowa. Support was also provided through NSERC Discovery Grants. Figure 2 was provided courtesy of the Roberta MacAdams School in the Edmonton Public Schools district. Figure 3 was provided courtesy of Lynwood School in the Edmonton Public Schools district. We thank Prof. Kathryn McWilliams for providing helpful feedback on an early copy of the manuscript.

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Congratulations

2018 Prize Winners / Gagnants des Prix 2018

University Prize Exam Results 2018 – *Résultats de l'examen du prix universitaire 2018*

The 2018 examination was coordinated by the Department of Physics at the University of Toronto and was held on March 13, 2018. The examination was written by 86 students from 15 universities/colleges./ *Cette année, 74 étudiants de 16 universités ont participé au concours universitaire qui a eu lieu le 7 février 2017 et qui était administré par l'Université de Toronto.*

Hanzhen Lin	**First prize/premier prix**	**University of Toronto**
Chan Gwak	**Second prize/Deuxième prix**	**University of British Columbia**
Pedram Amani	**Third prize/Troisième prix**	**University of British Columbia**

4. Hiromitsu Sawaoka	University of Toronto
5. Andrew Gomes	University of Toronto (tie)
5. Hong Zhe Chen	University of British Columbia (tie)
7. Stefan Divic	University of Toronto (tie)
7. Matthew Ward	University of British Columbia (tie)
9. Anqi Mu	University of Toronto
10. Miles Cranmer	McGill University

CAP High School Prize Exam – *l'examen du secondaire ou collégial de l'ACP*
2018 National Winners – *Gagnants 2018 à l'échelle nationale*

First prize / *Premier prix*	Guo Ming Zheng, Richmond High School, Richmond Hill, ON
Second prize / *Deuxième prix*	Ming Yange Ye, Bayview Secondary, Richmond Hill, ON
Third prize / *Troisième prix*	Pedram Amani, West Vancouver Secondary, West Vancouver, BC

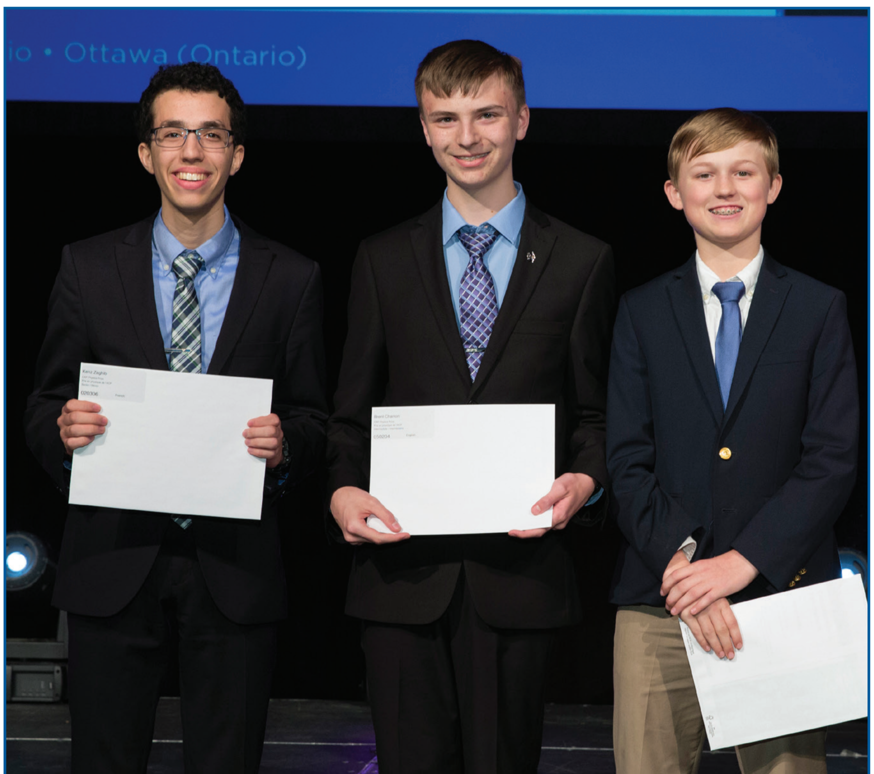
2018 Canada-Wide Science Fair – *2018 Expo-sciences* Pan Canadienne

The 2018 Canada-wide Science Fair was held from May 12-19 in Ottawa, ON. This year the CAP sponsored prizes at each of the "senior", "intermediate" and "junior:

Senior CAP Physics Prize – Kenz Zaghib Longueuil, QC

Project: Nouvelle approche vers la synthèse de nanocatalyseurs pour la production d'H2

Biography: Kenz Zaghib, étudiant en sciences de la nature, profils santé et sciences pures, au Collège Jean-de-Brébeuf à Montréal, en est à sa deuxième participation à l'Expo-sciences pancanadienne. Ce passionné des sciences est membre des clubs de mathématiques et de chimie de son école ainsi que du comité éditorial de la revue de sciences Perceptum. Il a eu la chance de suivre des stages en microscopie électronique et en électrochimie dans des universités, stages où il a développé



2018 CWSF prize winners (from left to right): Kenz Zaghib (senior), Brent Charron (intermediate) and Henry Mullins (junior).

un intérêt marqué pour la recherche de catalyseurs de nouvelle génération, efficaces et à base de métaux peu coûteux afin de remplacer le platine et l'iridium. Ces catalyseurs ont le potentiel de permettre l'implantation à plus grande échelle de technologies connexes à l'électrolyse de l'eau, telles les piles à hydrogène. Kenz Zaghib s'intéresse également à l'emploi de simulations assistées par ordinateur pour prédire les propriétés des matériaux et s'est interrogé sur leur déploiement dans la recherche de catalyseurs. Dans le futur, il aimerait explorer l'application des catalyseurs élaborés dans des piles à hydrogène, une technologie verte prometteuse. Il recommande aux étudiants désireux de se lancer dans une expo-sciences de consulter des experts pour enrichir leur projet et bénéficier de leurs judicieux conseils.

Abstract: Les catalyseurs sont essentiels en vue de l'implantation des technologies d'électrolyse pour la production d'hydrogène, vecteur d'énergie verte. Cependant, la plupart des catalyseurs sont composés d'iridium et de platine, des métaux nobles. Ce projet présente une approche intégrée en matière d'élaboration de nanocatalyseurs efficaces et peu dispendieux ens'appuyant sur des simulations quantiques par DFT. Les prédictions théoriques de structure électronique sont ensuite déployées.

Intermediate CAP Physics Prize – Brent Charron, Maidstone, ON

Project: Conformable LEECs using Elastomeric Emissive Materials

Biography: My name is Brent Charron. I am a fifteen-year-old, Grade 10 student at Vincent Massey Secondary School located in Windsor, Ontario, Canada. I have been participating in regional science fairs for the past seven years. I have been chosen to represent my region at two Canada Wide Science Fairs and was awarded a gold medal at both. My project deals with the fabrication of a novel flexible light emitting device known as a LEEC. After learning about semi-conductors, I was inspired to create this device. I would like to look at additional elastomeric emissive materials to determine if improved conductivity and flexibility can be achieved. In addition to science, I also enjoy playing piano and trumpet and I am a member of the Windsor Symphony Youth Orchestra. I also enjoy swimming, Aikido, and painting. I would encourage anyone who is considering developing a science fair project to find an area which is of interest and start looking at the literature to see what work has already been done and build off of that. In the future, I would like to pursue a career in chemical engineering.

Abstract: My project involves the fabrication of light emitting devices that are flexible, or even stretchable. Theses devices have many uses including biomedical applications in which they could be integrated into the body to monitor blood glucose levels for people who are diabetic, or for use in electronic environments such as foldable cell phones. Various substrates were experimented with to achieve flexibility while maximizing conductivity.

Junior CAP Physics Prize – Henley Mullins, St. Johns, NL

Project: Rockets are Such a Drag

Biography: My name is Henley Mullins. I am a grade 7 student at St Bonaventure's College in eastern Newfoundland. My interests include tinkering and rockets (following SpaceX). I am also an avid reader, play the string bass and love the outdoors. I want to be a mechanical engineer when I grow up. I believe that SpaceX and other private space companies will lead humanity into the future of space.

Abstract: The project compared the aerodynamic efficiency of three rockets (Falcon Heavy, Space Launch System and New Glenn). A wind tunnel was built that could test 3D-printed model rockets at speeds of up to 30 kilometers per hour. Drag force was measured and the aerodynamic drag coefficient was calculated.

> The 2018 Canada-Wide Science Fair will be held in Ottawa, ON.

2018 CAP Medal Recipients

2018 CAP Medal Recipients / Lauréats des médailles de l'ACP de 2018

The CAP is very pleased to recognize its 2018 medal recipients. Please visit the website below for the list of medal recipients with a link to the detailed citations and any remarks submitted by the recipient following the receipt of the award. An interview with Teaching medal recipient, Sarah Johnson, is included in this issue. An interview with the Lifetime Achievement recipient, Jean-Michel Poutissou, will appear in the 2019 theme issue commemorating TRIUMF's 50th anniversary celebrated in 2018.

L'ACP est très heureuse de reconnaître ses récipiendaires de médailles 2018. Veuillez consulter le site web ci-dessous pour obtenir la liste des récipiendaires de médailles, ainsi qu'un lien vers les citations détaillées et les remarques à la suite de la réception de la récompense. Une intervue avec Sarah Johnson, récipiendaire de la médaille d'enseignement, est incluse dans ce numéro. Une intervue avec Jean-Michel Poutissou, récipiendaire de la médaille carrière de l'ACP, paraîtra dans le numéro thématique 2019 commémorant le 50e anniversaire de TRIUMF, célébré en 2018.

https://www.cap.ca/programs/medals-and-awards/medal-recipients-year/ (choisi "francais" dans la boîte bleu pour voir l'annonce en français)

CAP-CRM Prize in Theoretical and Mathematical Physics Prix ACP-CRM de physique théorique et mathématique

Ariel Zhitnitsky
University of British Columbia

For his ground-breaking contributions to theoretical high energy physics, in particular for his development of the "invisible axion" model, and for his work on the vacuum structure of non-Abelian gauge theories.

Pour son apport novateur à la physique théorique des hautes énergies, en particulier pour la conception du modèle de « l'axion invisible » et pour ses travaux sur la structure à vide des théories de jauge non abéliennes.

Médaille de l'ACP-INO pour contributions exceptionnelles en photonique appliquée

Tigran Galstian
Université Laval

For the development and successful transfer of the "crystal lens" technology to the industry, for applications in cellphone cameras and dynamic lighting.

Pour la conception et le transfert fructueux de la technologie « lentille à cristal » à l'industrie en vue d'applications dans les caméras de cellulaires et l'éclairage dynamique.

Médaille Brockhouse

Andrea Damascelli
University of British Columbia

For his important contributions and leadership in the investigation of quantum solids and surfaces, in particular for what concerns strongly-correlated systems, through the design and development of unique angle-resolved photoemission spectroscopy (ARPES) instruments.

Pour son apport novateur et son leadership dans l'étude des solides et surfaces quantiques, notamment pour ce qui est des systèmes fortement corrélés, par la conception et le développement d'instruments uniques de spectroscopie photoélectronique avec résolution angulaire.

Médaille de l'ACP pour l'excellence en enseignement de la physique au premier cycle

Sarah Johnson
Simon Fraser University

For her overall accomplished contributions to teaching. In addition to her sustained excellence in classroom teaching, Sarah has been active in developing programming to ensure student success, such as a volunteer Peer Tutoring Program in Science & Math and Early Intervention Tutorials for students at risk of failure in first-year classes. She has been active in curriculum design, such as the development of a Studio

Physics version of first-year physics and was an early adopter of iClickers, which are a tremendous tool for improving student engagement during lectures. Sarah has a stellar record of community outreach in general (e.g., "Science Spooktacular"), and her efforts in encouraging young women to go into physics (e.g., "Girls Exploring Physics"), in particular.

