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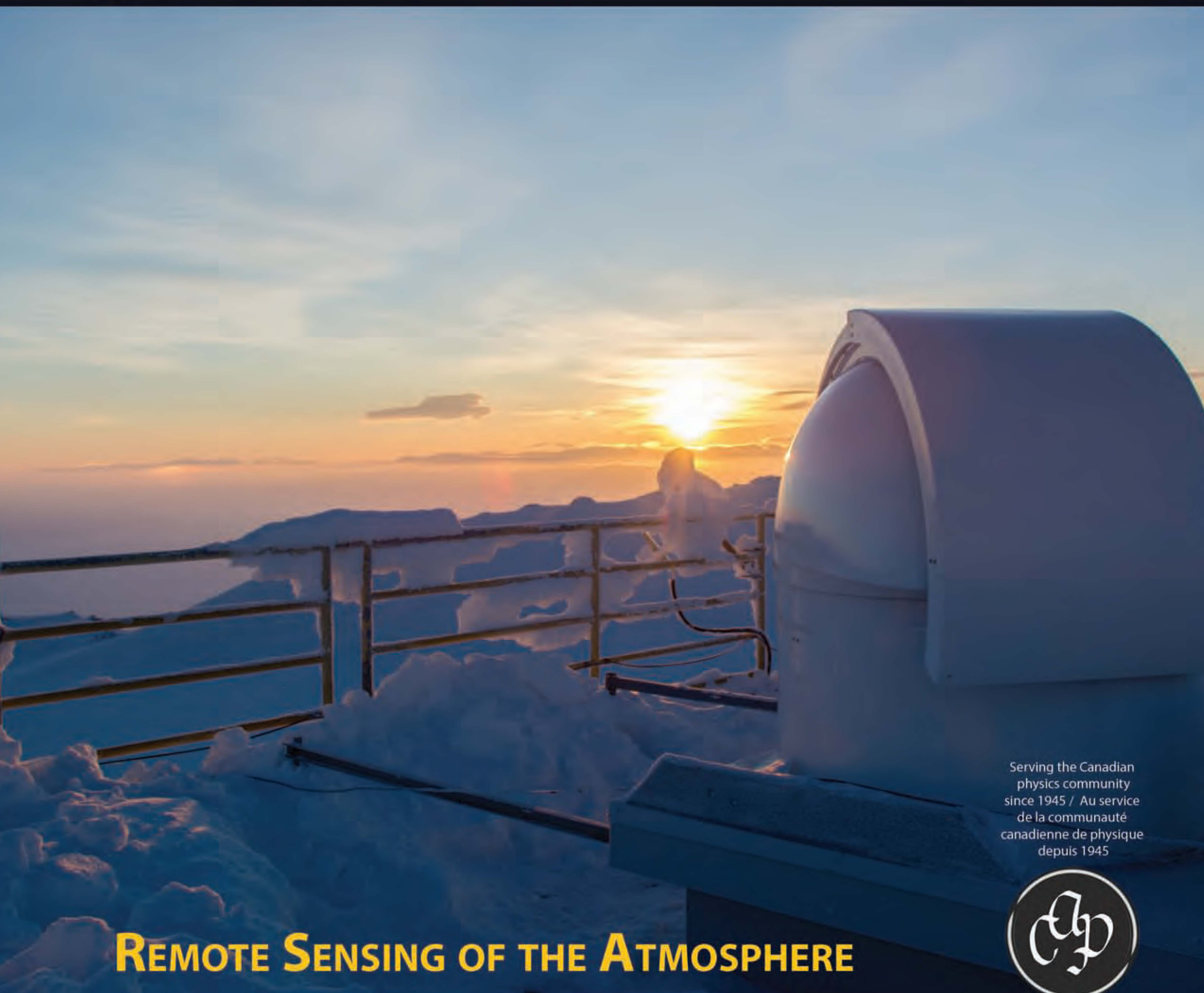

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Remote Sensing of the Atmosphere

La télédétection de l'atmosphère

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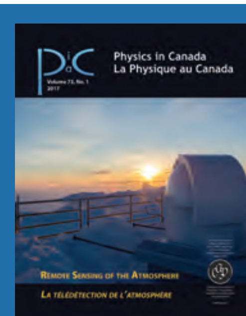

Solar tracker dome for atmospheric remote sensing at the Polar Environment Atmospheric Research Laboratory near the Eureka Weather Station on Ellesmere Island (Nunavut) (Photo credit: Dan Weaver).

Le dôme d'un pisteur solaire au centre de recherche atmosphérique en environnement polaire (PEARL), près de la station météorologique d'Eureka, sur l'île d'Ellesmere (Nunavut) (Photo courtoisie de Dan Weaver).

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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.

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REMOTE SENSING OF THE ATMOSPHERE

This themed mini-issue of *Physics in Canada* showcases selected research initiatives led by Canadian academics and their collaborators, and provides a glimpse at their current results. Canadian research groups are involved in many different aspects of terrestrial atmospheric research, a dynamic research field that continues to develop and grow. Space limitations allow us to show just a few of the many techniques and experimental methods in use across the country. Spectroscopic remote sensing techniques have been deployed on many satellite-, balloon-, aircraft-, and ground-based missions, probing the atmosphere at scales from the local to the regional and the global, and new missions are being planned.

Stratospheric measurements are key to learning about aspects of the atmospheric chemistry of the ozone molecule and unveiling specific physical properties of trace constituents (for example, nitrogen oxide radicals, hydrogen oxide radicals, bromine radicals, chlorine radicals) that interact with ozone and affect its distribution and associated seasonal changes. Tropospheric measurements increase the body of knowledge about sinks, sources, and fluxes of trace atmospheric constituents involved in physical and chemical mechanisms that influence climate change, and help us understand the evolution of Earth's atmosphere and predict how it may change in the future. For example, some trace constituents are known to be pollutants in the lowermost layers of the atmosphere, and their changing concentrations or transformations need to be known because of their potential societal impacts.

In a preface to the special issue of the *Journal of Molecular Spectroscopy* on "New visions of spectroscopic databases" used to interpret atmospheric spectra, published in late 2016, Dr. Nicole Jaquinet-Husson of Universite Paris 6, France and her colleagues highlighted that in the second half of the 20th century, the existent "synergy between the simultaneous development of new technologies (high speed processing with computers, high-resolution laboratory facilities, quantum-mechanical treatment in theoretical spectroscopy, etc.), provided the means to interpret a multitude of long-path atmospheric transmissions by performing radiance calculations for numerous scenarios and initiating notable progress in the development of molecular spectroscopy. The progress in Hamiltonian mechanics led theoreticians to demand more precision and detail in spectra, obtained from laboratory or planetary observations." Such tendencies are expected to continue in the 21st century and we hope to see Canada play a leading role in remote sensing technologies and research.

The people whose research is featured in this special issue are at the forefront of Canadian atmospheric research. The high spectral resolution, complemented by the high radiometric accuracy, of the atmospheric instrumentation described in these papers makes them powerful spectroscopic remote sensing tools that enable measurements of changes in atmospheric composition by simultaneous monitoring of select or multiple molecular trace constituents. In addition, they provide ground-based data that is vital for validation of present and future generations of airborne and satellite remote sensing instruments.

The paper by Strong *et al*. presents a review of measurements of chemical composition using ground-based UV-visible and Fourier transform infrared spectroscopy carried out for more than a decade in Toronto and at the Polar Environment Atmospheric Research Laboratory (PEARL) near the Eureka Weather station in the Canadian High Arctic. An overview of the research results and instrumentation at PEARL, where many ground-based remote sensing instruments are probing the entire atmosphere year-round, is presented in the paper by Drummond and the CANDAC team. The paper by K. LeBris discusses the challenges associated with the acquisition and interpretation of reference spectra of large atmospheric volatile molecules such as halocarbons. Finally, the paper by Wiacek *et al*. presents an experimental long-path technique and associated results for studies of atmospheric gases in the planetary boundary layer.

Adriana Predoi-Cross,
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Comments of readers on this Foreword are more than welcome.

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LA TÉLÉDÉTECTION DE L'ATMOSPHÈRE

Le présent mini-numéro thématique de *La Physique au Canada* illustre des initiatives de recherche dirigées par des universitaires canadiens et leurs collaborateurs, et donne un aperçu de leurs résultats récents. Des groupes canadiens de recherche prennent part à bien des volets différents de la recherche terrestre sur l'atmosphère, domaine de recherche dynamique qui ne cesse de s'élargir et de croître. Le manque d'espace ne nous permet d'illustrer que quelques-unes des nombreuses techniques et méthodes expérimentales utilisées au pays. Des techniques de télédétection spectroscopique ont été déployées lors de nombreuses missions à bord de satellites, ballons et aéronefs et basées à terre, sondant l'atmosphère à des échelles allant de locale à régionale et mondiale, et de nouvelles missions ont été préparées.

Les mesures stratosphériques sont la clé pour élargir nos connaissances sur divers aspects de la chimie atmosphérique de la molécule d'ozone et révéler les propriétés physiques particulières des constituants à l'état de trace (par exemple, les radicaux d'oxyde d'azote, les radicaux hydroxyles, les radicaux de brome, les radicaux de chlore) qui interagissent avec l'ozone et en affectent la distribution et les changements saisonniers associés. Les mesures troposphériques élargissent la masse du savoir sur les puits, les sources et les flux de constituants atmosphériques à l'état de trace intervenant dans les mécanismes physiques et chimiques qui influent sur les changements climatiques, et elles aident à comprendre l'évolution de l'atmosphère terrestre et à prévoir en quoi cela peut changer à l'avenir. Par exemple, on sait que certains constituants à l'état de trace sont des polluants dans les couches inférieures de l'atmosphère, et qu'il faut en connaître les concentrations changeantes ou les transformations en raison de leurs incidences possibles sur la société.

Dans la préface du numéro spécial publié fin 2016 dans *Journal of Molecular Spectroscopy*, sur les nouvelles visions des bases de données spectroscopiques qui servent à interpréter le spectre atmosphérique, la D^{re} Nicole Jaquinet-Husson de l'Université de Paris 6, en France, et ses collègues ont souligné que, dans la deuxième moitié du 20^{e} siècle, la synergie existant entre l'essor simultané des nouvelles technologies (traitement informatique à haute vitesse, installations de laboratoire de haute résolution, processus mécanique quantique en spectroscopie théorique, etc.) a fourni les moyens d'interpréter une multitude de transmissions atmosphériques à longue distance en effectuant les calculs du rayonnement de nombreux scénarios et en amorçant un essor notable de la spectroscopie moléculaire. Les progrès en mécanique hamiltonienne ont amené les théoriciens à exiger plus de précisions et de détails dans le spectre obtenu des observations en laboratoire ou planétaires. Ces tendances devraient se poursuivre au 21^{e} siècle et nous espérons voir le Canada jouer un rôle de chef de file en technologie et en recherches sur la télédétection.

Les personnes dont le présent numéro spécial expose les recherches sont à l'avant-plan de la recherche canadienne sur l'atmosphère. La haute résolution spectrale de l'instrumentation atmosphérique décrite dans ces articles, complétée par sa grande exactitude radiométrique, en fait de puissants outils de télédétection spectroscopique qui permettent de mesurer les changements dans la composition de l'atmosphère en suivant simultanément des constituants moléculaires choisis ou multiples à l'état de trace. En outre, ils fournissent des données terrestres qui sont vitales pour valider les générations actuelles et futures d'instruments de télédétection à partir d'avions et de satellites.