Pour l'ensemble de ses contributions à l'enseignement. Outre son excellence soutenue dans ses cours, Sarah a été active à élaborer des programmes afin d'assurer la réussite des étudiants, tel un programme volontaire de tutorat par les pairs en science et mathématiques et des tutoriels d'intervention précoce pour les étudiants risquant d'échouer leur première année de cours. Elle a été active dans la conception de programmes, telle une version de la physique en studio de première année en physique, et elle a tôt fait d'adopter des systèmes de réponse interactifs, outil remarquable pour améliorer l'engagement des étudiants pendant les cours. Sarah a un bilan exemplaire de sensibilisation en général (p. ex., « Science Spooktacular ») et, en particulier, elle s'efforce d'encourager les jeunes femmes à se diriger en physique (p. ex., « Girls exploring Physics »).

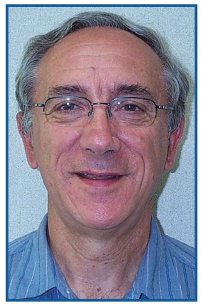
Médaille Herzberg

Alison Lister
University of British Columbia

For her many leadership roles in the ATLAS Collaboration and for the breadth of her contributions in particle physics, including the discovery of the Higgs boson, precision measurements of the top quark, new limits on physics beyond the Standard Model, and innovative efforts in using machine learning in experimental particle physics.

Pour ses nombreux rôles de leadership dans la Collaboration ATLAS et pour l'ampleur de ses contributions en physique des particules, dont la découverte du boson de Higgs, les mesures de précision du quark top, les nouvelles limites à la physique au-delà du modèle standard et ses efforts novateurs dans l'utilisation de l'apprentissage-machine en physique d'expérimentation des particules.

Médaille de l'ACP pour contributions exceptionnelles à la physique



Jean-Michel Poutissou
TRIUMF

For his lifelong contributions to the field of experimental particle physics. Jean-Michel's decades-long research career includes pioneering work on precision measurements of rare decays and their implications for the Standard Model, groundbreaking work on the use of off-axis neutrino beams for studying neutrino oscillations. Moreover, having served as TRIUMF's Associate/Science Director for 21 years, he's dedicated decades of outstanding leadership and stewardship in transforming TRIUMF into a world-class multidisciplinary research laboratory.

Pour contributions exceptionnelles de carrière à la physique, pour l'apport de toute une carrière au domaine de la physique d'expérimentation des particules. Les dizaines d'années de recherche de Jean-Michel comprennent des travaux innovateurs en mesures de précision des désintégrations rares et de leurs implications pour le modèle standard, ainsi qu'en utilisation de faisceaux de neutrinos hors axe dans l'étude des oscillations de neutrinos. De plus, après 21 ans à titre de directeur adjoint des sciences chez TRIUMF, M. Poutissou a consacré des dizaines d'années de leadership et d'intendance exceptionnels à transformer TRIUMF en un laboratoire de recherches multidisciplinaires de classe mondiale.

Médaille Vogt de l'ACP-TRIUMF

Rituparna Kanungo
Saint Mary's University / TRIUMF

For her leadership and contribution in the field of direct reaction and halo-nuclei studies with rare isotopes, including ground breaking discoveries of doubly-magic oxygen isotope.

Pour contributions à la physique des particules subatomiques, pour son leadership et son apport au domaine des études de la réaction directe et des noyaux à halo à isotopes rares, dont la découverte révolutionnaire de l'isotope de l'oxygène doublement magique.

Interview with Sarah Johnson, Recipient of the CAP's 2018 Medal for Excellence in Teaching Undergraduate Physics, September 2018 (by Daria Ahrensmeier)

Daria: Congratulations on your CAP teaching medal!

Sarah: Thank you.

Daria: Can you describe to us the work for which you received it?

Sarah: I guess I got it for multiple different things. I got it for my teaching undergraduates, I believe, for introducing innovative teaching methods to my classes at SFU. I also got it for, I believe, for all of my outreach activities. I've been heavily involved in outreach at SFU since I started there, various different events like workshops for girls called "Girls Exploring Physics", twice a year. We also run a big Halloween themed event for children in kindergarten through sixth grade, and I've also worked on a variety of other outreach projects.

Daria: That's pretty impressive. What got you interested in this work, specifically the teaching?

Sarah: Well, I think it was mostly when I was finishing up my PhD and trying to figure out what I wanted to do. I had done some TA'ing and I had started doing outreach, too, at that point, and I realized that I really enjoyed the teaching and the outreach and that kind of work much more than I enjoyed the research. I mean, I liked the research, but I liked the teaching more. I felt like I was better at the teaching than I was at the research. And so I started in the United States, I actually took a sabbatical replacement position at a small college in upstate New York. That sort of cemented it for me that this was something I would enjoy doing as a career. I did go off and then do a postdoc for a year. But then after that, I came back and worked at several different liberal arts colleges in the United States from 1994 until 2005, which is when we moved to Vancouver. We moved to Canada because of my husband's work, and I learned pretty quickly that Canada doesn't really have liberal arts colleges. At liberal arts colleges, you do a lot of teaching and a little bit of research, but these don't really exist in Canada. But I did see that there were big universities like SFU that had teaching faculty positions and I thought, well, that would be an interesting challenge to devote myself purely to teaching and also to teach large classes. The biggest class I had taught up to that point was 70 students, and I thought it would be an interesting challenge to try and teach 200+ students. So when I saw that Simon Fraser was looking for somebody, I was very excited. They were also specifically looking for somebody to teach their studio physics course, and I had a little bit of experience with that. I had just started getting interested in PER-based teaching and had heard about workshop physics, and I tried it out a little bit at La Verne where I was teaching before I moved to SFU. So the idea of being able to help develop a course like that was also very exciting.

Recipient of the 2018 Teaching Medal / Lauréate de la médaille d'enseignement 2018:

Sarah Johnson

Daria: It's so nice to have somebody call teaching - like teaching a large class or developing something new - a challenge in a good sense, in a positive sense. Now I'm curious: The liberal arts colleges in the U.S., do they just put more emphasis on the teaching or is the teaching handled differently as well?

Sarah: Well, the teaching loads are higher than you would expect for someone at a research university. Because of that, when they hire for professors at liberal arts colleges, they very specifically look at your teaching ability and whether you're interested in teaching, whether you have any teaching experience, and if you are good at it. They'll sometimes in the interview even have you do a lesson, to demonstrate your teaching ability. And then the expectation for research is just much lower. They realize that because of the heavier teaching loads, most people can only do any significant research in the summers. And so they don't expect the same kind of research output that a research university would expect.

Daria: But is the level of teaching the same as at a research university? Because of the label "liberal arts college", you might think that it's different?

Sarah: No, it's just what they call them in the United States. It's still undergraduate. Most liberal arts colleges don't have graduate programs, so you're only teaching undergraduate courses. But otherwise, the coursework is the same level, at least within the U.S. There are some differences, I think, between the level in the U.S. colleges and universities and Canadian universities, having to do with the coursework that

Canadian kids take in high school. I think they go a little bit further in high school than American students do.

Daria: Do you notice that in your classes?

Sarah: I do notice that, yes. For example, in B.C., our science students all come in having taken physics 11 and physics 12. Whereas in the United States, I would get students who had taken no physics in high school at all. Some might have taken one course, this was a while ago. Nowadays, I think more students are taking AP physics because there's been this explosion of people taking more AP courses over the last 20-30 years in the United States. But I still think there is a reasonable number of students you see in college that have taken no physics at all but are studying science, which always kind of amazes me. So you definitely notice a difference here, where the students have taken both physics 11 and physics 12.

Daria: Now, let's go back a little further. Did you yourself attend a liberal arts college?

Sarah: No, I didn't. I attended a large state university in New York, a lot like SFU actually. A little bit smaller than SFU but similar. It even looked a lot like SFU: large concrete buildings [it was SUNY Albany].

Daria: And what got you interested in physics? Were you already interested in physics when you started university?

Sarah: No. No, I started actually in chemistry. But then I had an amazingly good first year physics instructor who just made it really exciting and interesting. He was funny. He used to wear this tie that said, "Think" in seven different languages or something. I mean, my chemistry teacher was fine. I was in a small class just for chemistry majors, but he wasn't very inspiring and I had a not so great experience in the chemistry lab. I had a very intimidating TA in my first semester, and so the combination of the chemistry not being terribly exciting and having an exciting, interesting physics class played a role. And I realized how much math there is in physics, and how much I like math and I like using math to solve problems. You don't use as much math as you do in physics anywhere else, at least not in first year chemistry. That was also something I thought I'd be much happier with, less memorization and more solving problems with math.

Daria: This inspiring instructor in first year, is that somebody you think of when you teach? Is he a role model or did he just have a good influence on you?

Sarah: No. Just a good influence, I think. I don't have a lot of memories of it — I remember him doing some demos. It was a pretty traditional lecture class, you know, about a hundred of us. I remember doing a lot of tutoring. I tutored my fellow classmates a lot, in first year physics. So I must have had a good preparation in high school, I guess. But honestly, I didn't actually enjoy my high school physics class all that much. I enjoyed my high school chemistry, my AP I think I started in chemistry because I had a really good teacher in AP chemistry.

Daria: Did you have any mentor on the teaching side when you started teaching?

Sarah: I had some really good colleagues when I got my first tenure track job at Geneseo. I had some really good colleagues there. They have quite an extensive peer evaluation system where the faculty sit in on each other's classes and give you feedback on your teaching. That was quite useful. It was a little stressful at first, but it turned out that it was very much not summative but formative, very much supportive and giving you constructive feedback, so that was good.

Among my colleagues in Geneseo there were some very good teachers, very good about not just teaching but creating a welcoming, friendly physics program. They have an amazing track record of recruiting people to be physics majors and running a program that's supportive of lots of different students pursuing physics. They e-mail or call undeclared entering freshman and say, "have you ever thought about being a physics major?" They would actually convince a few students to give it a try, which I was very impressed with.

Daria: Is that something you think Canadian universities could do, too?

Sarah: Yes.

Daria: Does it require a lot of money?

Sarah: No, it doesn't. It does require somebody being willing to give you the list of undeclared entering students. I think we should not restrict our view of who might be successful in physics and not expect all of our students to be A students. There's nothing wrong with getting a B or a C. Those students won't go to graduate school, but it doesn't mean that they can't go out and be productive. Earning low B's, high C's in physics is still quite an accomplishment, I think, at least for the upper division classes. Those are not easy classes to pass. I worry sometimes that people expect all our physics majors to be like we were. We're the 5 per cent or less of physics students that go on to become physics faculty.

Daria: Do you think we need to do more for these students that are not going towards a career in physics?

Sarah: I think we do, actually. I really like the Phys 201 course here at SFU, the new course where we talk about careers and other options for the students. They take it in their second year

Daria: I've heard it in a workshop recently that the American universities seem to be more aware of these diverse students and supporting them more. Is that something that you have experienced? Was there something else that you think that the U.S. system does better than the Canadian system?

Sarah: I don't know if that's universal across the U.S. I think Geneseo was very good at it. When I was at La Verne, it was such a small program, me and one other guy. We did what we could. I would hire all my physics majors to help set up labs. That's something I did when I was an undergraduate, I set up the first year labs. It was a two-hour-a-week job, but it got me involved in the department. I think we could do more of that, and I think SFU is trying. We have various programs like "Adopt a Physicist" and other things where we try to get students more involved. So I don't think United States schools are universally better at that than Canadian schools. I think it varies a lot with the personality of the departments and the sizes of the departments.

Daria: Now, coming back to your work as an instructor. Where do you get your inspiration and your new ideas? Do you look around, see what's needed and then come up with something?