L'article de Strong et autres présente une étude des mesures de la composition chimique à l'aide de la spectrométrie terrestre UV/visible et infrarouge à transformée de Fourier, utilisée depuis plus d'une décennie à Toronto et au Laboratoire de recherche atmosphérique dans l'environnement polaire (PEARL) près de la station météorologique Eureka dans le Grand Nord canadien. Le document de Drummond et de l'équipe de CANDAC fournit un aperçu des résultats de recherche et instrumentation au laboratoire PEARL, où de nombreux instruments terrestres de télédétection sondent l'atmosphère entière toute l'année durant. L'article de K. LeBris expose les défis qui ont trait à l'acquisition et à l'interprétation du spectre de référence de grosses molécules volatiles de l'atmosphère tels les halocarbures. Enfin, l'article de Wiacek et autres présente une méthode expérimentale à longue distance et les résultats ayant trait aux études sur les gaz atmosphériques dans la couche limite planétaire.

Adriana Predoi-Cross,
Université de Lethbridge
Rédacteur honoraire, *La Physique au Canada*

Les commentaires de nos lecteurs (ou) lectrices au sujet de cette préface sont les bienvenus.

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

USING GROUND-BASED UV-VIS-IR SPECTROSCOPY TO PROBE ATMOSPHERIC COMPOSITION OVER CANADA

BY KIMBERLY STRONG, ERIK LUTSCH, AND XIAOYI ZHAO

Measurements are the life-blood of any attempt to understand atmospheric change. High-quality trace gas time series are essential for identifying and understanding the chemical and physical processes that underpin prediction through modelling. The importance of long-term data sets is increasingly recognized, most recently in the 2016 US National Academy of Sciences report on "The Future of Atmospheric Chemistry Research", which noted "*the central importance of long-term research sites for comprehensive atmospheric chemistry research*" [1]. This is particularly true in the Arctic, where the collection of such data can be challenging. For example, in 2015, a report by the Arctic Monitoring and Assessment Programme stated that "*Long-term monitoring of atmospheric composition at existing stations needs to be continued and integrated into a Pan-Arctic observation network*" [2]. Ground-based spectrometers provide a powerful tool for acquiring such measurements.

Canada has a long history in atmospheric remote sounding, with internationally recognized expertise in ultraviolet (UV), visible, and infrared (IR) spectroscopy [3]. Ground-based measurements of NO_2 using a grating spectrometer date back to the work of Alan Brewer and his colleagues at the University of Toronto [4]. This work led to the development of the Brewer spectrophotometer at Environment Canada, which is now deployed at about 80 stations worldwide for accurate measurements of ozone and UV radiation. Over the past 15 years, several new UV-visible and Fourier transform infrared (FTIR) spectrometers have been deployed in Canada for studies related to ozone, air quality, and climate. This article describes measurements and some science results from the University of Toronto Atmospheric Observatory (TAO, 43.66°N, 79.40°W) located in downtown Toronto, and from the Polar Environment Atmospheric Research Laboratory (PEARL, 80.05°N, 86.42°W) located in the high Arctic at Eureka, Nunavut [5]. Two case studies, one of biomass burning and one of stratospheric ozone depletion, are also presented.

SUMMARY

This article describes the use of ground-based UV-visible and Fourier transform infrared spectroscopy to measure atmospheric composition, with a focus on urban and Arctic sites.

FTIR SPECTROSCOPY

Infrared spectroscopy provides a valuable technique for measuring the concentrations of atmospheric constituents, and has been used for this purpose, from the ground, balloons, and aircraft, since the 1960s. Fourier transform infrared spectrometers have several advantages, including high spectral resolution, wide spectral coverage, and excellent throughput, which enable many species to be measured simultaneously. FTIR spectrometers are used to retrieve vertical columns and some vertical profile information using solar infrared absorption spectroscopy at several dozen sites worldwide, under the auspices of the Network for the Detection of Atmospheric Composition Change (NDACC) [6] and the Total Carbon Column Observing Network (TCCON) [7].

In Canada, there are currently two stations having FTIR spectrometers affiliated with these networks (Toronto and Eureka), with seven more instruments in use or available for deployment; several of which were part of the Canadian FTIR Observing Network (CAFTON). At TAO, we have an ABB Bomem DA8 spectrometer, which has been operational since 2002 and has undergone certification to become an NDACC instrument [8]. At PEARL, we have a Bruker IFS 125HR that currently alternates between NDACC and TCCON operations [9]. It was installed in 2006, replacing Environment Canada's Bomem DA8, which began making spring and some fall measurements at Eureka in 1993 [10]. Figure 1 shows the PEARL FTIR system, including the spectrometer and solar tracker. For both instruments, the main component is a Michelson interferometer, which is optically coupled to a solar tracker and records infrared solar absorption spectra during clear-sky daylight hours, typically achieving 80-120 observation days per year. NDACC spectra are recorded in the mid-infrared (750-4400 cm^{-1}) at high resolution (0.004 cm^{-1}) using a KBr beamsplitter, InSb and HgCdTe detectors, and a set of narrow-band optical interference filters. TCCON

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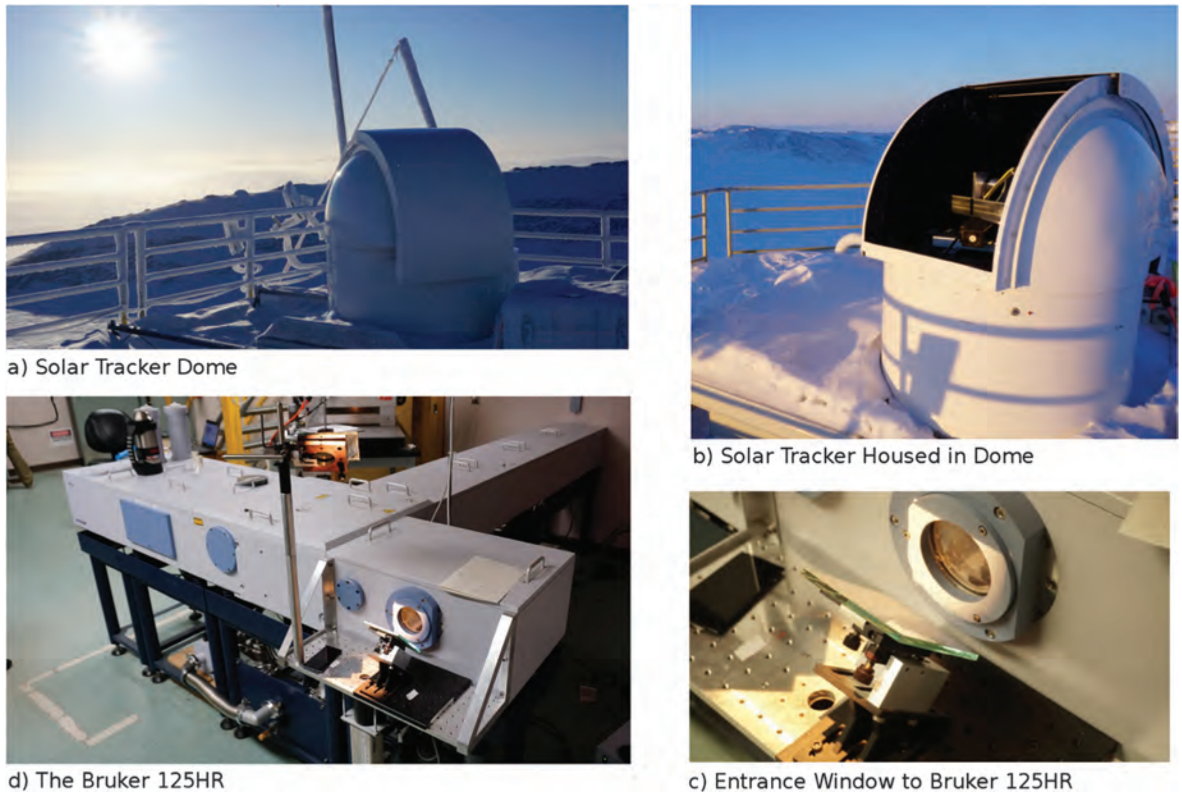

Fig. 1 The PEARL FTIR spectrometer and solar tracker system at Eureka.

spectra are recorded in the near-infrared (3800-11000 cm^{-1}) at 0.02 cm^{-1} resolution using a CaF_2 beamsplitter and InGaAs detector.

In addition to these two network-affiliated instruments, there are DA8 spectrometers installed at Environment and Climate Change Canada's (ECCC's) Centre for Atmospheric Research Experiments (CARE) at Egbert, Ontario, and at the Dalhousie Atmospheric Observatory in Halifax [11], an ABB Bomem Extended-range Atmospheric Emitted Radiance Interferometer (E-AERI) at PEARL [12,13], and the portable ABB Bomem Portable Atmospheric Research Interferometric Spectrometer for the Infrared (PARIS-IR) [14]. A new boreal TCCON site is also being established at East Trout Lake, Saskatchewan by Debra Wunch (University of Toronto), and horizontal long-path systems are being set up at Halifax [15] and Toronto for boundary layer measurements.

For both the PEARL and TAO NDACC measurements, spectra are processed using the SFIT4 retrieval algorithm (https://wiki.ucar.edu/display/sfit4/), widely used by the NDACC FTIR community. SFIT4 is based on the optimal estimation method [16], which combines a priori information with information contained in the spectral measurements. A line-by-line radiative transfer model is used as the forward model to calculate absorption spectra of the trace gas of interest given temperature, pressure, and a priori volume mixing ratio (VMR) profiles and spectroscopic line parameters. The a priori VMR profile is iteratively adjusted until convergence is reached and the difference between the measured and calculated spectra is minimized. The retrieved VMR profiles can be converted to density profiles using temperature and pressure profiles and integrated to yield total and partial column densities. Numerous trace gases have been retrieved from our FTIR spectra, including O_3, HF, HCl, HNO_3, NO, NO_2, and $ClONO_2$, for stratospheric studies, and N_2O, H_2O, HDO, CO, OCS, CH_4, C_2H_6, C_2H_2, HCN, HCHO, CH_3OH, and HCOOH for tropospheric science. For PEARL TCCON spectra, the GFIT nonlinear least-squares spectral fitting algorithm is used; the general approach is similar but the a priori profile is scaled to obtain a profile that is converted into a total column and then into a column-averaged dry-air mole fraction using the retrieved column of O_2 [7], with CO_2 and CH_4 being the two primary data products.

UV-VISIBLE SPECTROSCOPY

The measurement of atmospheric constituents using UV-visible differential optical absorption spectroscopy (DOAS) is a well-proven and widely used technique, also included in NDACC. Spectra are recorded over a wide spectral range, allowing simultaneous detection of several gases, while the DOAS approach of ratioing spectra to a reference spectrum eliminates solar lines, the instrument response function, and smoothly varying features such as Rayleigh and aerosol scattering, allowing the detection of very weak absorptions. Historically, ground-based UV-visible spectrometers made measurements of scattered sunlight using zenith-sky viewing geometry [17,18]. With this technique, sunlight traverses a long path through the stratosphere, but only a short path through the troposphere, enhancing the relative contribution of stratospheric absorption. In recent years, multi-axis DOAS (MAX-DOAS) has been successfully applied to retrieve trace gas concentrations in the troposphere from spectra of scattered sunlight measured over a range of elevation angles above the horizon [19].

We have two UV-visible instruments, the University of Toronto Ground-Based Spectrometer (UT-GBS) and the PEARL-GBS. These both include a Horiba/Jobin-Yvon Triax-180, which is a crossed Czerny-Turner triple-grating imaging spectrometer, coupled to a thermoelectrically cooled charge-coupled device detector. Depending on the choice of grating, spectra can be recorded over different spectral ranges at varying spectral resolution. As NDACC instruments, the GBSs use the zenith-sky DOAS technique. The UT-GBS was assembled in 1998 and deployed on the ground during the four Middle Atmosphere Nitrogen TRend Assessment (MANTRA) balloon campaigns [20-22]. It has also taken measurements at Eureka during polar sunrise from 1999-2001 and 2003-2016 (as part of the Canadian Arctic ACE/OSIRIS Validation Campaigns since 2004 [23]) and was permanently installed at PEARL in 2008, primarily operating in the visible for measurements of ozone and NO_2. The PEARL-GBS is a newer instrument that was installed inside at PEARL in August 2006 [24] and primarily works in the UV for measurements of BrO and OClO. With the later installation of solar trackers, the instruments were upgraded in 2011 (PEARL-GBS) and 2015 (UT-GBS) to enable MAX-DOAS measurements.

The relative portability of UV-visible spectrometers makes it possible to conduct intercomparison campaigns to assess their performance and improve measurement strategies. In 2009, the UT-GBS participated in the Cabauw Intercomparison of Nitrogen Dioxide Measuring Instruments (CINDI), an NDACC campaign held in the Netherlands [25]. This was followed by the CINDI-2 campaign in September 2016, also held at Cabauw (http://www.tropomi.eu/science/cindi-2). The goal of this campaign was to characterize differences between the measurement approaches and systems used within the international DOAS community, and to work towards harmonisation of MAX-DOAS settings and retrievals in preparation for global validation of satellite missions focusing on air quality, such as the European Space Agency's upcoming Sentinel 5 Precursor. The PEARL-GBS was one of about 30 instruments participating in this initiative (see Fig. 2) and detailed comparisons are now underway.

COMPOSITION MEASUREMENTS

The troposphere is a chemically complex region of the atmosphere, where gases from natural and anthropogenic sources undergo transport and chemical processing on similar time scales. Measurements of atmospheric composition in the troposphere provide insight into issues related to air quality and climate change. Air quality is generally monitored by measurements of "criteria air contaminants" that are correlated with adverse health consequences. The chemical and dynamical relationships between these species and their precursors are complex and non-linear. Changes in anthropogenic emissions and climate will alter these relationships and the oxidizing capacity of the troposphere. While an urban location like Toronto is clearly subject to pollution events, the Arctic also experiences poor air quality due to transport from mid-latitudes.

Current research questions include the links between regional air quality and global atmospheric chemistry, the impact of climate change on air quality, production of ozone from tropical and mid-latitude emissions of precursors such as methane, transport pathways of pollutants into the Arctic, new sources of local pollution from shipping and oil/gas extraction, and deposition of harmful contaminants in snow. Arctic tropospheric ozone is greatly affected by severe surface ozone depletion events, first observed at Alert and since linked to extremely high concentrations of BrO in bromine explosion events. These are still not fully understood, but are important because they increase the deposition of mercury to snow, causing harmful effects on ecosystems and humans. Tropospheric ozone in the Arctic also acts a significant short-term climate forcer.

Meanwhile, increases in the concentrations of greenhouse gases are well documented, but "*Understanding the global carbon cycle, and predicting its evolution under future climate scenarios is one of the biggest challenges facing science today*" [26]. These challenges are due to lack of sufficient knowledge about carbon sources and sinks, feedbacks between climate change and carbon reservoirs, and anthropogenic emissions from fossil fuel burning and land use change. The issues are more acute at high latitudes where measurements are scarce and the magnitude and distribution of carbon sinks and sources are poorly known.

We are using trace gas measurements at Toronto and Eureka to address some of these scientific issues. The combined TAO/CARE FTIR dataset of HF, HCl, N_2O, and O_3 columns has been used to identify polar vortex intrusion events over Toronto, and establish a dynamical cause for some of the winter/spring variability of stratospheric trace gases observed at this mid-latitude site [27]. In another study, the GEOS-Chem 3-D chemical transport model was used to interpret the FTIR measurements of tropospheric O_3, CO, and C_2H_6, and to identify the sources of air pollution over Toronto [28]. Our FTIR data have been included in numerous multi-station studies; a few

Fig. 2 Remote sensing instruments performing measurements during the CINDI-2 campaign held at the Royal Netherlands Meteorological Institute's Cabauw site in September 2016. PEARL-GBS is inside the white box in the middle of the picture, with its tracking system mounted on top of the box.

examples include solar and lunar measurements of nitric acid compared with models [29], source attribution of Arctic pollution [30,31], CO_2 flux inversions [32], trends in HCl, $ClONO_2$, and HF [33], tropospheric water vapour isotopologues [34], global methane signals [35], sources and sinks of carbonyl sulfide [36], and detecting and attributing the recent rise in ethane and methane emissions to expansion of oil and natural gas extraction in North America [37]. Other studies have included the first detection of NO in the upper atmosphere by ground-based FTIR spectroscopy [38] and determination of the Arctic NOy budget [39]. The data have also been used to evaluate and improve atmospheric models [40,41], including ECCC's new Carbon Assimilation System [42]. DOAS measurements of BrO and ozone have been combined with satellite data to track a bromine explosion event transported from the Beaufort Sea to Eureka [43] and used to investigate the impact of the 2008 solar eclipse on ozone and NO_2 [44]. Measurements from both sites have also been used for validation of data products from

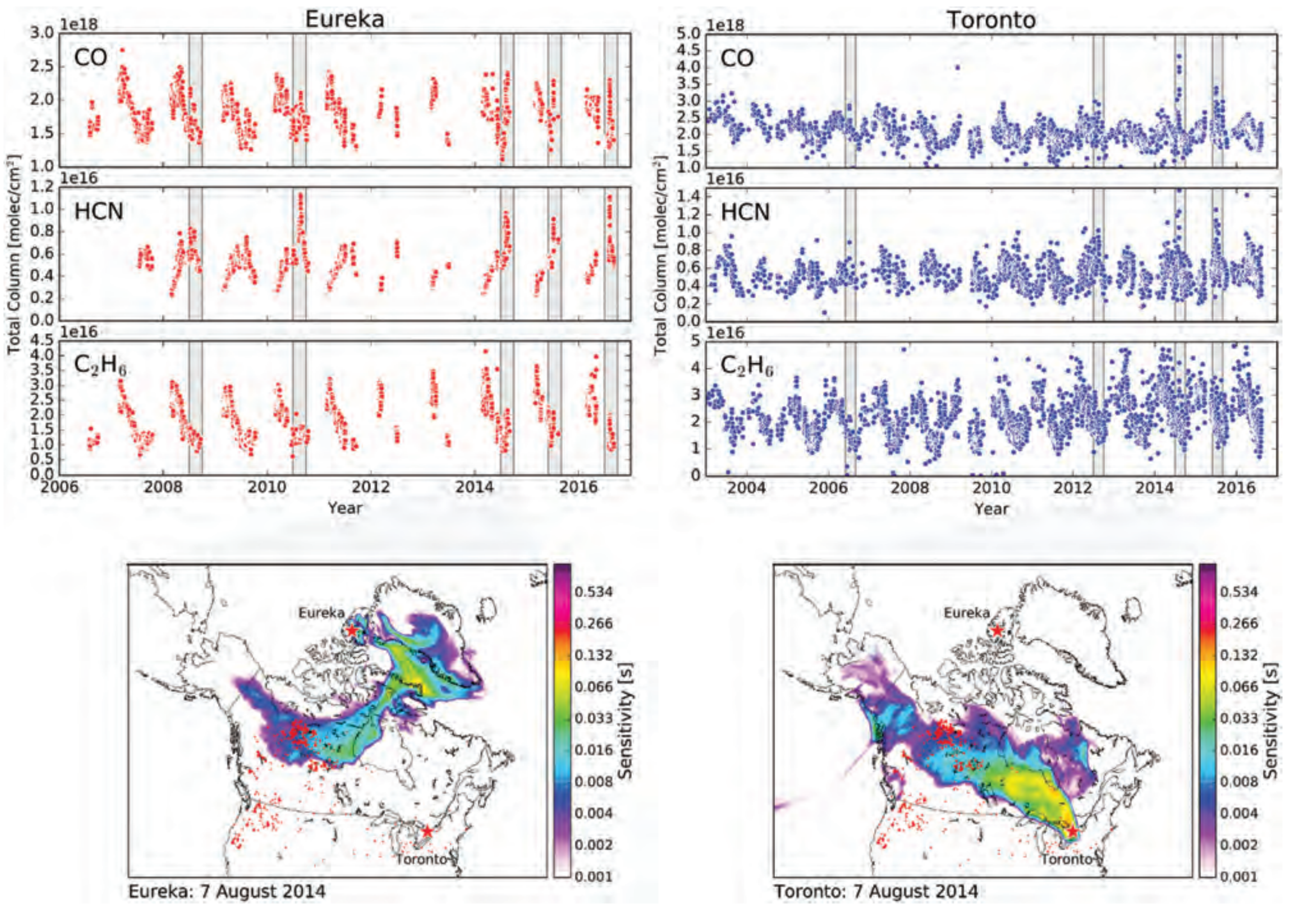

Fig. 3 Top panel: Time series of CO, HCN and C_2H_6 for Eureka (left, red) and Toronto (right, blue). Bottom panel: FLEXPART sensitivity of Eureka and Toronto measurements on August 7, 2014 to the Northwest Territories fires. The red points are the MODIS fire hot spots, indicating the location of wildfires.

Canadian (ACE-FTS and MAESTRO on SciSat, OSIRIS on Odin), American (OCO-2), European (SCIAMACHY on Envisat, IASI on MetOp), and Japanese (TANSO-FTS on GOSAT) satellite instruments.

DETECTION OF BIOMASS BURNING POLLUTION

One focus of attention over the last several years has been the detection of smoke plumes transported from forest fires and the derivation of emission factors. Biomass burning is a considerable source of trace gases and aerosols that can affect tropospheric chemistry and radiative balance. The Arctic is a major receptor to pollution from mid-latitude regions, including emissions from boreal fires. The influence of biomass burning is further complicated by the sensitivity of fire intensity and frequency to climate change and to land use practices. There have been some suggestions that wildfire activity in North America is increasing in response to climate change [45,46], but the interannual variability of biomass burning events and trends in emissions remain uncertain.

Trace gas measurements by FTIR instruments provide a means of detecting transport of biomass burning plumes into the Arctic where satellite and in-situ observations may be sparse. Emissions from boreal wildfires have been shown to contribute to the day-to-day variabilities of seven tropospheric species observed at Eureka [47]. In the time series presented in Fig. 3, the gray shaded regions highlight periods of fire-affected measurements for major biomass burning events. The species CO, HCN, and C_2H_6 are all emitted in large abundances from wildfires, and enhancements of their total columns were observed at Eureka in July-August 2008, 2010, and 2016 due to boreal fires in Russia. For Toronto, pollution from forest fires in Northern Ontario was detected in July 2006. Pollution was observed at both sites in July-August 2014 from wildfires in the Northwest Territories, and in June 2015 due to fires in Saskatchewan.