Sarah: I get lots of inspiration from AAPT (American Association of Physics Teachers) meetings. Now I go twice a year because I'm the B.C. representative to the AAPT. But even before that, I was trying to go when I could. It's easier now that my kids are older. I'm always amazed at these people in physics education research and the ideas they come up with, and the things they've learned over the years about how students learn, or the best way to present material so that they can learn more. I go to the talks and also just talk to people, you know, networking with colleagues who teach physics, both people at those meetings and also local people. People like my friend Marina at UBC, and also you, and other people at SFU. So I've been trying different things. I go to these meetings and then I have this new idea … I really want to try this now! And then I think I'm really lucky that SFU is some place where I've been able to try all these new things and see which ones work with our students and our classes.

The thing that bothers me the most right now is students not putting the time in on the homework, giving up and googling the answer. I just feel like they're missing out on all this learning by not struggling with the problems.

Daria: Can you expand a little bit on that? Why do you think SFU is a place that is welcoming to those innovations?

Sarah: Some of it is the personality of the department, I think. All the department chairs have been very supportive about letting me try new things. When I first got to SFU, we made the switch from open labs to tutorials in most of our first year courses. Just presenting the evidence that tutorials are valuable for student learning, it was relatively easy to convince the department. I've been on the Physics Undergraduate Curriculum Committee for pretty much the entire time I've been at SFU. That's a place where you can present new ideas, and I think as long as you've got some evidence that it's valuable, people are willing to try it. We have a reasonable amount of autonomy and flexibility, and great support from the technicians, too, when you want to do new demos. I introduced a bunch of interactive lecture demonstrations (ILDs). When I came back from an AAPT meeting and said I want to do this and that, it meant not just changing the course a little bit, but requiring one of the technicians to help me. Jeff Rudd, who is an amazing technician we used to have, did all the work. He basically built all these demos for me. We had a lot of the equipment already, but we had to make it fit with the worksheets that went with the ILD's. Jeff Rudd was very inspiring. He knew a lot about teaching and a lot about what demos would work, where and when. He wrote down every demo I did, every time I taught so the next time I taught, he had a list. I feel like teaching is valued here, it's not considered secondary at all.

Daria: Going one step further, doing education research, is that supported as well?

Sarah: Yes. I mean, as much as it can be when your primary job is teaching. My job is 80 per cent teaching, 20 per cent service. So I do small amounts of educational research, sort of, on my own classes. The university offers what are called teaching and learning grants, and I've had two smaller teaching and learning grants to try out different pedagogical changes in my classes. The grants were very helpful to hire research assistants to help analyze data. And then I also got a bigger grant: I was a Dewey Fellow in the Institute for the Study of Teaching and Learning in the disciplines here. I used that money to expand a tutoring program I had started in physics to include chemistry and math and biology. I got some colleagues together, and we did a study on the effectiveness of the program with that money. I hired two different research assistants, one from communications and one from physics, to help me with analyzing the data. The physics person did the numbers, and the communications person did things like focus groups and surveys, things that I'm less familiar with. So I think there's definitely university support for doing projects like that.

Daria: Did you write up your results?

Sarah: It's not published but it is online: https://www.sfu.ca/istld/faculty/grant-programs/projects/ISTLDDeweyFellows/G0155.html.

Daria: Now, speaking of money. If, say, the department, the university, maybe the Faculty of Science received a large amount of money, what would you like to use it for, regarding teaching?

Sarah: Well, one thing I really want to try is learning assistants in the big first year classes. It's a bit like the peer tutoring, except that they're paid, and they come back after taking their undergraduate class and basically help to teach the class. They act sort of like TAs, but they come in during the big first year classes, so that even if you have 200 students in your class, you could have them do group problem-solving because you would have enough people walking around answering questions. You would be able to make it like a big tutorial session, you could truly flip the classroom. I mean nowadays, we do some flipping, but the things we do in class are still mostly traditional. We make it interactive with clickers and things like that, and interactive lecture demos, but it's hard to make it truly flipped. But if we had these learning assistants come in, then I could do a lot more in terms of hands-on problem-solving with a large class. I'd really like to try that because there are quite a few universities in the United States now who do the learning assistant thing, and I go to their talks at AAPT meetings and it's really inspiring. They're often linked up with their teacher education programs, and they have a lot of the students who are learning assistants go on to become physics teachers. We don't seem to produce very many physics teachers here, and I don't see why we couldn't produce more. I think there is, to some extent, a need for physics teachers. That would be a side benefit, but the main benefit would be improving the big first year classes.

I also really would like to see the peer tutoring program go university-wide. I mean, ultimately, I think the university should be running a tutoring centre, where the tutors are paid and they're available to all students. Right now, I run it just for science and math, and the tutors are volunteers. We've already expanded a little bit this year: a faculty member in computer science is running the peer tutoring independently of science and math, but using the same model. One thing I really would like is our own room, a room to host the peer tutoring, because one of the most difficult parts of the whole program is scheduling the rooms and the tutors. If we had our own room, I think that would also help us with visibility. There would be a place that students would know they can go to and get help with their science and math classes.

Daria: When you think of your students, do you see a general change in student population over the years that you have been here? Are they getting more diverse or not? Are there trends?

Sarah: Not a huge change. I've been here 13 years. The only thing that's somewhat noticeable is more students coming in without physics 12. That seems to be a trend. I think they are concerned about their marks in high school and getting into university because the Canadian system, from what I can tell, is very centred on your marks for acceptance to university. In the United States, they write essays, they get letters from their teachers, there are all these other factors, not just marks. They take SATS. But here in Canada it's very much your high school marks, and so they're worried that if they do poorly in physics 12, it'll hurt their chances of getting into the Faculty of Science. I can understand that, but it's a pity. A lot of people, especially young women, are not taking physics 12 and then that closes the door on their chances for fields like physics and engineering. They can catch up if they take our physics 12 equivalent course, our physics 100, but that puts them at least a semester behind and it's hard to catch up, especially with engineering. Physics is easier to catch up, I think. But it's frustrating and I'm not sure what to do about that. I mean it would be nice if the acceptance at university took more things into account. I know UBC now has essays and I think SFU should think about expanding their acceptance criteria to look at more than just grades.

Daria: That's an interesting idea. Are there other things you can think of that you would like to do but haven't had a chance yet to do, to try?

Sarah: Well, I have study leave coming up and I want to create a new breadth course. I think the university could benefit from another physics breadth course. So one of the things I'm hoping to do on my study leave is have a look at what other people do in their breadth courses and try to come up with a good fit for me and for the university, something that students might like taking. I haven't completely decided. I've taught astronomy in the past, which is one of our big breadth courses. Astronomy is not my field, though, but I do enjoy teaching that class. I think there are lots of possibilities for topics, and I think it's an interesting challenge to teach non-scientists. I really enjoy showing them how cool physics is, and that it's really not this impossibly hard subject only for total brainiac nerds, right? It's something that they can understand. In the past, I also taught future elementary teachers and that was a fun course. We have a course like that coming up at SFU soon, which I'm excited about: it's a science course for education majors, which is starting, I believe, next fall (2019). I'm looking forward to teaching that course, too, because again, it's very rewarding to get to someone who is not at all familiar with physics and maybe even thinks physics is scary, to get them comfortable with it, enjoying it and learning new things. Like I said, it's very rewarding when that happens.

Daria: That's very true. You mentioned earlier how your inspiration and your ideas often come from the AAPT meetings. Now, this interview is for the magazine of the CAP, the Canadian Association of Physicists. Do you think there could be more collaboration between the CAP and the AAPT? Or would it just be a duplication of effort?

Sarah: I think what CAP does with the DPE is great. And I was really impressed with the sessions when I went to [the CAP Congress in] Halifax. I thought that was really great. The last CAP meeting I had gone to was a few years before that and there weren't as many DPE sessions, so I was really impressed with the quality of the speakers and everything. I can imagine trying to do a joint meeting or something. In the past, AAPT has done joint meetings with the American Astronomical Society and with the American Association for the Advancement of Science, I think. I just find AAPT meetings so valuable, and it would be great for more Canadian physics faculty and high school teachers to have the opportunity to have that experience. We could bring in some of the people who've been doing exciting things in the U.S., and then everybody who is doing exciting things in Canada could share their work. I could almost imagine doing a yearly

Canadian Physics Teacher's Conference, so do our own and model it on the AAPT. Something like that where it's all about physics education. I don't know how that would work, but I would go to something like that. It's hard because we're such a smaller population, right? But I could imagine especially if we were to do it in one of the population centres like here or Ontario or Quebec, so that it's relatively easy for people to get to. We do have a few things in Canada that are unique compared to the U.S. like the level of our students coming in.

Daria: Now, would you perhaps like to leave the readers with a puzzle or homework to think about? A really hard physics education question that bothers you, that you haven't been able to figure out yet, something that should be done maybe?

Sarah: Hmm … The thing that bothers me the most right now is students not putting the time in on the homework, giving up and googling the answer. There are so many solutions online for everything. I understand they're busy and they're stressed, and I can see why they resort to that when they get stuck. I just feel like they're missing out on all this learning by not struggling with the problems. We try to get them to do some of that hard work in tutorials or in class, like in the studio in physics, but I think they need a lot more of that, and they need to do some of it on their own at home. I have memories of sitting with my physics textbooks, going through problems, and hours of just thinking and trying things, and I feel like they don't always get that. I think some of them still do, but there's too large a fraction that isn't getting that experience. And then they're confused when they do poorly on exams, because they think that just looking at solutions is enough to understand it. I know our Math Faculty, for example, do quizzes in their classes to try and make up for that, but then they lose class time, and the logistics of giving a quiz are cumbersome. I don't know if that's the best solution for that. I'm not really sure what the solution is. I think that's one thing that has gotten worse over the years. Ten years ago, it was not really a problem, and then it started to get worse about six or seven years ago. I started to notice student with access to the solutions manuals and then it got to the point where students now come in and say "I have the solution, I found it online, but I don't understand it. Can you explain it to me?" Which is fine, but it would have been much better if they came in with "I tried this problem and I got stuck here. Can you help me?" That would be better than copying the solution. I think that's maybe one of the biggest differences for the students over the years, the internet, Google, and the ubiquity of solutions manuals to every single textbook online. It's frustrating.

Daria: Do you know if your students still read their textbooks?

Sarah: I think that some do and some don't. To be honest, I wasn't a huge textbook reader, at least not in first year. I definitely read my books a lot more when I got to the advanced levels. But I think a lot of them aren't reading their textbooks. The thing that frustrates me: it's one thing to read the textbook and not go to class, or to go to class and not read the textbook - but there are students who are doing both. They're not reading the book and they're not going to class, and I really don't know how they expect to learn the material and to do well if they're not doing either. With the FlipIt Physics, we can see how long they spend on the videos. You can see over the course of the semester that they spent less and less time watching the videos. Some of that, I think, is they're just really busy and they have other time commitments. But I do wonder if they're just not finding the videos useful or they just don't have the time.

Daria: My students told me they just don't have the time - when I showed them that I can see all the data.

Sarah: I haven't told my group yet that I can see the data. That's always interesting when you tell them that. Last time I looked, there were very few comments, and I'm going to try and encourage them to start commenting. In the beginning of the semester they commented a lot about the lecture and what they understood and what they didn't. But the last time I looked, only 8 out of 70 commented on the lecture. It always cracks me up, the ones that spent two minutes watching the lectures and then go ahead and comment.

Daria: We've been chatting for almost an hour … can you think of anything I should have asked you that I haven't asked you?

Sarah: No, I don't think so. I don't know what else you have on your list.

Daria: We covered all that.

Sarah: Wow, very impressive.

Daria: Thank you very much.

Sarah: You're welcome.