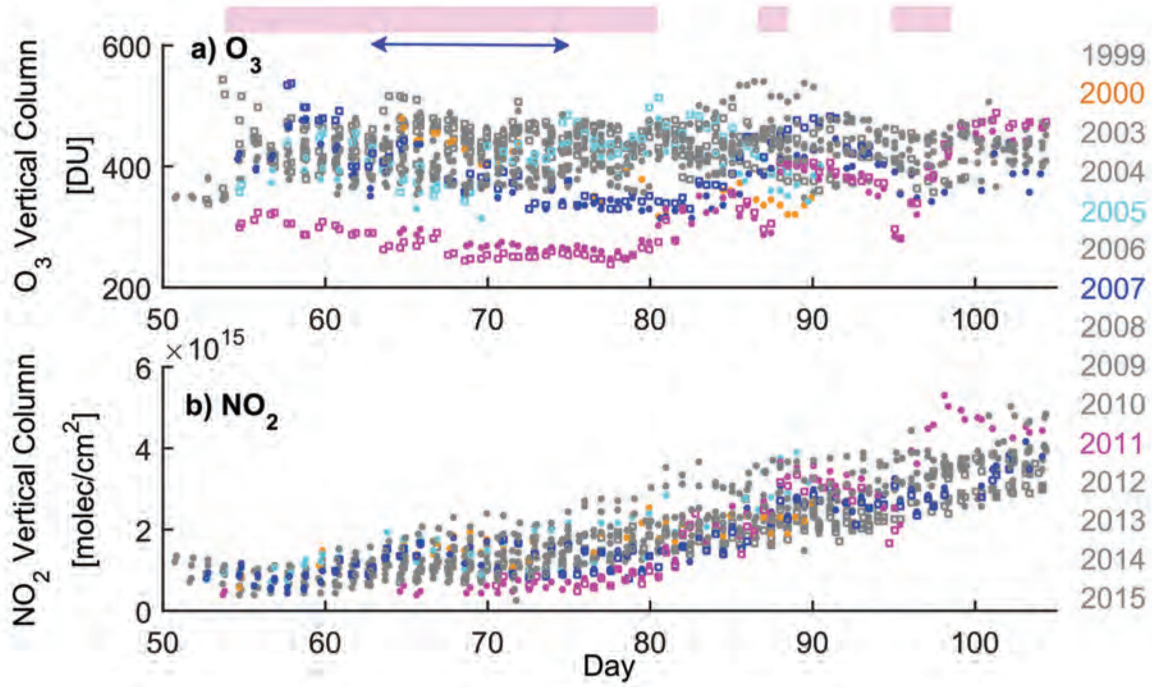

Fig. 4 Time series of zenith-sky DOAS measurements of ozone and NO_2 for 1999-2015 versus day of year. Year 2000 is shown in orange, 2005 in cyan, 2007 in blue, 2011 in magenta, and all other years are shown in grey. (a) Ozone total columns measured by the UT-GBS (closed circles) and SAOZ (open squares). The magenta bar at the top indicates periods when the polar vortex was above Eureka and the blue line indicates when temperatures were below the threshold for the formation of polar stratospheric clouds. (b) NO_2 partial columns (17 km to top of atmosphere) measured by UT-GBS (closed circles) and PEARL-GBS (open squares). SAOZ data courtesy of Florence Goutail and Andrea Pazmino, Laboratoire Atmosphères, Milieux, Observations Spatiales (LATMOS), France.

The long-range impact of wildfires is evident in the source attribution for each measurement site. An example is shown in Fig. 3 for the 2014 Northwest Territories fires. For each site, the Lagrangian particle dispersion model FLEXPART [48] is run backwards in time. A total of 60,000 air-tracer particles are released over a 6-hr period about the peak enhancement of CO at Eureka and Toronto. The model is then run backwards in time for 7 days. The residence time of the particles is proportional to the sensitivity of the measurement to various source regions. The fire locations are indicated by the Moderate Resolution Imaging Spectroradiometer (MODIS) fire hot-spots, plotted in red. For both sites, sensitivity of the measurements to the fires in the Northwest Territories is observed. Measurements of pollution are thus not only influenced by nearby sources, but also by long-range transport from distant sources; this is particularly important in the Arctic, a region isolated from local anthropogenic and biomass burning sources.

Using CO as a tracer of biomass burning emission, the measured ratio of the abundance of a trace gas species to the abundance of CO for fire-affected measurements is indicative of the emissions of the species at the fire source, which is dependent on the type of vegetation burned. This is referred to as the emission factor, which is the ratio of the abundance of a species emitted to the amount of dry matter burned. Precise emission factors are required for improved accuracy of atmospheric chemistry and climate models. FTIR measurements at Eureka and Toronto have been used to determine emission factors from boreal forests for HCN and C_2H_6 [49-51], as well as for other minor species including C_2H_2, HCOOH, CH_3OH and H_2CO [50], and NH_3 [51]. The latter are the first long-term measurements of ammonia in the High Arctic transported from wildfires.

ARCTIC STRATOSPHERIC OZONE DEPLETION

The PEARL Ridge Lab, which houses the FTIR and GBS instruments, was built by Environment Canada in 1992. It was originally named the Arctic Stratospheric Ozone Observatory, reflecting its scientific focus given the intense interest in polar stratospheric ozone after the discovery of the Antarctic ozone hole in 1985. Arctic ozone chemistry, in both the troposphere and the stratosphere, remains a subject of interest. While the Montreal Protocol and its amendments have reduced the production of ozone-depleting chlorofluorocarbons, their long lifetimes mean that stratospheric ozone depletion will continue for several decades. In the Arctic, there continues to be springtime ozone depletion, averaging 10-15% since 1980. At the same time, the impact of climate change on ozone is increasing, and there is considerable interest in the processes coupling stratospheric chemistry and climate, in the Arctic and globally. While increasing concentrations of CO_2 are cooling the stratosphere and thereby reducing global ozone loss rates, this cooling may generate more polar stratospheric clouds (PSCs) and enhance chemical ozone depletion in the Arctic. Springtime ozone depletion continues in this region, with significant interannual variability driven by atmospheric dynamics, transport, and temperature. Chemistry-climate models predict that springtime Arctic ozone will recover to 1980 values between 2025 and 2035, with the evolution of the ozone layer in the late 21st century strongly influenced by atmospheric abundances of CO_2, N_2O, and CH_4 [52].

In 2011, PEARL observations captured the largest stratospheric ozone depletion event ever seen in the Arctic. This occurred exactly over PEARL, with about 40% of the ozone column destroyed due to the stable vortex and very low stratospheric temperatures. Eureka is an ideal location for stratospheric measurements, as the winter polar vortex regularly passes overhead, allowing measurements to be made under both chemically perturbed and unperturbed conditions; the site of the Ridge Lab was chosen for this reason. Both the PEARL FTIR and the GBS instruments measured unprecedentedly low ozone columns in spring 2011, when the polar vortex was typically circular, cold and centered above the pole, with Eureka mostly inside the vortex from October 2010 until late March 2011. Complementary measurements of unusually low HCl, NO_2, $ClONO_2$, and HNO_3 total columns, enhanced OClO columns, and lidar observations of polar stratospheric clouds above Eureka all indicated chlorine activation on cold aerosol particles followed by chemical ozone destruction [53,54].

As seen in Fig. 4, ozone columns measured by the GBSs and a similar System d'Analyse par Observations Zenithales (SAOZ) UV-visible spectrometer [55] were lower than in any other year between 1999 and 2015. In 2000, 2005, and 2007, the polar vortex was also overhead and low ozone and NO_2 columns were also observed. However, 2011 is notably different, with a maximum percent ozone loss of 47% or 250 Dobson Unit (DU, 1 DU $= 2.69 \times 10^{16}$ molec cm^{-2}) derived from UT-GBS data on 5 April 2011. These measurements agree with photochemical model runs, which indicate that prolonged denitrification by sedimentation of polar stratospheric clouds delayed chlorine deactivation, leading to the record ozone loss [56]. Unusual conditions were also observed in late spring 2011, when a frozen-in anticyclone in the middle stratosphere above Eureka resulted in anomalous chemistry, enhancing the NO_2 VMR in this region and causing unusually large ozone loss in April/May compared with previous years [57]. Over the next few decades, while stratospheric chlorine and bromine loading remains high, similar ozone depletion events are expected to occur when dynamic variability results in an isolated polar vortex with persistently cold stratosphere [52].

CONCLUSION

Measurements of chemical constituents are essential for understanding atmospheric composition and its spatial and temporal variability, as well as the underlying chemical processes and the role of dynamical transport. Ground-based UV-visible and Fourier transform infrared spectrometers are capable of measuring several dozen atmospheric species over many years, providing data sets that can be used to address a wide array of scientific questions related to ozone, air quality, and climate. Such measurements have been made in Toronto and Eureka for over a decade and have contributed to improving our knowledge of atmospheric composition over Canada.

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TAO and PEARL data mentioned in this paper can be found at ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/toronto, ftp://ftp.cpc.ncep.noaa.gov/ndacc/station/eureka/, and ftp://tccon.ornl.gov/2014Public/eureka01/R0_archive/.

REFERENCES

1. National Academies of Sciences, Engineering, and Medicine, *The Future of Atmospheric Chemistry Research: Remembering Yesterday, Understanding Today, Anticipating Tomorrow*, doi:10.17226/235730, The National Academies Press, 2016.
2. AMAP Assessment, *Black carbon and ozone as Arctic climate forcers*, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, 2005.
3. G. Shepherd and A. Kruchio, *Canada's Fifty Years in Space – The COSPAR Anniversary*, Apogee Books, 2008.

4. A.W. Brewer, *et al*., "Nitrogen dioxide concentration in the atmosphere", *Nature*, **246**, 129-133 (1973).
5. J.R. Drummond, "Atmospheric Chemistry in the Arctic at the PEARL Observatory Located at Eureka", *Physics in Canada*, **73**, this issue (2017).
6. A. Goldman, *et al*., Network for the Detection of Stratospheric Change Fourier transform infrared intercomparison at Table Mountain Facility, November 1996", *J. Geophys. Res*., **104** (D23), 30481-30503 (1999).
7. D. Wunch, *et al*., "The Total Carbon Column Observing Network", *Phil. Trans. R. Soc. A*, **369** (1943), 2087-2112 (2011).
8. A. Wiacek, *et al*., "Ground-based solar absorption FTIR spectroscopy: Characterization of retrievals and first results from a novel optical design instrument at a new NDACC complementary station", *J. Atmos. Oceanic Technology*, **24** (3), 432-448 (2007).
9. R.L. Batchelor, *et al*., "A new Bruker IFS 125HR FTIR spectrometer for the Polar Environment Atmospheric Research Laboratory at Eureka, Canada – measurements and comparison with the existing Bomem DA8 spectrometer", *J. Atmos. Oceanic Technology*, **26** (7), 1328-1340 (2009).
10. H. Fast, *et al*., "A ten-year record of Arctic trace gas total column measurements at Eureka, Canada, from 1997 to 2006", *Atmos.-Ocean*, **49** (2), 67-94 (2011).
11. J.E. Franklin, *et al*., A case study of aerosol scavenging in a biomass burning plume over eastern Canada during the 2011 BORTAS field experiment, *Atmos. Chem. Phys*., **14**, 8449-8460 (2014).
12. Z. Mariani, *et al*., "Infrared measurements in the Arctic using two Atmospheric Emitted Radiance Interferometers", *Atmos. Meas. Tech*., **5**, 329-344 (2012).
13. Z. Mariani, *et al*., "Year-round retrievals of trace gases in the Arctic using the Extended-range Atmospheric Emitted Radiance Interferometer", *Atmos. Meas. Tech*., **6**, 1549-1565 (2013).
14. D. Fu, *et al*., "The Portable Atmospheric Research Interferometric Spectrometer for the InfraRed, PARIS-IR", *J. Quant. Spectrosc. Rad. Transfer*, **103**, 362-370 (2007).
15. A. Wiacek, "Active open-path spectroscopic measurements of marine boundary layer composition in Halifax", *Physics in Canada*, this issue (2017).
16. C.D. Rodgers, *Inverse methods for atmospheric sounding: theory and practice*, World Scientific Co. Pte. Ltd., 2000.
17. S. Solomon, *et al*., "On the interpretation of zenith sky absorption measurements", *J. Geophys. Res*., **2**, 8311-8319 (1987).
18. U. Platt and J. Stutz, *Differential Optical Absorption Spectroscopy: Principles and Applications*, Springer, 2008.
19. G. Hönninger, *et al*., "Multi axis differential optical absorption spectroscopy (MAX-DOAS)", *Atmos. Chem. Phys*., **4**, 231-254 (2004).
20. M.R. Bassford, *et al*., "Ground-based measurements of ozone and NO_2 during MANTRA 1998 using a new zenith-sky spectrometer", *Atmos.-Ocean*, **43** (4), 325-338 (2005).
21. S.M.L. Melo, *et al*., "Retrieval of stratospheric NO_2 vertical profiles from ground-based measurements: Results for the MANTRA 1998 field campaign", *Atmos.-Ocean*, **43** (4), 339-350 (2005).
22. A. Fraser, *et al*., "Intercomparison of ground-based ozone and NO_2 measurements during the MANTRA 2004 campaign", *Atmos. Chem. Phys*., **7**, 5489-5499 (2007).
23. A. Fraser, *et al*., "Intercomparison of UV-visible measurements of ozone and NO_2 during the Canadian Arctic ACE validation campaigns: 2004-2006", *Atmos. Chem. Phys*., **8**, 1763-1788 (2008).
24. A. Fraser, *et al*., "The Polar Environment Atmospheric Research Laboratory UV-visible Ground-Based Spectrometer: First measurements of O_3, NO_2, BrO, and OClO columns", *J. Quant. Spectrosc. Radiat. Transfer*, **110**, 986-1004 (2009).
25. A.J.M. Piters, *et al*., "The Cabauw Intercomparison campaign for Nitrogen Dioxide Measuring Instruments (CINDI): design, execution, and early results", *Atmos. Meas. Tech*., **5**, 457-485 (2012).
26. P. Ciais, *et al*., *Geo Carbon Strategy*, Geo Secretariat Geneva / FAO Rome (2010).
27. C. Whaley, *et al*., "Using FTIR measurements of stratospheric composition to identify mid-latitude polar vortex intrusions over Toronto", *J. Geophys. Res. Atmos*., **118** (2), 12766-12783 (2013).
28. C.H. Whaley, *et al*., "Toronto area ozone: Long-term measurements and modeled sources of poor air quality events", *J. Geophys. Res. Atmos*., **120** (D21), 11368-11390 (2015).
29. E.E. Farahani, *et al*., "Nitric acid measurements at Eureka obtained in winter 2001-2002 using solar and lunar Fourier transform infrared absorption spectroscopy: comparisons with observations at Thule and Kiruna and with results from three-dimensional models", *J. Geophys. Res*., **112**, D01305 (2007).
30. J.A. Fisher, *et al*., "Source attribution and interannual variability of Arctic pollution in spring constrained by aircraft (ARCTAS, ARCPAC) and satellite (AIRS) observations of carbon monoxide", *Atmos. Chem. Phys*., **10**, 977-996 (2010).
31. C. Wespes, *et al*., "Analysis of ozone and nitric acid in spring and summer Arctic pollution using aircraft, ground-based, satellite observations and MOZART-4 model: source attribution and partitioning", *Atmos. Chem. Phys*., **12**, 237-259 (2012).
32. F. Chevallier, *et al*., "Global CO_2 fluxes inferred from surface air-sample measurements and from TCCON retrievals of the CO_2 total column", *Geophys. Res. Lett*., **38**, L24810 (2011).
33. R. Kohlhepp, *et al*., "Observed and simulated time evolution of HCl, $ClONO_2$, and HF total column abundances", *Atmos. Chem. Phys*., **12**, 3527-3557 (2012).
34. M. Schneider, *et al*., "Ground-based remote sensing of tropospheric water vapour isotopologues within the project MUSICA", *Atmos. Meas. Tech*., **5**, 3007-3027 (2012).

35. M. Schneider, *et al*., "Ground-based remote sensing of tropospheric water vapour isotopologues within the project MUSICA", *Atmos. Meas. Tech*., **5**, 3007-3027 (2012).
36. Y. Wang, *et al*., "Towards understanding the variability in biospheric CO_2 fluxes: using FTIR spectrometry and a chemical transport model to investigate the sources and sinks of carbonyl sulfide and its link to CO_2", *Atmos. Chem. Phys*., **16**, 2123-2138 (2016).
37. B. Franco, *et al*., "Evaluating ethane and methane emissions associated with the development of oil and natural gas extraction in North America", *Environ. Res. Lett*., **11**, 044010 (2016).
38. A. Wiacek, *et al*., "First detection of meso-thermospheric nitric oxide (NO) by ground-based FTIR solar absorption spectroscopy", *Geophys. Res. Lett*., **33** (3), L03811 (2006).
39. R. Lindenmaier, *et al*., "A study of the Arctic NOy budget above Eureka, Canada", *J. Geophys. Res*., **116**, D23302 (2011).
40. C. Risi, *et al*., "Process-evaluation of tropospheric humidity simulated by general circulation models using water vapor isotopologues. Part 1: comparison between models and observations", *J. Geophys. Res*., **117**, D05303 (2012).
41. S. Kulawik, *et al*., "Consistent evaluation of ACOS-GOSAT, BESD-SCIAMACHY, CarbonTracker, and MACC through comparisons to TCCON", *Atmos. Meas. Tech*., **9**, 683-709 (2016).
42. S.M. Polavarapu, *et al*., "Greenhouse gas simulations with a coupled meteorological and transport model: the predictability of CO_2", *Atmos. Chem. Phys*., **16**, 12005-12038 (2016).
43. X. Zhao, *et al*., "A case study of a transported bromine explosion event in the Canadian high Arctic", *J. Geophys. Res. Atmos*., **121** (D1), 457-477 (2016).
44. C. Adams, *et al*., "Ozone and NO_2 variations measured during the August 1, 2008 solar eclipse above Eureka, Canada with a UV-visible spectrometer", *J. Geophys. Res*., **115**, D19310 (2010).
45. N.P. Gillett, *et al*., "Detecting the effect of climate change on Canadian forest fires", *Geophys. Res. Lett*., **31**, L18211 (2004).
46. A.L. Westerling, *et al*., "Warming and earlier spring increase Western U.S. forest wildfire activity", *Science*, **313** (5789), 940-943 (2006).
47. C. Viatte, *et al*., "Five years of CO, HCN, C_2H_6, C_2H_2, CH_3OH, HCOOH, and H_2CO total columns measured in the Canadian High Arctic", *Atmos. Meas. Tech*., **7**, 1547-1570 (2014).
48. A. Stohl, *et al*., "Technical note: The Lagrangian particle dispersion model FLEXPART version 6.2", *Atmos. Chem. Phys*., **5**, 2461-2474 (2005).
49. C. Viatte, *et al*., "Measurements of CO, HCN, and C_2H_6 total columns in smoke plumes transported from the 2010 Russian boreal forest fires to the Canadian High Arctic", *Atmos.-Ocean*, **51** (5), 522-531 (2013).
50. C. Viatte, *et al*., "Identifying fire plumes in the Arctic with tropospheric FTIR measurements and transport models", *Atmos. Chem. Phys*., **15** (5), 2227-2246 (2015).
51. E. Lutsch, *et al*., "Long-range transport of NH_3, CO, HCN and C_2H_6 from the 2014 Canadian wildfires", *Geophys. Res. Lett*., **43**, 8286-8297 (2016).
52. World Meteorological Organization (WMO), *Scientific Assessment of Ozone Depletion: 2014,* World Meteorological Organization, Global Ozone Research and Monitoring Project—Report No. 55, Geneva, Switzerland, 2014.
53. C. Adams, *et al*., "Severe 2011 ozone depletion assessed with 11 years of ozone, NO_2, and OClO measurements at 80°N", *Geophys. Res. Lett*., **39**, L05806 (2012).
54. R. Lindenmaier, *et al*., "Unusually low O_3, HCl, and HNO_3 column measurements at Eureka, Canada during spring 2011", *Atmos. Chem. Phys*., **12**, 3821-3835 (2012).
55. F. Hendrick, *et al*., "NDACC/SAOZ UV-visible total ozone measurements: improved retrieval and comparison with correlative ground-based and satellite observations", *Atmos. Chem. Phys*., **11**, 5975-5995 (2011).
56. G.L. Manney, *et al*., "Unprecedented Arctic ozone loss in 2011", *Nature*, **478**, 469-475 (2011).
57. C. Adams, *et al*., "The spring 2011 final stratospheric warming above Eureka: anomalous dynamics and chemistry", *Atmos. Chem. Phys*., **13**, 611-624 (2013).

ATMOSPHERIC CHEMISTRY IN THE ARCTIC AT THE PEARL OBSERVATORY LOCATED AT EUREKA, NUNAVUT

BY JAMES R. DRUMMOND AND THE CANDAC TEAM

The Polar Environment Atmospheric Research Laboratory (PEARL) is located at 80°N, 86°W on Ellesmere Island, near Environment and Climate Change Canada's (ECCC's) Eureka Weather Station. PEARL is a self-contained scientific laboratory operated year-round by the Canadian Network for the Detection of Atmospheric Change (CANDAC) since 2006. Most of the research conducted at PEARL concerns the Arctic atmosphere, but other branches of science are supported including geology and astronomy.

The equipment installed at PEARL comprises a complete monitoring system for looking at the atmosphere from the surface of the earth to a height of about 100 km. More than 20 instruments are currently deployed and there is a "guest instrument" program in place for those who wish to place equipment at PEARL.

Measurements for atmospheric studies at the PEARL are of two types: "in situ" measurements where a sample of the atmosphere is ingested into an apparatus for measurement, and remote sensing measurements which monitor the atmosphere at a distance from the measuring instrument. These remote sensing measurements all rely implicitly or explicitly on spectroscopic and related parameters and use many wavelengths and interactions between the atmosphere and electromagnetic radiation for their success.

INSTRUMENTATION AT PEARL

Remote sensing instruments rely on analyzing incoming electromagnetic radiation to the instrument. At PEARL there are four major sources of radiation:

(1) Sunlight outside of the atmosphere can be nearly described by a Planck function for $\sim$5780K which peaks around 11,000 cm^{-1} ($\sim$1 μm). The main advantages of using solar radiation as a source are its directionality which allows for easy localization of the measurement and the strength of the solar beam which results in high(er) signal-to-noise at the detector. However, there is a major disadvantage to solar radiation at PEARL – from mid-October to mid-February there is none and it is dark. We can use moonlight (reflected sunlight) or starlight as substitutes, but these are very much weaker than sunlight and the signal-to-noise of measurements is correspondingly worse. The dark polar night also has profound effects on the atmosphere as we discuss below.

(2) Thermal radiation is ubiquitous for any object above absolute zero temperature and radiation is emitted appropriate to the Planck function which averages below zero degrees centigrade at PEARL. The peak of the radiation is around 500-600 cm^{-1} (16-20 μm). The radiation is omnidirectional and so the instrument receiver defines the field of view and the localization of the measurement. Thermal radiation can be used year-round but the signal-to-noise of measurements tends to be lower than with the solar beam and the radiative transfer calculations are more involved.

(3) Several processes can excite atoms and molecules in the upper atmosphere which then decay emitting radiation at detectable wavelengths. The most usable wavelengths for measurement are in the visible region because the atmosphere is transparent in this region and the interactions that occur at high altitudes are visible from the ground. Measurements are more easily made during the polar night because of the absence of sunlight.

(4) Finally, we can provide our own radiation source by emitting energy and detecting energy transmitted or, more frequently, "backscattered" to the receiver. Some of these measurements are possible in both day and night and this method, through "time of flight" measurements, provides range determination and therefore better localization of the measurement. However, the complexity (and power consumption) of the source also need to be factored into any discussion of usability.

SUMMARY

The remote sensing equipment for atmospheric studies at the Polar Environment Atmospheric Research Laboratory (PEARL) at Eureka, Nunavut is described.

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TABLE 1
SOME SPECTRAL CHARACTERISTICS OF THE REMOTE SENSING INSTRUMENTATION AT PEARL.