High School / CEGEP Physics Teaching Awards / *Prix ACP en enseignement de la physique au secondaire et au collégial*

2018 Winners / Récipiendaires 2018

British Columbia and Yukon / Colombie-Britannique et Yukon

Giselle Lawrence[1]
Brentwood College School
Mill Bay, BC

Giselle is a teacher who inspires and supports students' curiosity about the world around them, encourages them to ask their own questions and seek their own answers. She achieves highly engaged classes by providing students with multiple hands-on opportunities where students' voice and choice are encouraged. This teaching style allows her the differentiation required to support the success of each of her students. The use of a variety of technologies and cross-curricular activities play a key role in her approach. An example of this is the use of NASA's ISS EarthKAM program by her Physics 12 students, in collaboration with junior science and Geography 12 students, to study artificial satellites. Giselle complements her work in class with extracurricular activities such as amusement park physics field trip and UBC Physics Olympics.

Giselle is always open to share her craft with next generations of physics and science teachers as a guest speaker and as sessional adjunct professor at UBC Faculty of Education. In addition, she volunteers as Member of the Executive of the BC Association of Physics Teachers and supports the professional development of physics teachers across British Columbia. Moreover, Giselle has not allowed the distance that separates her physically from her native land, Peru, to limit her commitment to education there. As a volunteer, she has organized and run workshops on Inquiry Based Teaching in Physics for rural secondary science teachers working in impoverished areas of Peru, and for student teachers and teachers at the Instituto Pedagógico Nacional in Lima.

Giselle is an outstanding teacher not only for her diverse teaching approach and her contributions to the professional development of physics teachers and the training of future science teachers but also for her passion for teaching and her commitment to the academic growth and emotional well-being of her students.

Giselle est une enseignante qui inspire et stimule la curiosité des étudiants sur le monde qui les entoure en incitant ceux-ci à poser leurs propres questions et à chercher leurs propres réponses. Elle donne des cours très engagés en fournissant aux étudiants plusieurs opportunités pratiques dans lesquelles les voix et les choix des étudiants sont encouragés. Ce style d'enseignement lui permet la différentiation requise pour soutenir le succès de chacun de ses étudiants. L'utilisation d'une variété de technologies et d'activités extracurriculaires joue un rôle clé dans son approche. Entre autres, elle utilise le programme ISS EarthKAM de la NASA avec ses étudiants de physique 12 en collaboration avec les étudiants de sciences junior et de géographie 12 pour étudier les satellites artificiels. Giselle complète son travail en classe par des activités extracurriculaires comme une sortie éducative sur la physique au parc d'attraction et aux olympiques de la physique à UBC.

Giselle est toujours disposée à partager ses expériences avec les prochaines générations d'enseignants de physique et de sciences en tant que conférencière invitée et comme chargée de cours adjointe à la faculté de l'Éducation de la UBC. De plus, elle fait du bénévolat comme membre de l'exécutif de l'Association des enseignants en physique de la Colombie-Britannique et soutient le perfectionnement professionnel des enseignants en physique à travers la Colombie-Britannique. Giselle n'a d'ailleurs pas limité son engagement en éducation au Pérou, son pays natal, malgré la distance. En tant que bénévole, elle a organisé et dirigé des ateliers en enseignement fondés sur la recherche en physique pour les enseignants de sciences au secondaire dans le milieu rural des régions appauvries du Pérou, et pour les étudiants et enseignants de l'Instituto Pedagógico Nacional de Lima.

Giselle est une enseignante exceptionnelle pour son approche d'enseignement diversifiée et ses contributions au perfectionnement professionnel des professeurs de physique et à la formation des futurs enseignants en sciences, mais aussi pour la passion qu'elle démontre à enseigner ainsi que son engagement envers la croissance académique et le bien-être émotionnel de ses étudiants.

1. Selected to attend 2018 CERN Workshop; see report on page 147.

Prairies and Northwest Territories / Prairies et Territoires du Nord_ouest

Thana Rahim[2]
Ecole St. Patrick High School
Yellowknife, NWT

Thana Rahim started working at Ecole St.Patrick High School as a Physics teacher in August of 2006. Since that time, she has taught a variety of Science and Mathematics courses from grades 9-12. She is presently serving as Department Head for Science. Mrs. Rahim's Physics 30 classes have been successful in achieving the highest Physics diploma exam marks the the NWT for the last five years. She has been chosen to mark Physics diploma exams on three separate occasions and this year she was the NWT representative on the committee charged with creating Physics 30 Field testing material.

Thana has been the recipient of the Science Teaching Award by the Northwest Territories and Nunavut Association of Professional Engineers and Geoscientists. She was nominated by students for the Thank You For Making A Difference contest. In 2012, she won the Strong Mind, Strong North, Inspired Teaching Changing Lives Award sponsored by the NWT Department of Education, Culture and Employment. In 2018 she organized the Innovation 150, Power of Ideas Tour presentation held at St. Pat's in March.

Thana Rahim a commencé à travailler à l'École St. Patrick High School comme enseignante de physique en août 2006. Depuis ce temps, elle a enseigné une variété de cours en sciences et mathématiques des niveaux 9 à 12. Elle est présentement chef du département des sciences. Les classes de physique 30 de Mme Rahim ont réussi à obtenir les meilleures notes dans les examens de physique du diplôme aux TNO pendant les cinq dernières années. Elle a été choisie pour corriger les examens de physique du diplôme à trois occasions différentes et cette année, elle était la représentante des TNO sur le comité chargé de créer le matériel de tests sur le terrain pour la physique 30.

Thana fut la récipiendaire du Prix des enseignants en sciences de l'Association des Ingénieurs et géoscientifiques professionnels des Territoires du Nord-Ouest et du Nunavut. Nommée par les étudiants dans le cadre du concours Merci de faire une différence, elle a également remporté le Prix Esprit fort, Nord fort : l'enseignement inspiré change des vies commandité par le ministère de l'Éducation, de la Culture et de l'Emploi des TNO, en 2012. En 2018, elle a organisée la présentation de la Tournée des innovations 150 : la puissance des idées à St. Pat en mars.

Quebec and Nunavut / Québec et Nunavut

Jason Leblanc
Centre matapédien d'études collégiales
Amqui, QC

We, Jason's nominators, are very pleased to showcase the tremendous contribution to the teaching of physics made by Dr. Jason Leblanc, teacher at the Centre Matapédien des Études Collégiales (CMEC) in Amqui (Quebec) to the Canadian physicist community. We recognize Jason's unique work, since 1999, in the use of new state-of-the-art equipment for college-level physics instruction, including the combined use of interactive smart boards and the Pasco data acquisition system for experiments in classical mechanics. Dr. Jason Leblanc was the first person to successfully practise the mathematics and physics team-teaching experiment, demonstrating unprecedented openness to new teaching methods in physics education. We would also like to highlight his commitment and special attention implementing projects related to the use of "clean" energy sources, such as the combined photovoltaic-wind system project that is able to produce the energy needed to light the CMEC physics laboratory.

C'est avec un immense plaisir que nous, les nominateurs de Jason, présentons à la communauté des physiciens et des physiciennes du Canada l'énorme contribution à l'enseignement de la physique faite par Monsieur Jason Leblanc, enseignant au Centre matapédien des études collégiales (CMÉC) d'Amqui (Québec). Nous reconnaissons le travail unique réalisé par Jason, depuis 1999, dans l'utilisation de nouveaux équipements à la fine pointe pour l'apprentissage de la physique au niveau collégial, notamment l'utilisation combinée de tableaux interactifs (Smartboard) et du système d'acquisition de données (Pasco) pour les expériences de mécanique classique. Monsieur Jason Leblanc a été le premier qui a pratiqué avec succès l'expérience d'enseignement partagé (team-teaching) des mathématiques et de la physique, démontrant une ouverture sans précédent à des nouvelles méthodes pédagogiques d'enseignement de la physique. Nous soulignons aussi l'engagement et l'attention particulière dédiés par Monsieur Jason Leblanc dans la mise en place de projets liés à l'utilisation de sources d'énergie dites « propres », comme le projet d'un système combiné photovoltaïque-éolienne capable de produire de l'énergie nécessaire pour éclairer le laboratoire de physique du CMÉC.

2. Selected to attend 2018 CERN Workshop; see report on page 147.

CERN High School Teacher Programme 2018

by Giselle Lawrence and Thana Rahim

This year we had the honour to be the recipients of the Canadian Association of Physicists (CAP) High School Teaching Award 2018 for British Columbia and the Yukon (Giselle), and the Northwest Territories and Prairies (Thana). Following the announcement, we were asked to submit a statement of why we would be interested in attending CERN High School Teacher Program 2018 (HST 2018) and how it would impact our teaching in the classroom. After this, CAP informed us that we were selected to be Canada's representatives for the HST 2018, what a great privilege! This was the most valuable professional development experience of our career.

The CERN HST program in Geneva is a three week residential program for selected participants that has been taking place for the last 20 years. It consists of 100 hours of lectures given by many distinguished scientists, on-site visits, exhibitions, and hands-on workshops that introduce its participants to leading-edge particle physics. In addition to these activities, participants devote 20 hours to group work to prepare presentations on selected topics. The purpose of this work it to gain a deeper understanding of topics related to particle physics while working and exchanging knowledge in a collaborative way.

Our first week started with a social evening to allow us to get to know the 44 other participants, representing 32 other countries, and CERN organizers followed by the "Discover CERN Treasure Hunt" to get familiarized with the different locations where the program would take place. We then had an introduction to CERN and to the program prepared by the program manager, Dr. Jeff Wiener. After this, the technical lectures started right away.

The first lecture was an Introduction to Particle Physics by the renowned British physicist, Dr. John Ellis. During the week, we also had lectures on Particle Physics, Particle Accelerators and Particle Detectors. We looked into topics related to education and particle physics in a lecture on Elementary Particle Physics in Early Education by Dr. Wiener and a Cloud Chamber Workshop where we learned how to build a simple and affordable cloud chamber that can be used in the classroom. During this week we also had the opportunity to visit the Synchrocyclotron, the Cryogenic Test Facility Hall SM18 and the Alice Control and Exhibition rooms (Fig. 1).

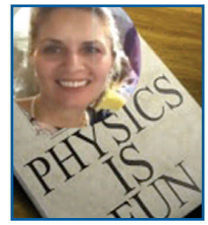
We were divided into small working groups and we chose two topics: S'cool LAB Quadruple Ion Trap and Beam Optics, and Medical Applications. The S'cool LAB Quadruple Ion Trap and Beam Optics working group (Fig. 2) was in charge of building an astable multivibrator (Fig. 3) to simulate the functioning of a Quadrupole Ion Trap using spores instead of ions and performing an experiment to explore electric fields, charge distributions and frequency. This work enabled the group to gain a deeper understanding of how Quadrupole Ion Traps work while further developing their circuit construction and electronic skills, 3D printing skills and basic mechanical assembly skills. The group also worked on a beam optics lab.

The Medical Applications group was in charge of learning all about the recent CERN Medical Technology Hackathon (Medtech:Hack 2018) and exploring how to adapt the hackathon model to make it viable in a high school setting. CERN's MedTech:Hack 2018 was an innovation competition where teams came up with solutions to medical challenges. These solutions had to involve the use of CERN technologies. The group had the opportunity to work at IdeaSquare (Fig. 4), a unique innovative environment where people can get together to think, do and collaborate in order to generate new ideas and work on building prototypes. The working group came up with a series of recommendations on how to run a high school

Summary

Giselle Lawrence and Thana Rahim were selected from among the 2018 High School Teaching Award winners to attend the CERN High School Physics Teacher Program. The three-week program brings together teachers from around the world who attend lectures, facility tours, workgroup sessions, and lots of discussions.