Wavelength	Instrument	Parameter Measured	Comments
287-363 nm	Brewer ozone spectrophotometer	Ozone	Uses sunlight and differential absorption
Transmit: 308/353 nm Receive: 308/332/353/ 385/406 nm	Differential Absorption Lidar (DIAL)	Aerosol, temperature, ozone, water vapour	Uses differential absorption to detect ozone profiles
340-1640 nm	CIMEL	Aerosols and optical depth	Measures attenuation of sunlight or moonlight
340-540 nm	Ground-Based Spectrometers (UT and PEARL-GBS)	Ozone and other constituents	Measure direct or scattered sunlight
420-1040 nm	Star photometer	Aerosols and optical depth	Measures attenuation of starlight
Transmit: 532/355 nm Receive: 355-607 nm	CANDAC Rayleigh-Mie-Raman Lidar (CRL)	Clouds, aerosol properties, droplets/ice particles	Uses polarisation to distinguish ice from water
428-910 nm	All-Sky Imager (ASI)	Spatial and temporal fluctuations in airglow and aurora	Several narrow band images at specific airglow wavelengths
558-866 nm	E-Region Wind Interferometer (ERWIN)	Winds in the mesosphere	Interferometric measurement of Doppler shifts of airglow
834-868 nm	Spectral Airglow Temperature Imager (SATI)	Dynamics and temperature of the mesosphere	2-channel spatial scanning Fabry-Perot interferometer
2.4-14 µm	Bruker Fourier Transform Spectrometer (FTS)	minor constituents	Absorption of direct solar beam
3-25 µm	Extended-Range Atmospheric Emitted Radiance Interferometer (E-AERI)	Downwelling radiance and minor constituents	Measures downwards directed radiation throughout the year
Transmit/Receive: 35 GHz	MilliMeter Cloud Radar (MMCR)	Cloud properties	Active radar
23.8 and 31.4 GHz	Microwave Radiometer	Water vapour/liquid	Microwave emission
Transmit/Receive: 52 MHz	VHF radar	Winds and turbulence	Backscatter from atmospheric inhomogeneities
Transmit/Receive: 34.1 MHz	Meteor radar	Winds Temperature around 80-100 km	Measures scatter from ionised meteor trails

Table 1 shows many of the instruments used for remote sensing at PEARL. They include both active sensors, generating their own probe beams and passive instruments relying on natural radiation arriving at the surface. Use is made of the entire spectrum from the ultraviolet to the radio region to elucidate a wide range of atmospheric parameters.

Ultraviolet and Visible Region

In the range 300-600 nm we have a series of lidars. In their simplest form these measure the time of flight of an upward-directed coherent light pulse from the transmitter to a backscattering layer. Scattering can occur from any "particle" from a molecule to a water droplet and the scattering can be elastic or inelastic. Inelastic scattering is particularly interesting because it can reveal details about the composition of the atmosphere as well as its physical state.

Of particular interest is the ozone Differential Absorption Lidar (DIAL) which makes use of the fact that ozone has a very highly structured absorption with wavelength in the ultraviolet whereas most of the other absorbers in the region have relatively unstructured absorption. Thus by choosing two wavelengths close to one another with similar unstructured absorption but with very different ozone absorptions, a unique signature for ozone can be developed as a function of altitude.

This differential absorption technique is exploited in many similar forms by other instruments at PEARL. For example, the Brewer Ozone spectrometer (developed by Dr. Alan Brewer and colleagues at the University of Toronto and further enhanced by the staff at Environment and Climate Change Canada before going into commercial production) uses very similar wavelengths to the DIAL, but it measures the attenuation of sunlight through the atmosphere rather than producing its own radiation. Two other Ultraviolet-Visible spectrometers – the ground-based spectrometers (GBS) – also measure direct and scattered sunlight to produce measurements of atmospheric constituents including ozone.

For measurements in the upper atmosphere, around 100 km altitude, we can use observe the radiation produced by interaction with incoming particles. We can observe the entire sky at particular wavelengths using an All-Sky imager which allows us to observe spatial and temporal fluctuations in the incoming radiation. We can also measure the energy at specific wavelengths to gain information on density and temperature at these levels and by measuring the Doppler shift of the emissions we can deduce winds.

Infrared Region

As wavelengths increase from the visible into the infrared, the interaction with the components of the atmosphere shifts to the vibration-rotation bands. Since oxygen and nitrogen molecules are homopolar and therefore have a negligible vibration-rotation spectrum, the spectra observed are from more minor components of the atmosphere, some with concentrations in the parts-per-billion range. These components including water vapour, ozone, carbon oxides, nitrogen oxides, all play a considerable role in the energy balance of the atmosphere since they interact radiatively with the atmosphere, surface, sun and space. They also chemically interact with each other and incoming sunlight when present. This gives the winter polar atmosphere a distinctly different composition to the summer atmosphere and the transitions at dusk and more importantly at sunrise are extremely interesting. There is always a major observing campaign at PEARL around sunrise in mid-February to study this change-over. The paper by Strong et al in this issue gives some more detail on the infrared spectroscopy of these constituents accomplished at PEARL.

As already mentioned, daylight at PEARL occurs between mid-February and mid-October with much of this time being 24-hour daylight allowing for many measurements of solar attenuation per 24-hour period if the equipment is sufficiently automated. However, there is also the night period when there is no sunlight and in this period instruments that rely on the solar beam make no measurements. Filling in the measurements during the polar night is a major focus of instrument development at PEARL with efforts to exploit different wavelength regions, sighting off of the moon and stars, and active sensing using the lidars and radars.

As the wavelength increases through the infrared, the atmospheric emission (Planck function) also increases and by sensing this signal, measurements can be extended throughout the year.

The annual light/dark cycle at these latitudes is considerably different from the daily cycle further south and combined with the perpetually low solar zenith angles this results in a cold atmosphere. During the polar night there is no sunlight at all and therefore no solar warming of either the atmosphere or the surface and temperatures drop considerably. Surface temperatures in January are on *average* about -20°C. A spectroscopic consequence is that there is very little water vapour in the atmosphere and this has a very noticeable effect on the atmospheric transmission. This can be clearly seen in Fig. 1 which shows spectra measured by the Extended-Range Atmospheric Emitted Radiance Interferometer (E-AERI) which uses a Fourier Transform spectrometer to determine the downwards directed radiation at the surface. The first panel shows spectra taken on November 1, 2008. The "window" region at 800-1200 cm^{-1} (8-13 μm) where the atmosphere is practically transparent except for the ozone feature at 9.6 μm can clearly be seen. Since this this is close to the peak of the surface blackbody spectrum much energy from the surface is emitted directly through the atmosphere to space. A temperature inversion (where the temperature increases with altitude at and near the surface) has the effect of suppressing convection and it is no surprise that the surface becomes extremely cold and this reinforces the temperature inversion which is almost a permanent feature of the near-surface winter polar atmosphere.

As clouds move in they intercept radiation leaving the surface, closing the windows to space (cyan line in Fig. 1), and therefore the surface will warm the atmosphere and the atmosphere the surface.

In addition to the 800-1200 cm^{-1} (8-12 μm) window, at longer wavelengths a "dirty window" appears below 400 cm^{-1} (25 μm). The line structure seen in this region is due to water vapour and in a warmer atmosphere at lower latitudes the water vapour absorption would be more complete thus closing the window for transmission of energy to space. This can be seen in the second panel of Fig. 1 which was taken in the summer when atmospheric temperatures and water vapour content were higher. The presence of this additional window in the polar atmosphere accelerates the energy loss to space from both the atmosphere and the surface, further lowering temperatures.

As has already been noted, there are features for different constituent gases in the downwelling spectrum from the

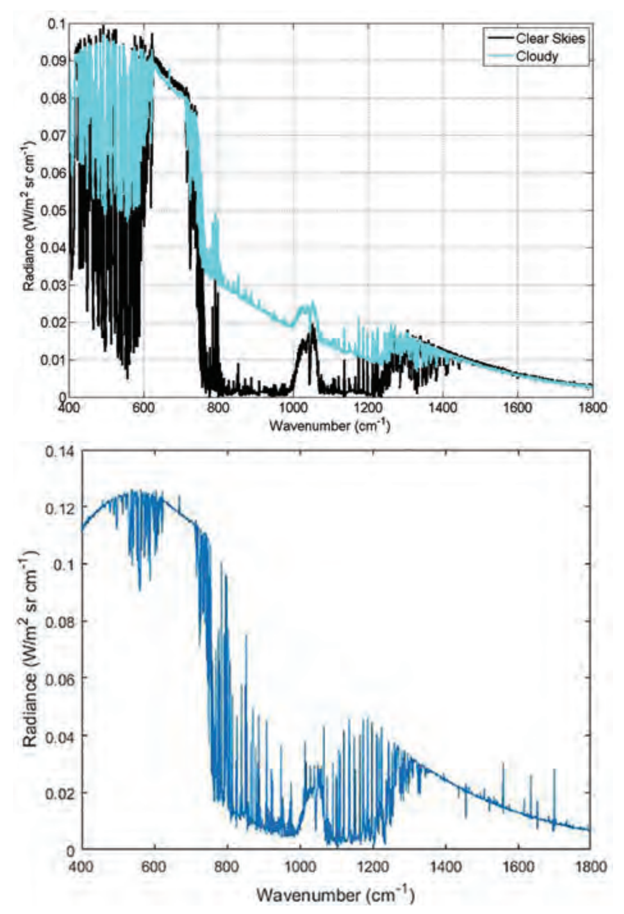

Fig. 1 Spectra of downwelling radiation measured by the Extended Range Atmospheric Emitted Radiance Interferometer (E-AERI) at PEARL. The upper panel compares two times in November 2008. The black line is for clear sky and the cyan line for a cloudy sky. The lower panel is for a summer (warmer) atmosphere with some cloud and shows the closing of the very long wavelength window below 600 cm^{-1} (16 µm) to space due to the increased water vapour in the atmosphere. (Figures courtesy of Zen Mariani)

atmosphere and analysis of these spectra provides a method of determining gaseous composition as well as the radiance spectrum throughout the year limited only by the available signal-to-noise ratio.

The cold, dry atmosphere of the polar regions is of interest to the astronomers who desire very good “seeing” in the atmosphere for good astronomical observations. There is also the attraction of prolonged periods of total darkness. Studies at PEARL have shown that in the winter the seeing can be very good – comparable with that at major telescope locations – and plans are underway to conduct further tests at PEARL as to its suitability as the site of a polar telescope.

Microwave and Radio Region

As we move to longer wavelengths we come to the microwave and radar instrumentation. Even the 4-6 GHz (C-band) satellite communications system at PEARL has to be considered a research problem because of the long pathlengths through the atmosphere on the way to the geostationary satellite. There is some attenuation due to water at these wavelengths especially in summer, but more importantly there are density fluctuations that can cause lensing and dissipation effects of the beam, particularly in the summer. Specific techniques have been developed to overcome these problems and provide a continuous internet connection throughout the year.

The PEARL cloud radar is a vertically-pointing cloud radar operating at 35 GHz. By measuring the characteristics of the echo, especially the magnitude and the Doppler shift, information on the cloud and aerosols directly above PEARL can be obtained and this is complementary to the information from the lidars since the radar information is weighted more towards the larger particles and the lidars to the smaller.

Water vapour and liquid absorption are sensed at frequencies of 20-30 GHz (K-band) and 31.4 GHz (liquid) using a microwave radiometer (MWR). By looking upwards and measuring the brightness temperature at these frequencies and comparing it to the cosmic background and the actual temperature known from climatology or radiosondes, the amounts of water vapor and liquid can be determined.

A radar at 52 MHz measures wind and turbulence in the atmosphere from near the surface and into the stratosphere around 20 km by tracking echoes from small-scale fluctuations in the atmospheric state. It is one of a number of similar radars deployed in Canada and around the world.

Another radar at 34 MHz measures reflections from ionized meteor trails in the upper atmosphere. There are a large number of sub-visible meteors arriving at the Earth daily and these disintegrate in the upper atmosphere leaving trails that are detectable by radar. The resulting echoes can be interpreted in terms of the density and winds in the atmosphere around 85 km altitude.

DATABASES

Data collected at PEARL is analyzed by the PEARL team and then made available to the scientific community. There are very few measurement sites this far North and so the data are very important to developing a Canadian and global view. PEARL data are placed in many international databases including the Aerosol Robotic Network (AERONET), the Network for the Detection of Atmospheric Composition Change (NDACC) and the Total Column Carbon Observing Network (TCCON). In some instances these are the only data available for the Canadian Arctic. Radar data are also regularly ingested by the European Centre for Medium Range Weather

Forecasting (ECMWF). And finally data are also available from our own website at http://www.candac.ca. The PEARL team aims to have as much data as possible publicly available.

CONCLUSIONS

As can be seen from this brief survey, spectroscopy and more generally the physics of the interaction between particles and electromagnetic energy are at the heart of all the remote sensing measurements made at PEARL. The veracity of these measurements depends upon a detailed understanding of these interactions and as understanding increases, so does our ability to interpret the measurements. Also of importance is the ability to quickly make the calculations which are necessary to interpret the measurements. With many atmospheric components and many processes operating simultaneously, the situation can rapidly become extremely complex. The PEARL team is continuously refining and upgrading the measurement interpretation capabilities to provide the best information available.

ACKNOWLEDGEMENTS

PEARL has been supported by a large number of agencies whose support is gratefully acknowledged: The Canadian Foundation for Innovation; the Ontario Innovation Trust; the (Ontario) Ministry of Research and Innovation; the Nova Scotia Research and Innovation Trust; the Natural Sciences and Engineering Research Council; the Canadian Foundation for Climate and Atmospheric Science; Environment and Climate Change Canada; Polar Continental Shelf Project; the Department of Indigenous and Northern Affairs Canada; and the Canadian Space Agency.

Active Open-Path Spectroscopic Measurements of Marine Atmospheric Boundary Layer Composition

by Aldona Wiacek, Li Li, Keane Tobin, Julia Purcell, and Bicheng Chen

Summary

We commissioned a mobile spectrometer to study atmospheric trace gas composition in the boundary layer. Technique details and first diurnal trace gas concentrations are presented.

Air quality in developed nations has significantly improved through regulatory action in transportation and electricity sectors [1]. In 2012, the Canadian Council of Ministers of the Environment (CCME) adopted a new national air quality management system which uses updated and more stringent Canadian Ambient Air Quality Standards (CAAQS) for ground-level O_3 and Particulate Matter (PM) as drivers of regulatory action [2]. The CAAQS are being expanded to include SO_2 and NO_2 at the same time as, e.g., fuel sulphur content regulations in marine transport have been reduced from 1.5% to 1.0% (2010) and further to 0.1% (2015) within Emission Control Areas (ECAs). It is in this changing regulatory framework as well as rapid economic growth (and changes to power generation, heating and transportation sectors) that air quality measurement and modeling activities now take place, requiring greater capacity and integration across the measurement and modeling communities.

With this in mind, the mobile spectrometer described below was acquired and commissioned to study atmospheric trace gas concentrations in the boundary layer, initially in Halifax. Understanding boundary layer air composition *in situ* is complementary to satellite observations, which most often detect integrated column amounts with limited or no vertical sensitivity to trace gas concentrations. As to the measurement location, while Halifax is relatively clean, it nonetheless occasionally exceeds [2] desirable 1-hour average ground level O_3 levels ($>$50 ppb) due to a combination of a rapidly changing local industry, long-range pollution transport, and biogenic precursors of O_3 formation from surrounding forests. The relative contribution of each of these factors to local air quality is an open research question.

MEASUREMENT TECHNIQUE

Boundary layer trace gas concentrations are derived from infrared absorption spectra recorded by an Open-Path Fourier Transform Infrared (OP-FTIR) spectrometer. FTIR spectroscopy has a long history of application in ground- and satellite-based observations of atmospheric composition due to the numerous and strong mid-infrared (~2 to ~20 µm) rotational-vibrational absorption features of gases with a permanent dipole moment. In solar absorption FTIR spectroscopy, the Sun is the infrared source and absorption spectra reflect an underlying vertical distribution of trace gases in a slant column through the entire atmosphere (0-100 km). The open-path configuration described here uses an active broadband IR source (Fig. 1) which is modulated by a Fourier transform spectrometer and then passed through a second beamsplitter to a modified transmitting 12” telescope [3]. The collimated IR beam traverses a horizontal open path of ~500 m (one-way) before encountering a retroreflecting corner cube array, which doubles the optical path and target trace gas absorption and sends the beam back to the same telescope, now serving as a receiving unit. The second beamsplitter passes the returning radiation to a broadband IR detector, in our system a Mercury Cadmium Telluride (MCT) element with Stirling cycle cryocooling, which eliminates the need for liquid nitrogen in field applications and greatly increases system mobility. Each pass through the second beamsplitter reduces the signal by 50%, which is a trade-off in the much simplified monostatic configuration that employs a single transmitting and receiving telescope, a two-way open path and a collocated detector, as well as completely passive non-translating retroreflecting optics. Under normal conditions, the system can be unpacked and aligned in the field in less than 1 hour.

Electronic signal processing ensures that only the modulated returning radiation is detected, while unmodulated emitted atmospheric radiation in the same wavelength range as the IR source is ignored. In practice the separation between the telescope and retroreflector must

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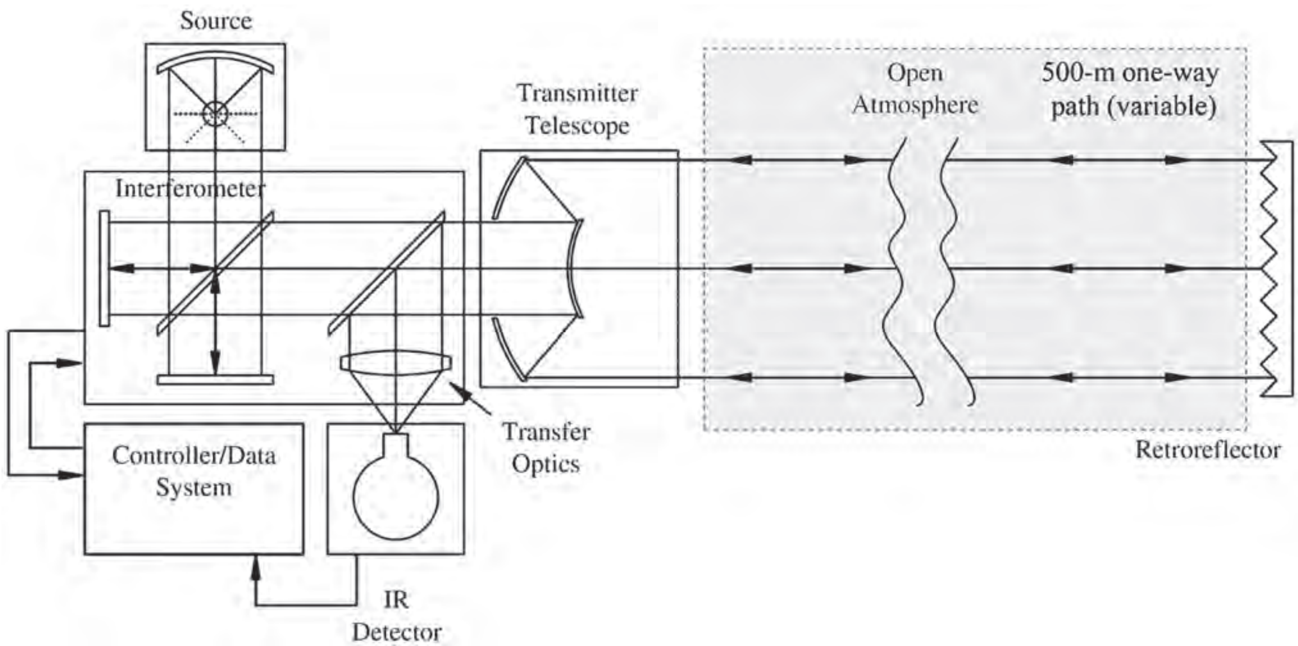

Fig. 1 Components of an Open Path Fourier Transform Infrared (OP-FTIR) system in a monostatic configuration with a single receiving and transmitting telescope and two beamsplitters (image adapted from [3]).

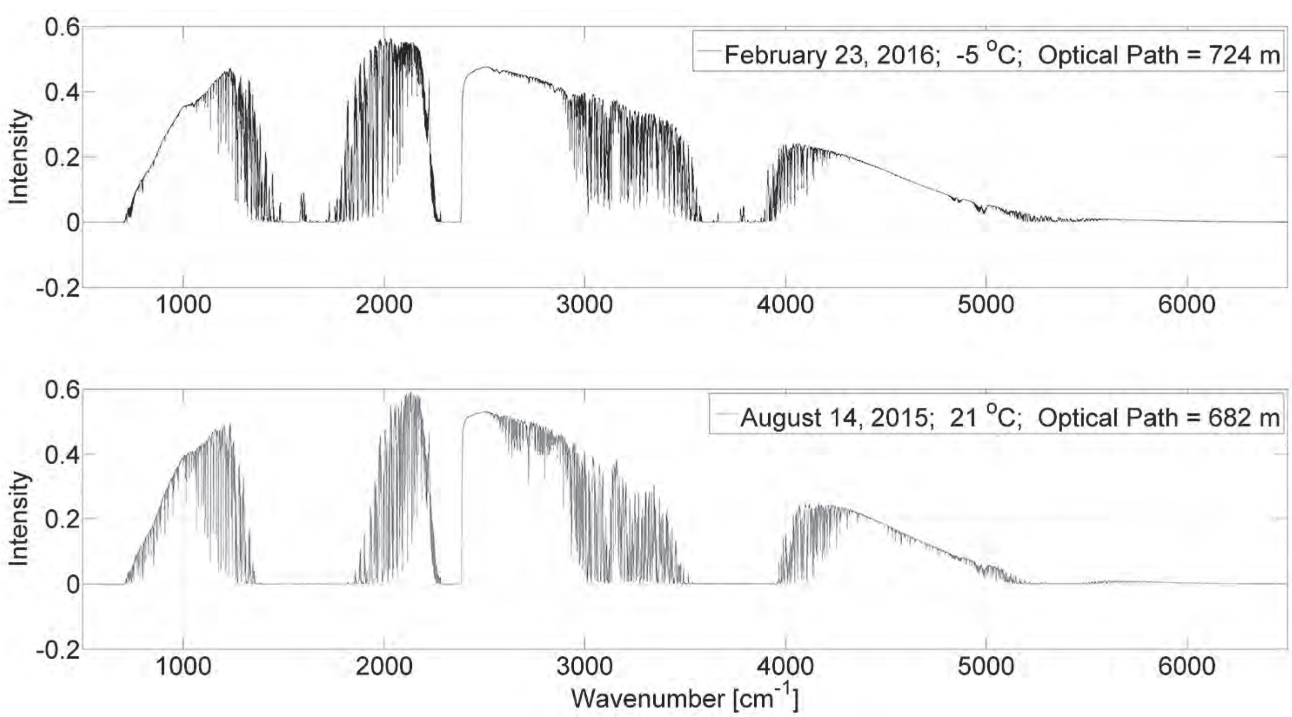

Fig. 2 Sample measured open-path spectra in winter and summer, showing saturated absorption due to water (1500-1800 cm^{-1} and 3500-3800 cm^{-1}) and carbon dioxide (2300 cm^{-1}).