Sponsors of the CAP-Perimeter Physics Education (CERN) Scholarship



Giselle Lawrence, <giselle.naranjo@icloud.com>, Brentwood College School, Mill Bay, BC

and

Thana Rahim, <thana.rahim@ycs.nt.ca>, Ecole St. Patrick High School, Yellowknife, NT

Fig. 1 Thana Rahim and Giselle Lawrence visiting ALICE Control and Exhibition rooms.

Fig. 2 Quadrupole Ion Trap and Beam Optics Working Group. From the left:Ayyaz Mehmood - Pakistan, Thana Rahim - Canada, Susanna Schort - Austria, Bahareh Azad - Iran, Kazuoki Ehara - Japan, Lidwina Felisima Tae - Indonesia.

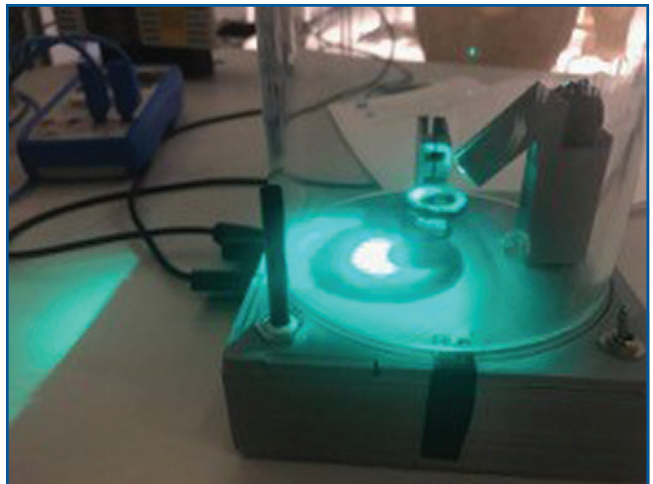


Fig. 3 Astable multivibrator simulating a Quadrupole Ion Trap.

Fig. 4 The Medical Applications group at IdeaSquare From the left: Oksana Zhyvotova - Ukraine, Natthawin Cho - Thailand, Giselle Lawrence - Canada, Marina Lici - Romania and Sarutaya Lunsakawong - Thailand.

hackathon and some examples of challenges that high school students could address. We ended the week with a "Discover Geneva Treasure Hunt" followed by the Official Dinner of the HST program at Hotel Edelweiss in Geneva.

During our second week at CERN, we had great lecturers sharing their knowledge on Data Analysis in Particle Physics, Computing at CERN, Neutrino Physics, Cosmology, Theoretical Physics, Engineering at CERN, Antimatter Research and Medical Applications of Particle Physics. This last lecture emphasized how CERN contributes to society and industry by transferring knowledge and new technology. During this lecture, it was very exciting to hear the announcement of the first 3D Colour X-Ray image obtained using technology developed at CERN (Fig. 5).

We also had the opportunity to visit the Data Centre, the Control Centre, the ISOLDE facility, the AMS POCC , the Large Magnet Facility and, the Low Energy Ion Ring and Antimatter Factory. Although all visits were truly amazing, the highlight of our week was the visit to the Large Magnet Facility (Fig. 6) where we learned how superconducting magnets that work at a temperature below 2 K are made. We also learned about the design of the new enhanced quadrupoles magnets that reach a magnetic field strength of 12 T and will be used in the High Luminosity LCH (HL-LHC) which is an upgrade of the LCH that will be operative in 2025. In addition, we were informed about the compact superconducting crab cavities that have been funded by the Canadian government and will also be part of the HL-LHC. During this visit, it was very interesting to hear first-hand, from one of the engineers involved, the recount of the 2008 accident that happened just nine days after the LHC turned on for the first time. The engineer explained to us how a faulty wire connecting two of the magnets heated up, heating up the magnet, leaving the current to build up and boil the liquid helium that was supposed to keep the magnet cold, and how this generated an explosion. The engineer proceeded to explain the challenges they had to face to assess and fix the damage, how they replaced magnets along more that 600 m of the accelerator ring and how they have worked all these years to make sure nothing blows up again.

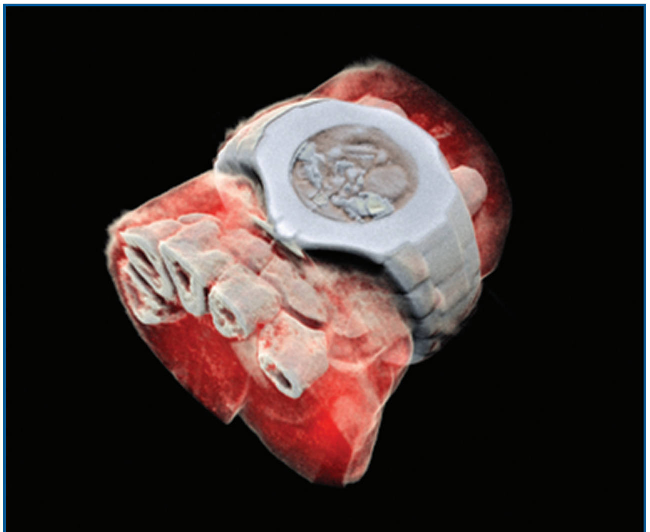


Fig. 5 A 3D Colour X-Ray image of a wrist with a watch. (Image: MARS Bioimaging Ltd).

Our third week at CERN started with a fantastic Perimeter Institute Workshop run by Dave Fish and Greg Dick (Fig. 7) where teachers learned how to incorporate uncomplicated activities for the study of dark matter and the expansion of the universe into the regular curriculum. All teachers were highly engaged and valued very much the ideas and resources that this Canadian organization shared with them. The night before the workshop, Greg and Dave organized a casual evening gathering where they kindly invited everybody in the program to share about their teaching context, philosophy and experience. It was very nice to have the opportunity to learn more about the teaching context of all the other participants.

The week continued with lectures on CERN's Teachers in Residence program, Gender Equality in Education, the AWAKE project, the Discovery of the Higgs Boson, and CERN Future Strategies and Technologies. We ended our lectures with a session called "Final questions, final answers" run by the Head of CERN's Education Group, Dr. Rolf Landua. The discussion centered on the role of the HST program in creating awareness about the research that takes place at CERN, how the LHC has started a journey of discovery that will extend for decades, how this journey will require new scientists and engineers that could

Fig. 6 Multiple images taken at the Large Magnet Facility.

Fig. 7 Greg Dick from Perimeter Institute introducing the workshop on Dark Matter.

be our current and future students, and our duty to instill in our students a greater appreciation for the scientific method and the role of scientists in society. This week we also had the opportunity to visit the University of Geneva to get familiarized with their outreach programs called Physiscope & Mathscope. Finally, the program ended with the Work Group presentations where all groups shared very interesting educational resources. All lectures and work group presentations can be found at: https://indico.cern.ch/event/651996/timetable/.

Wow, what intense, stimulating and memorable three weeks we had! Fascinating particle physics lectures, awe-inspiring visits to world renowned facilities and engaging workshops, all these while getting to know outstanding school teachers (Fig. 7), equally passionate about the teaching and learning of physics, from all continents in the world. What a great honour it was to represent Canada and to experience first-hand the peaceful collaboration and diversity that CERN stands for. We will be forever grateful to the Canadian Association of Physicists, Perimeter Institute, the Particle Physics Institute and CERN for this invaluable opportunity.

Official HST 2018 Group picture. Photo by Tony Valsamis/CERN.

Report on Canada's Participation in the 49th International Physics Olympiad in Lisbon, Portugal (December 3, 2018)

by Andrzej Kotlicki and Sepehr Ebadi

The 49th International Physics Olympiad (IPhO) was held from July 21st to 29th, 2018, in Lisbon. Portugal. Due to lack of funding, we were unable to organize the Canadian Olympiad Finals. The students scoring top in the Canadian Association of Physicists (CAP) High School exam were invited to represent Canada in IPhO. 778 students from 149 Canadian schools wrote the exam this year (about 80 less than last year).

Our students did not get any formal training to prepare them for IPhO. The four Toronto students had some training sessions organized at UoT by Dr. Natalia Krasnopolskaia with the help of Dr Brett Teeple. Two Ontario students got some preparation in afterhours Olympiads school. The BC student obtained some training at UBC from Andrzej Kotlicki and Pedram Amani (our last year's IPhO participant and UBC student).

It is worth mentioning that teams from other countries are given anywhere from 2 weeks to 2 years of additional training for this competition.

The members of the Canadian team this year were:

Manqiu Wu from A. Y. Jackson Secondary School (Ontario) the student of Gavin Kanowitz

Steven Mai from University of Toronto Schools (Ontario) the student of Marisca Vanderkamp

Alex You from Richmond Secondary (British Columbia) the student of Philip Freeman

Summary

The 49th International Physics Olympiad (IPhO) was held from July 21st to 29th, 2018 in Lisbon, Portugal. Organizers were able to provide minimal training due to lack of funding, putting Canadian participants at a significant disadvantage.

Tang David from University of Toronto Schools (Ontario) the student of Marisca Vanderkamp

Isaac Liao from Earl Haig Secondary School (Ontario) the student of Adam Morin

The team leaders were Dr. Andrzej Kotlicki (UBC), Director for the Canadian Physics Olympiad Program, and Sepehr Ebadi Harvard graduate student and past IPhO medalist.

The observer was:

Yadong Jiang from the Olympiads school in Toronto

This year we were able to pay for the trip to the IPhO for all of students and Sepehr while A. K. and the observer paid for their travel and the observer's fees.

This year's IPhO was hosted by the Ministry of Education of the Portuguese Republic and the Portuguese Physical Society. The opening ceremony took place at the University of Lisbon. There were the usual speeches by the organizers and the President of IPhO. There were some modern dance performances and all students were presented by spotlighting them and showing their image on the screen (Fig. 1).

Eighty-seven countries sent teams of students to this year's Olympiad. According to the IPhO's rules, roughly 67% of the participants were awarded Olympic medals or honorable mentions.

As usual, the competition had both theoretical and experimental parts that were meant to challenge students at a level more advanced than typical high school or even first year university physics exams. The competition consisted of 3 theoretical and 2 experimental problems.

The first experimental problem introduced students to the Junction Field Effect Transistors, in particular, thin film transistors. After the short introduction, describing this active electronic element the students were guided through the measurements of the characteristics of a thin film transistor printed on paper.

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and

Sepehr Ebadi, Harvard graduate student and past IphO medalist

Fig. 1. Canadian team being presented during the opening ceremony.

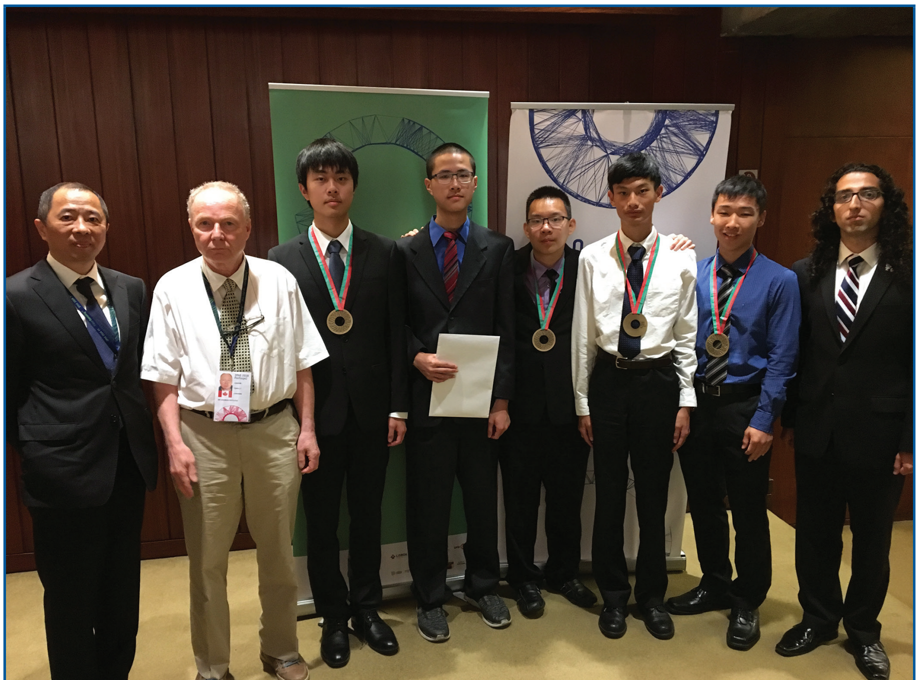

Fig. 2. The Canadian Team with awards after the Closing Ceremony. From the left: Yadong Jiang, Andrzej Kotlicki, Manqiu Wu, Isaac Liao, David Tang, Alex You, Steven Mai, and Sepehr Ebadi.

In the second experimental problem student were characterizing the viscoelasticity of a polymer thread. Both problems were educational for students, introduced new for them effects, and tested well the experimental skills.

First theoretical problem was related to the first observation of the passing of gravitational waves through Earth. It involved some simple Newtonian calculations and the relativistic energy dissipation as well as some measurements based on the original LEGO plot. David Tang got one of the best scores for this problem.

The second problem asked students to analyze the data of the two very high energy protons collision at the Large Hadron Collider.

The third problem involved the analysis of two simplified models of blood flow in vessels and a model of the tumor growth.

All the problems were very well prepared and written and required very small corrections from the International Board. Our students did reasonably well considering their very limited preparation: Manqiu Wu, David Tang, Alex You and Steven Mai got bronze medals and Isaac Liao got honorary mention (see Fig. 2).

In the free time both students and leaders enjoyed interesting excursions to the beautiful old Portuguese towns and tourist attractions: Castello de S. Jorge, Alfama, Palacio do Marques in Oeiras, old walled town of Obidos, Alcobaca and Nazare. In Lisbon students visited old Cassel, Oceanorium, National Coach and National Maritime museums and the Gulbenkian Planetarium There was also a lot of socializing and some sports activities.

After 10 years of leading the IPhO the President Prof Hans Jordan from Netherland retired. The International board thanked him for his hard work and leadership with a standing ovation. Prof. Rajdeep Singh Rawat from Singapore was elected as the new President.

Next year, Israel will host the IPhO in *Tel* Aviv from July 7th to July 15th.

REPORT OF THE CAP'S 2018-19 OUTGOING PRESIDENT

When I took over as President of the Canadian Association of Physicists from Richard MacKenzie, during the 2017 Congress at Queen's University, I was only too aware of the leadership that previous Presidents had provided in past years. In recent years, improving communication with our members had been a focus, and these improvements continued to be made under the able direction of Marcello Pavan during my tenure. Assisting him were Francine Ford, Chantal Éthève-Meek, Ann-Marie Robertson, and Gina Grosenick, and I must extend my thanks to them for all their hard work in this regard. During the year we saw further website improvements, the selection of a new customer relations management (CRM) System, and we look forward to its implementation, which will further improve our ability to connect with members in an effective and seamless fashion.

While there were, and still are, many areas where changes and improvements can be made, I decided to focus my energy on trying to improve the Governance of the Organisation, which was one of the outstanding goals of our previous strategic plan. To this end, the Board Structure was revised, and a Governance Committee was established under the able leadership of Mike O'Neil, who had previously served on the Board, as Director of Professional Affairs. Terms of Reference, Policies, and Procedures for Board Committees have been created and are being rolled out to the Board portfolios, committees, and divisions. The Board has approved the establishment of a Student Council, which will have a direct reporting relationship to the Board and the Chair of the CAP Advisory Council will in the future be elected from and by the members of the Council, thereby moving away from the President of the CAP chairing both the Advisory

Summary

There are many, many people who are involved in making the CAP an organization we can be proud of and who deserve the community's support. With the outstanding individuals who will follow in my footsteps, and the staff who are too often unrecognised, but are the glue of the organisation, I am sure that the CAP is in good hands.

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RAPPORT DU PRÉSIDENT SORTANT DE 2018-19

Lorsque j'ai accédé à la présidence de l'Association canadienne des physiciens et physiciennes au congrès de 2017, à l'Université Queens, succédant à Richard MacKenzie, je n'étais que trop conscient du leadership dont les anciens présidents avaient fait preuve par le passé. Ces dernières années, améliorer les communications avec les membres a été au centre de nos préoccupations et ces améliorations se sont poursuivies sous l'habile direction de Marcello Pavan pendant mon mandat. Lui ont prêté main forte Francine Ford, Chantal Éthève-Meek, Ann-Marie Robertson et Gina Grosenick, que je tiens à remercier d'avoir travaillé avec ardeur en ce sens. Au cours de l'année, notre site Web a connu des améliorations, dont un nouveau système de gestion de la relation clients (SGRC) qu'il nous tarde de mettre en œuvre et qui facilitera nos rapports avec les membres avec plus d'efficacité et de cohérence.

Il y avait et demeure bien des domaines où des changements et des améliorations s'imposaient, mais j'ai décidé de concentrer mes énergies à tenter d'améliorer la gouvernance de l'organisation, l'un des principaux objectifs de notre plan stratégique antérieur. À cette fin, la structure du Conseil a été revue et un comité de gouvernance a vu le jour sous l'habile direction de Mike O'Neil qui avait déjà siégé au Conseil à titre de directeur des Affaires professionnelles. Pour les comités du Conseil, on a établi des mandats, politiques et procédures qui sont actuellement mis en œuvre au sein des portefeuilles, comités et divisions du Conseil. Celui-ci a approuvé l'établissement d'un conseil étudiant relevant directement de lui et, à l'avenir, le président du Conseil consultatif de l'ACP sera élu par les membres du Conseil d'entre leurs rangs, ce qui évitera que le président de l'ACP préside à la fois le Conseil consultatif et le Conseil. D'autres améliorations à notre gouvernance ont

Council and the Board. Other improvements to our governance were the addition of new or revamped Board committees for finance, audit & HR, nominations & awards, and equity, diversity and inclusion. These changes are designed to try to ensure that the Board is able to focus on high level (strategic decision making) while ensuring that the operational activities of the CAP gets broad input from all members and are focused on meeting the needs of members, no matter what stage of their career they are at, where they live, or in what field of physics they practice. As part of the Governance portfolio, we have also developed a draft 2019-2024 Strategic Plan, which includes a new Mission, Vision and set of Values by which the organization will be managed. This draft will soon be available for feedback from all stakeholders before its ratification and implementation.

Another change that took place during my tenure was the amalgamation of the Division of Industrial and Applied Physics (DIAP) and the Division of Instrumentation and Measurement Physics (DIMP) to form the Division of Applied Physics and Instrumentation (DAPI)/Division de la physique appliquée et de l'instrumentation (DPAI). We look forward to seeing the benefits of this change.

There are many, many people who are involved in making the CAP and all its activities successful. My thanks must once again go out to all of the members who volunteered to serve on the CAP Council, as CAP Friends, those who set and marked University and High-School exams, those who worked on the P.Phys. Certification committee, the CAP speakers who encouraged undergraduate students to sign up, and those that put together a stimulating scientific program and Congress at Dalhousie University and played key roles in the other congresses that we support.

I want to express my thanks to the Directors of the Board (both old and new) who so ably supported me while I was President. They include the current President, Bruce Gaulin, Shohini Ghose who is now Vice-President and was responsible for the 2019 Congress at Simon Fraser University, Robert I. Thompson, our Vice-President Elect whom we welcome back to the Board. The Secretary/Treasurer, Gordon Drake; the Director of Academic Affairs, Ubi Wichoski, Director of Communications, Marcello Pavan, the Director of Industrial Affairs Ian D'Souza have continued to play key roles in the organisation. Kris Poduska and Maikel Rheinstadter have (with their large and enthusiastic committee) provided leadership in science policy, Steven Rehse has spent many years in his role as Director of Member and Affiliate Services trying to encourage people to join the CAP and Richard MacKenzie, my predecessor, who has clearly not yet finished providing

été l'addition de comités du Conseil, nouveaux ou repensés, pour les finances, la vérification et les ressources humaines, les prix et nominations, ainsi que l'équité, la diversité et l'inclusion. Ces changements visent à assurer que le Conseil puisse se concentrer sur la prise de décisions stratégiques de haut niveau tout en veillant à ce que les activités opérationnelles de l'ACP bénéficient de l'apport de tous les membres et puissent répondre à leurs besoins, peu importe où ils en sont dans leur carrière, l'endroit où ils habitent et dans quelle branche de la physique ils exercent. Quant au portefeuille de la gouvernance, nous avons aussi élaboré un projet de plan stratégique (2019-2024), qui comprend un nouvel énoncé de la mission et de la vision et un ensemble de valeurs devant présider à la gestion de l'organisation. Ce projet sera bientôt soumis aux commentaires de tous les intervenants avant qu'il soit ratifié et mis en œuvre.

Un autre changement survenu au cours de mon mandat a été l'amalgamation de la Division de la physique industrielle et appliquée (DPIA) et de la Division de la physique des instruments et mesures (DPIM) afin de former la Division de la physique appliquée et de l'instrumentation (DPAI)/ Division of Applied Physics and Instrumentation (DAPI). Il nous tarde de voir les avantages de ce changement.

Il y a bien des gens qui participent à faire un succès de l'ACP et de toutes ses activités. Je tiens aussi à remercier tous les membres qui ont bien voulu siéger au Conseil de l'ACP, à titre d'amis de l'ACP, ceux qui ont établi et corrigé les examens de niveaux universitaire et secondaire, qui ont siégé au Comité de certification « phys.», les orateurs de l'ACP qui ont encouragé les étudiants du premier cycle à adhérer et institué un programme scientifique stimulant et un congrès à l'Université Dalhousie, et qui ont joué un rôle clé dans les autres congrès que nous appuyons.

Je tiens à exprimer mes remerciements aux administrateurs (tant anciens que nouveaux) du Conseil qui m'ont si habilement appuyé quand j'occupais la présidence. Ce sont le président, Bruce Gaulin, Shohini Ghose, actuellement vice-présidente et responsable du congrès de 2019 à l'Université Wilfrid-Laurier, Robert I. Thompson, notre vice-président élu que nous accueillons à nouveau au Conseil. Le secrétaire-trésorier, Gordon Drake; le directeur des Affaires académiques, Ubi Wichoski, le directeur des Communications Marcello Pavan et le directeur des Affaires industrielles Ian D'Souza ont conservé leur rôle clé au sein de l'organisation. Kris Poduska et Maikel Rheinstadter (avec leur comité important et enthousiaste) ont assuré un leadership sur le plan des politiques scientifiques, Steven Rehse a consacré bien des années à son rôle de directeur des Services aux membres et affiliés, cherchant à encourager l'adhésion à l'ACP, et Richard MacKenzie, mon prédécesseur, qui n'a nettement pas encore cessé d'appuyer l'ACP, support to the CAP and has taken over from Steven. Ritu Kanungo, in her role as Director of International Affairs has been working hard to increase the international recognition of the CAP, Daniel Cluff (and the active Professional Affairs Committee) continues to strengthen the Professional Affairs portfolio, while Ben Newling has been developing the nascent Student Council in his role as Director of Student Affairs.

Last, but not least, I would like to thank all the staff in the office. They put up with me, helped me and provided guidance not only to me but to many members, day after day. Francine Ford in her role of Executive Director is supported by Ann-Marie Robertson who ably manages the many CAP programs, and Chantal Éthève-Meek, who proficiently manages CAP's membership and assists with the CAP finances. The volunteers and staff work hard to make the CAP an organization we can be proud of and deserve your support. With the outstanding individuals who will follow in my footsteps, and the staff who are too often unrecognised, but are the glue of the organisation, I am sure that the CAP is in good hands.

One of my new roles will be to ensure that we have enough nominations for vacant positions in the organization. If you would like to improve the CAP and are looking for ways to get more actively involved in the CAP's future direction, please contact me.

Thank you.
Regards
Stephen Pistorius, P.Phys.
2018-19 Past President

succédant par là à Steven. Dans son rôle de directrice des Affaires internationales, Ritu Kanungo s'est employée avec ardeur à étendre la reconnaissance de l'ACP à l'international, Daniel Cluff (et le Comité actif des affaires professionnelles) continue de renforcer le portefeuille des affaires professionnelles, tandis que Ben Newling a poursuivi la mise sur pied du nouveau Conseil étudiant à titre de directeur des Affaires étudiantes.

Et, dernier point mais non le moindre, je tiens à exprimer mes remerciements à tout le personnel du bureau. Ils m'ont supporté, aidé et guidé, et pas seulement moi mais bien d'autres membres, jour après jour. Dans son rôle de directrice exécutive, Francine Ford jouit de l'appui d'Ann-Marie Robertson qui gère avec brio les nombreux programmes de l'ACP, et de Chantal Éthève-Meek, qui traite avec compétence les questions touchant les membres et les finances de l'ACP. Les volontaires et le personnel travaillent fort à faire de l'ACP une organisation dont nous pouvons être fiers et qui mérite votre appui. Grâce aux personnes remarquables qui m'emboîteront le pas et au personnel trop souvent peu reconnus mais qui sont le ciment de l'organisation, je suis sûr que l'ACP est entre bonnes mains.

L'un de mes nouveaux rôles sera d'assurer la présence de suffisamment de candidatures pour combler les postes vacants au sein de l'organisation. Si vous souhaitez améliorer l'ACP et cherchez des moyens de prendre une part plus active à l'orientation future de l'ACP, veuillez communiquer avec moi.

Je vous remercie.
Mes meilleures salutations.
Stephen Pistorius, phys.
Président sortant 2018-19

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CAP members are given the first opportunity to request books. For non-members, only those residing in Canada may request a book. Requests from non-members will only be considered one month after the distribution date of the issue of *Physics in Canada* in which the book was published as being available.

The Book Review Editor reserves the right to limit the number of books provided to reviewers each year. He also reserves the right to modify any submitted review for style and clarity. When rewording is required, the Book Review Editor will endeavour to preserve the intended meaning and, in so doing, may find it necessary to consult the reviewer. Reviewers submit a 300-500 word review for publication in PiC and posting on the website; however, they can choose to submit a longer review for the website together with the shorter one for PiC.

LA POLITIQUE POUR LA CRITIQUE DE LIVRES

Si vous voulez faire l'évaluation critique d'un ouvrage, veuillez entrer en contact avec le responsable de la critique de livres, Richard Marchand, en utilisant le formulaire de demande électronique à http://www.cap.ca.

Les membres de l'ACP auront priorité pour les demandes de livres. Ceux qui ne sont pas membres et qui résident au Canada peuvent faire une demande de livres. Les demandes des non-membres ne seront examinées qu'un mois après la date de distribution du numéro de la Physique au Canada dans lequel le livre aura été déclaré disponible.

Le Directeur de la critique de livres se réserve le droit de limiter le nombre de livres confiés chaque année aux examinateurs. Il se réserve, en outre, le droit de modifier toute critique présentée afin d'en améliorer le style et la clarté. S'il lui faut reformuler une critique, il s'efforcera de conserver le sens voulu par l'auteur de la critique et, à cette fin, il pourra juger nécessaire de le consulter. Les critiques pour publication dans la PaC doivent être de 300 à 500 mots. Ces critiques seront aussi affichées sur le web; s'ils le désirent les examinateurs peuvent soumettre une plus longue version pour le web.

BOOKS RECEIVED / *LIVRES REÇUS*

The following titles are a sampling of books that have recently been received for review. Readers are invited to write reviews, in English or French, of books of interest to them. Unless otherwise indicated, all prices are in Canadian dollars.

Lists of all books available for review, books out for review and book reviews published since 2011 are available on-line at www.cap.ca (Publications).

In addition to books listed here, readers are invited to consider writing reviews of recent publications, or comparative reviews on books in topics of interest to the physics community. This could include for example, books used for teaching and learning physics, or technical references aimed at professional researchers.

Les titres suivants sont une sélection des livres reçus récemment aux fins de critique. Nous invitons nos lecteurs à nous soumettre une critique en anglais ou en français, sur les sujets de leur choix. Sauf indication contraire, tous les prix sont en dollars canadiens.

Les listes de tous les livres disponibles pour critique, ceux en voie de révision, ainsi que des critiques publiées depuis 2011 sont disponibles sur : www.cap.ca (Publications).

En plus des titres mentionnés ci-dessous, les lecteurs sont invités à soumettre des revues sur des ouvrages récents, ou des revues thématiques comparées sur des sujets particuliers. Celles-ci pourraient par exemple porter sur des ouvrages de nature pédagogique, ou des textes de référence destinés à des professionnels.

GENERAL LEVEL

A WELL-ORDERED THING: DMITRII MENDELEEV AND THE SHADOW OF THE PERIODIC TABLE, REVISED EDITION [V], Michael D. Gordin, Princeton University Press, 2018; pp. 384; ISBN: 9780691172385; Price: 41.99. (Live: 1)

NEWTON THE ALCHEMIST: SCIENCE, ENIGMA, AND THE QUEST FOR NATURE'S, William R. Newman, Princeton University Press, 2018; pp. 560; ISBN: 9780691174877; Price: 49.99. (Live: 1)

NO SHADOW OF A DOUBT: THE 1919 ECLIPSE THAT CONFIRMED EINSTEIN'S THEORY OF RELATIVITY [V], Daniel Kennefick, Princeton University Press, 2019; pp. 416; ISBN: 9780691183862; Price: 40.99. (Live: 1)

QUANTUM MANY-BODY PHYSICS IN A NUTSHELL [V], Edward Shuryak, Princeton University Press, 2018; pp. 312; ISBN: 9780691175607; Price: 93.99. (Live: 1)

THE PHYSICS BEHIND: DISCOVER THE PHYSICS OF EVERYDAY LIFE, Russ Swan, Firefly Books, 2018; pp. 192; ISBN: 978-0228100898; Price: 22.46. (Live: 1)

TIME AND TIME AGAIN: DETERMINATION OF LONGITUDE AT SEA, Richard de Grijs, Iop Publishing Ltd, 2017; pp. 368; ISBN: 978-0750311953; Price: 160.12. (Live: 1)

UNDERGRADUATE LEVEL

HOW TO FALL SLOWER THAN GRAVITY: AND OTHER EVERYDAY (AND NOT SO EVERYDAY) USES OF MATHEMATICS AND PHYSICAL REASONING [V], Paul J. Nahin, Princeton University Press, 2018; pp. 320; ISBN: 9780691176918; Price: 34.22. (Live: 1)

THEORETICAL FLUID MECHANICS, Richard Fitzpatrick, Iop Publishing Ltd, 2017; pp. 0; ISBN: 978-0750315524; Price: 75.63. (Live: 1)

SENIOR LEVEL

ALGÈBRE LINÉAIRE ET APPLICATIONS (5° ÉD.) (MANUEL + MONLAB XL), LAY David, LAY Steven R., MACDONALD Judi J., Pearson, 2017; pp. 530; ISBN: 9782761376525; Price: 109.95. (Live: 1)

ASTROPHYSICS OF RED SUPERGIANTS, Emily Levesque, Iop Publishing Ltd, 2018; pp. 100; ISBN: 978-0750313308; Price: 176.88. (Live: 1)

HIGH TIME-RESOLUTION ASTROPHYSICS, Editors: Tariq Shahbaz, Jorge Casares Velázquez, Teodoro Muñoz Darias, Cambridge University Press, 2018; pp. 208; ISBN: 978-1107181090; Price: 160.95. (Live: 1)

STRING THEORY IN A NUTSHELL: SECOND EDITION [V], Elias Kiritsis, Princeton University Press, 2019; pp. 888; ISBN: 9780691155791; Price: 128.99. (Live: 1)

TOPOLOGICAL AND NON-TOPOLOGICAL SOLITONS IN SCALAR FIELD THEORIES, Yakov M. Shnir, Cambridge University Press, 2018; pp. 278; ISBN: 978-1108429917; Price: 166.95. (Live: 1)

BOOK REVIEWS / *CRITIQUES DE LIVRES*

Book reviews for the following books have been received and posted to the *Physics in Canada* section of the CAP's website: http://www.cap.ca.

Des revues critiques ont été reçues pour les livres suivants et ont été affichées dans la section "La Physique au Canada" de la page web de l'ACP:http://www.cap.ca.

MOLECULAR ENGINEERING THERMODYNAMICS, by Juan J. de Pablo and Jay D. Schieber, Cambridge University Press, 2014, pp. 505, ISBN 978-0-521-76562-6, price 120.00.

The authors state in the preface that "Traditional boundaries between science and engineering are becoming blurred, and versatility in engineering is necessarily built upon a broader understanding of far–reaching scientific principles". I wholeheartedly agree with the authors on this point, and my perception is that engineering education in most of the developed world (apart from Canada) is moving in this direction. However, I perceive that such blurring from the science perspective is active here, and the book provides a good introduction to important practical applications of thermodynamics that are of potential interest to members of the Canadian applied physics community.

The book addresses the perceived need for a modification of thermodynamics education by combining the mathematical foundations of macroscopic thermodynamics and its molecular-based underpinnings, accompanied by illustrative applications to problems in physics, chemistry and biology. The authors indicate that they have used the book for a two-semester undergraduate course and a for one-semester graduate course, directed at chemical, biological and biomedical engineers, materials scientists and chemists.

The topics covered are based on those of a typical chemical engineering curriculum, which arose historically due to the importance of the petroleum industry. For example, phase equilibrium plays a prominent role, for which the emphasis on the fugacity concept is evident. One consequence is the lack of any treatment of electrolyte solutions, which would readily evolve from an emphasis on the chemical potential itself, as well as provide a foundation for the treatment of phase equilibria.

Chapter 1 gives a short introduction to the scope of thermodynamics, and lays out the topics of the subsequent chapters. It also contains a list of 23 "relevant questions for thermodynamics", designed to whet the student's interest in what is to come, followed by a short review of the important concepts of Work and Energy.

Chapter 2 outlines the postulates of thermodynamics, introducing the First Law (Postulate I) and Second Laws (Postulate IV), and the definitions of temperature, heat, pressure and chemical potential in terms of mathematical derivatives of the internal energy function U (N, V, T). It relates the concepts of Work and imperfect differentials. The state postulate, relating the number of independent intensive thermodynamic variables required to fix all others, is implied but not stated explicitly in the context of their Postulate III. Postulate V sets the zero of S, followed by a digression on the link between entropy and statistical mechanics. A disappointment to this reviewer (see my earlier comment concerning fugacity) is that the introduction of the chemical potential, one of the most important quantities in chemical thermodynamics, is by means of its formal definition as the partial derivative of U with respect to Ni at constant S, V and N_j, j being different from i.

Chapter 3 contains many useful mathematical topics, beginning with Legendre Trans forms, Extremum Principles, the Maxwell Relations and thermodynamic manipulations using the method of Jacobians described in an Appendix. The chapter ends with interesting one- and two-dimensional applications to rubber bands, DNA unzipping, and adsorption.

Chapter 4 begins with a discussion of stability criteria, in preparation for a brief section on single–component vapor-liquid equilibria (VLE). This is the first mention of this chemical engineering "workhorse", which plays a prominent role in chemical engineering education. There follows a section on crystalline solids and a description of the phase diagram of a pure substance. Chapter 5 extends the treatment to flow systems, based on the control volume concept (although this term is not used in the text), and the conservation equations for an open system are given in the Appendix. Applications are presented to the thermodynamics of power cycles and the vapor-compression refrigeration cycle.

Chapter 6 gives an introduction to classical statistical mechanics, and Chapter 7 discusses its implementation in terms of classical molecular force field models. Chapter 8 is devoted to the concept of fugacity and vapor-liquid equilibrium (solid–liquid equilibrium is also covered.) Emphasis instead on the chemical potential would provide a unifying concept that would make the teaching of the concepts in Chapters 9 (Activity and equilibrium) and 10 (Reaction equilibrium) far more understandable to the student.

Chapter 10 on Reaction equilibrium (somewhat belatedly) introduces the concept of standard property changes, which are intimately linked to the notion of reference states. It might be more useful to introduce the reference state concept much earlier, in conjunction with the chemical potential and energy–related properties in general. Chapters 11 and 12 present applications to polymers and surfaces.

Many worked examples are provided in the text, and interesting problems are provided at the end of each chapter. The Appendices contain useful material on mathematical foundations, fluid equations of state, the differential equations of mass, momentum, energy and entropy balance equations for spatially distributed systems, and thermochemical tables.

William Smith, University of Guelph

Optical Magnetometry, by Dmitry Budker and Derek F. Jackson Kimball, Cambridge University Press, 2013, ISBN 978-1-107-01035-2, price 471.25.

This book is a collection of pedagogical chapters on the physics and techniques in optical magnetometry. Each chapter is written by experts in the respective topic in optical magnetometry. This is an excellent reference book to start from if you want to learn about a particular application or technique in optical magnetometry.

The introductory chapters are devoted to understanding the sources of noise and uncertainty that limit the sensitivity in magnetometry measurements. Many of the optical magnetometers rely on measuring the Faraday rotation of the light polarization as it passes through a magnetic field. We learn that the sensitivity of the magnetic field measurement in this method depends on contributions from photon shot noise of the probing light, and from atomic spin-projection noise.

There are chapters devoted to understanding different types of magnetometers including nuclear magnetic resonance (NMR) type magnetometers on alkali vapours, spin-exchange-relaxation-free (SERF) magnetometers, and optical magnetometers using modulated light. The chapter on NMR type magnetometers has a useful review of the Bloch equation, and tracking of magnetization of an atomic vapour in a magnetic field.

Several chapters deal with systematic effects and detailed experimental conditions needed to make the magnetometers work. For example, there is a chapter on magnetic shielding that is required when measuring very small magnetic fields. Of particular interest to me, was the chapter on tests of fundamental physics, that reviews the sensitivity of different magnetometer systems that are being used in neutron electric dipole moment experiments.

Finally, there are several chapters, that provide reviews of different applications of magnetometry. These are quite interesting applications, including remote detection, space magnetometry, detecting biomagnetic fields, and geophysical applications. The final chapter is on commercial magnetometers, and their history.

In conclusion, I would recommend this book to anyone interested in learning the physics of optical magnetometers. The chapters provide excellent reviews of different aspects of optical magnetometry, and include detailed references to further reading on the state of the art in the topic.

Blair Jamieson, Associate Professor of Physics, University of Winnipeeg

Review of 100 Years of Subatomic Physics, by Ernest M Henley, Stephen D Ellis, Ernest M. Henley and Stephen D. Ellis, World Scientific, 2013, pp. 560, ISBN 978-981-4425-80-3, price 49.08.

When I first saw this title on the list of books available for review on the CAP web site, I immediately sent in a request for a copy. I've been working in experimental particle physics for more than 40 years and, like many people in the late stages of their career, I have become increasingly interested in the history of my field. I was hoping for a technical narrative describing the key developments of nuclear and particle physics over the last century that would fill in any gaps in my knowledge and, more importantly, be a source that I could recommend to incoming students to provide them with a context for their research. I was disappointed.

This book is a collection of contributions from leading workers in subatomic physics, edited by Ernest Henley and Stephen Ellis from the University of Washington. There are 19 chapters, starting with a short overview by Steven Weinberg and ending with a review of string theory and M theory by John Schwarz. The articles in between are evenly divided between topics in nuclear and particle physics; some are worth reading and others can be safely passed over.

I enjoyed the too-short history of colliders by Lyn Evans - the man who directed the building of the LHC - and the chapter on large underground detectors for proton-decay searches and neutrino physics by Kate Scholberg. However I am less enthusiastic about the section on 4-pi detectors by Christopher Tully. He seems not to have read the instructions - there is nothing about the historical evolution of full-coverage detectors, starting with detectors like the seminal SLAC-LBL Mark I at SPEAR. Instead he has written a comprehensive description of the elements of the ATLAS and CMS detectors at the LHC. It's a worthwhile contribution and something I can recommend to students but I don't think it's what the book is supposed to be about. This is in contrast to the chapter on jets and QCD, nicely written by Stephen Ellis and Davison Soper - they followed the instructions and have provided an excellent account of the evolution of this topic. Rabindra Mohapatra and Lincoln Wolfenstein have provided similarly brief and historically interesting overviews of weak interactions and neutrino physics, respectively. There is also a well-written summary of parity and time-reversal tests in nuclear physics, by David Hertzog and Michael Ramsey-Musolf.

Some topics are completely absent. One example is the search for dark matter particles and axions. It has been going on for more than a quarter of the last century so it should rightly have a place in this book but somehow has been left off the list.

Despite its shortcomings, the book is a valuable resource. As a collection of review articles it can be a place to get a quick overview of some topics and most of the chapters have excellent bibliographies. Although not for the purpose I originally had in mind, I would definitely recommend it to an incoming graduate student. It seems the book I'm looking for has not yet been written.

David Hanna, McGill University

The Little Book of Black Holes, by Steven S. Gubser and Frans Pretorius, Princeton University Press, 2017, pp. 200, ISBN 9780691163727, price 24.99.

The "Little Book of Black Holes" at 200 pages is indeed as the title promises a concise book filled with very interesting stories about black holes and their behavior. The book has seven chapters, each discussing some aspect of black hole physics and one epilogue. The first two chapters introduce the reader to the theory of special relativity and general relativity; basics for learning physics of black holes. The next five chapters each discuss details of the Schwarzschild black hole solution, the Kerr black hole solution, the observation of black holes (e.g., Cygnus X-1, Sagittarius A*), black hole collisions and black hole thermodynamics. The epilogue is a letter to Albert Einstein informing him of the recent physics uncovered, including the discovery of gravity waves. It brings forth the excitement the authors have as young physicists; co-writers of the cosmic story started by the great physicist.

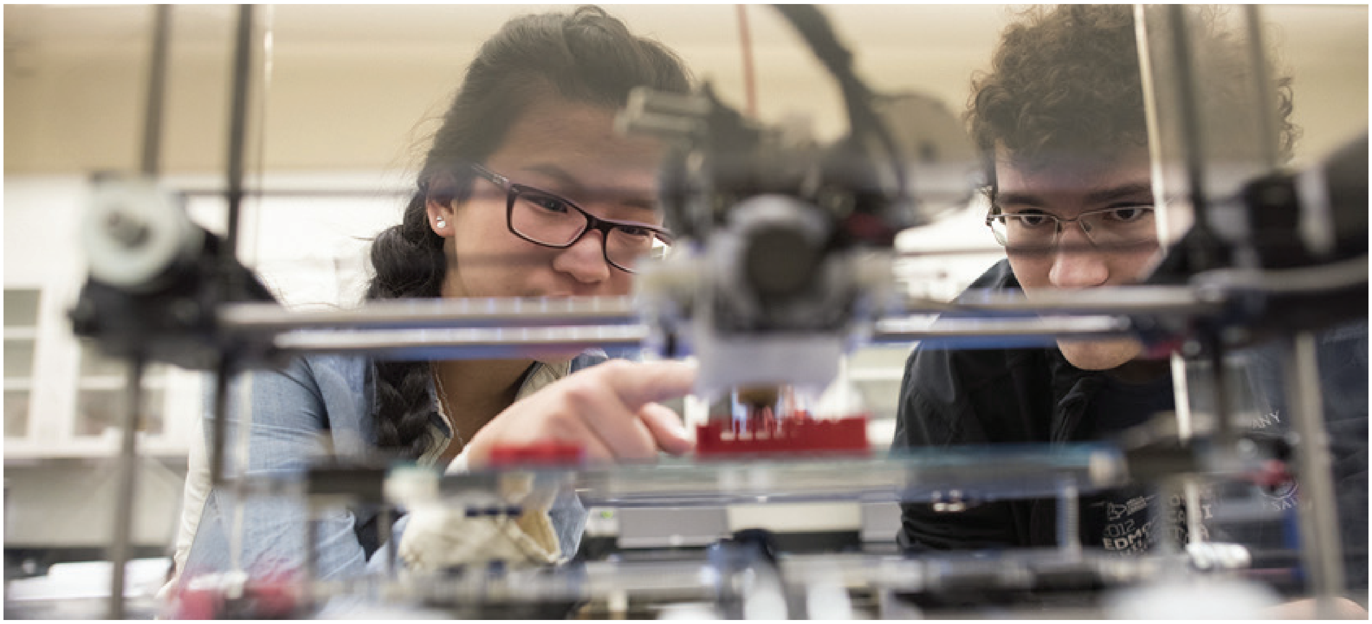
Given the expertise of the authors, this is the best place to learn about particle trajectories near black holes, the ergo sphere and space dragging of rotating black holes, their collisions and emission of energy in the form of gravitational waves. Some of the descriptions are fantastically precise (e.g., "The free falling probe will measure a time of 2,638 seconds to reach the ISCO from its initial position of 150 million kilometers, and then an additional 122 seconds to reach the horizon"), and you don't have to read a formidable technical article in a scientific journal. The style of writing is very smooth, and the book is pitched at the level accessible to science geeks, or young physics students, for whom Maxwell's equations are not a mystery, yet they do not have to be experts in special theory of relativity. The chapters on black hole orbits are some of the best descriptions I have seen in literature (though without equations). Given the discovery of gravitational waves this book is very timely. Many of the details about gravitational wave's discovery (e.g., gravitational wave detectors are blind to one of the polarizations); are facts easily found here: a reader will find difficult to find these from the plethora of existing technical papers and websites.

The chapter on black hole thermodynamics is equally insightful in the introduction to the quantum and black hole entropy. The incompatibility of quantum fields at the horizon with general relativity or the `Information loss' problem of Hawking radiation however doesn't come across as the dramatic focus in the discussion.

In the end, the book is a treasure to have, and read whenever one has a craving for black hole orbits and ergo spheres. The book can be completed in one day, and thus is ideal to take along during travels. The most impressive aspect of the book in my opinion is the use of illustrations. These are very clear drawings, and impactful depictions of the physics explained. If you wish to buy the book (it is reasonably priced at $24.95), this might be one of the reasons.

Arundhati Dasgupta, University of Lethbridge

Explore Physics



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Biophysics: Measure how molecules fold and unfold, unravel RNA, learn how prions operate and explore quantum biosystems.

Condensed Matter Physics: Study and develop quantum nanoscience and technology, including quantum fluids and solids, topological materials, nanomechanics and quantum simulation; research and use scanning microscopes, including atom-scale manipulation and ultrafast terahertz atomic imaging.

Geophysics: Study seismic monitoring, paleomagnetism, petrophysics and fluid dynamics; perform innovative computational studies of Earth and planetary dynamics; participate in one of our international field programs.

Particle Physics: Design, build and operate detectors to study high energy particles from the Higgs boson to neutrinos to dark matter and help to solve extremely complex calculations that make physical predictions about particle interactions.

Space and Plasma Physics: Study how charged particles and magnetic fields interact and apply it to plasmas in fusion experiments, lasers and space; probe space weather from both the ground and space to illuminate the physics of magnetic storms and particle energization.

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