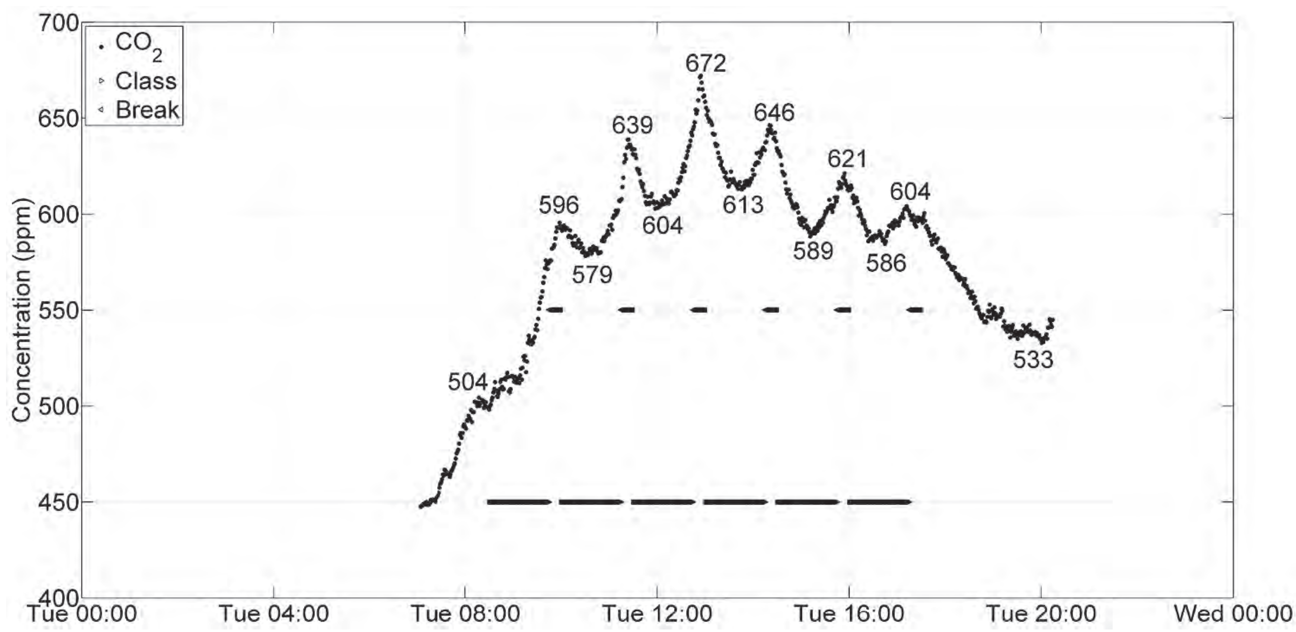

Fig. 3 Retrieved carbon dioxide concentration over a 30-m one-way open path in an indoor campus environment (November 10, 2015). 15-minute class breaks and 75-minute class times are shown with left and right triangles, respectively.

be large enough that sufficient absorption for detection can be achieved, which is different for each target trace gas. One-way open paths larger than 500 m lead to diminishing returns due to imperfect beam collimation, which in our system leads to overfilling the retroreflector array at and beyond separations of about 300 m. Moreover, with increasing atmospheric path, strong interfering absorption from water vapour and carbon dioxide increases (Fig. 2), reducing overall signal levels in the spectrum and strongly overlapping other target gas absorptions.

As with the solar absorption technique, open-path absorption spectra contain the fingerprints of dozens of air quality (AQ) and greenhouse gases (GHGs) present in detectable quantities. The spectra represent a permanent record of atmospheric composition in the open path sampled and "new" gases may be analyzed at any point in the future from the appropriate spectral region. One advantage of the open-path configuration is that the ~500 m horizontal path is well defined spatially in the planetary boundary layer, and bridges the spatial scales of *in situ* point measurements on one hand and space-based satellite measurements on the other. Another major advantage of an active source system is that measurements are possible during both sunny and cloudy atmospheric conditions, during both day and night. By definition, solar absorption FTIR spectroscopy is possible only during sunny conditions, which leads to a dry, sunny, daytime sampling bias in trace gas concentrations. Due to weak scattering of infrared radiation by condensed phase fog and rain droplets in the beam, we have also made successful measurements during light fog and rain, which opens the possibility of studying heterogeneous atmospheric chemistry processes. Finally, the maximum spectral resolution of our system is 0.5 cm^{-1}, as is appropriate for sampling strongly Lorentz-broadened rotational-vibrational gas absorption features at 1 atm. This translates into fast acquisition speeds, up to a maximum of 5 Hz. To improve signal to noise ratios, we co-add 240 interferograms operating at 4 Hz to produce a single spectrum once per minute when sampling ambient atmospheric conditions.

Trace gas concentrations are derived from transmittance spectra through an iterative fitting process that minimizes a least squares cost function between measured and calculated spectra, taking into account target and interfering gas absorptions, spectrum baseline shape, as well as instrumental line shape parameters describing line broadening and asymmetry under both ideal and real spectrometer conditions [4]. The forward spectral model does not assume linearity in Beer's Law for absorbance vs. concentration, meaning that both weakly and strongly absorbing spectral features can be used in the analysis. Forward spectra are either calculated based on temperature- and pressure-dependent line-by-line absorption coefficients from the HITRAN database [5] or are based on measured reference spectra, e.g., from the PNNL reference library [6]. The inverse result is not unique because of noise in the spectra and represents the most probable set of trace gas concentrations, baseline coefficients and instrumental parameters given the measured spectrum. Retrieval pressures and

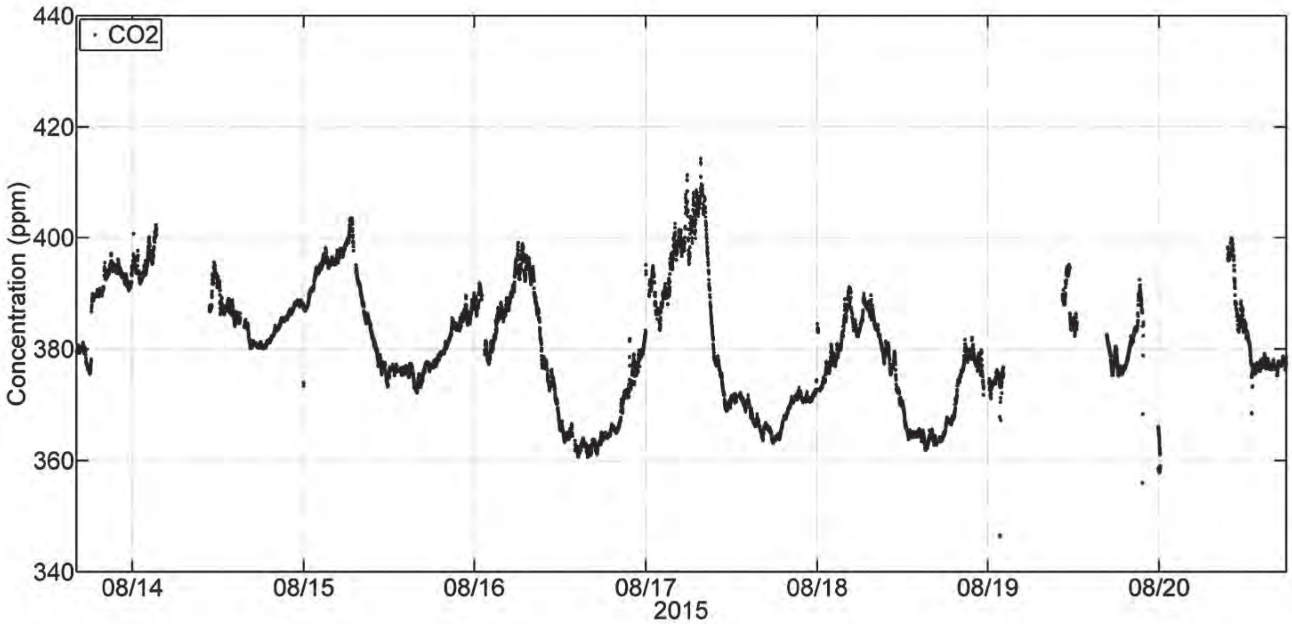

Fig. 4 Retrieved carbon dioxide concentration over a 340-m one-way open path in an outdoor campus environment (August, 2015).

temperatures are measured at one point as close as possible to the open path sampled.

FIRST RESULTS

To date, we have conducted field campaigns in Halifax Harbour, on campus (outdoors and indoors), near traffic emission sources, as well as in coastal forest and Nova Scotia wildfire-influenced environments. One-way atmospheric open paths ranged from 30-500 m and measurements lasted from just 2 hours to 6 weeks. Figure 3 illustrates the sensitivity of our measurement technique and shows retrieved carbon dioxide concentrations over a 30-m open path in an indoor campus environment on November 10, 2015. The space sampled is a three-storey Atrium where students gather on the ground floor during class breaks, while our measurements are sampling the air above them from the second floor balconies. The concentration of CO_2 is lowest early in the morning, but – as expected – still 50 ppb higher than ambient outdoor CO_2 levels of 400 ppm in a global annual mean. Gradually, CO_2 levels rise and peak just after noon at ~700 ppm, then begin to taper off again around 8 PM. Health Canada sets a CO_2 exposure limit at 3500 ppm and CO_2 levels below 1000 ppm in occupied spaces indicate good air quality and ventilation. The comb-shaped pattern of pronounced CO_2 peaks correlates extremely well with 15-minute class breaks shown with short dashes on the 550 ppm line. During class times, shown with long dashes on the 450 ppm line, the Atrium occupancy is reduced, leading to a quick reduction in CO_2 levels due to efficient ventilation.

Figure 4 shows ambient outdoor carbon dioxide concentrations over the course of a week of nearly continuous observations on campus. In August, average concentrations are below 400 ppm, as expected for northern hemisphere mid-latitudes, which experience a minimum in CO_2 concentration at this time due to strong plant growth and the associated CO_2 drawdown. (The peak-to-peak amplitude in the CO_2 seasonal cycle at 45°N is ~10 ppm.) Superimposed on the average concentration are strong diurnal variations due to daytime photosynthesis (consumes CO_2) and nighttime respiration (releases CO_2). Indeed, our measurements indicate decreasing CO_2 levels from sunrise until sunset and increasing CO_2 levels from sunset until sunrise. Each day is characterized by slightly different levels of photosynthesis and respiration, with unclear results due to fog and rain on August 19th and 20th. Overall reasonable results of our indoor and outdoor CO_2 tests increase confidence in our spectral measurement and trace gas retrieval process.

SUMMARY AND FUTURE WORK

As part of a new research program dedicated to understanding atmospheric composition, we have initiated measurements of marine boundary layer trace gases using the active source technique of Open-Path Fourier Transform Infrared Spectroscopy (OP-FTIR). First test results with indoor and outdoor CO_2 concentrations show reasonable and expected patterns of temporal variation. The recently acquired system (2015) significantly expands the measurement capability of atmospheric trace gases in Halifax and in Atlantic Canada. A long-term marine boundary layer composition observatory is being designed to house the instrument and make automatic measurements when weather conditions permit. The retrieval process is being optimized to robustly target greenhouse gases (CO_2, CH_4, N_2O), ozone and its precursors (CO, NO_x and many VOCs), trace gases implicated in particle formation (SO_2, HNO_3, NH_3), and other IR-active species permanently imprinted in stored absorption spectra above detection limits. A future focus of measurements and analysis will be the quantification of shipping emissions' contributions to Halifax ambient air quality.

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REFERENCES

1. H. Reid, and J. Aherne, "Staggering reductions in atmospheric nitrogen dioxide across Canada in response to legislated transportation emissions reductions", *Atm. Env*., **146**, 252-260 (2016).
2. Nova Scotia Environment, "Nova Scotia's Air Quality Report (2000-2007)", (2009).
3. J.M. Jarvis, *Open Path Spectrophotometry (UV, IR, FT-IR)*, Instrument Engineers Handbook, 4th Ed., 2003.
4. D.W.T. Griffith, "Synthetic calibration and quantitative analysis of gas phase infrared spectra", *Appl. Spectrosc*., **50**(1), 59-70 (1996).
5. L. Rothman *et al*., "The evolution and impact of the HITRAN molecular spectroscopic database", *Journal of Quantitative Spectroscopy and Radiative Transfer*, **111**, 1565-1567 (2010).
6. S.W. Sharpe *et al*., "Gas phase databases for quantitative infrared spectroscopy", *Appl. Spectrosc*., **58**(12), 1452-1461 (2004).

LABORATORY MID-INFRARED ABSORPTION CROSS-SECTION SPECTRA OF LARGE VOLATILE MOLECULES FOR ATMOSPHERIC REMOTE SENSING

BY KARINE LE BRIS

Remote sensing techniques of terrestrial and astrophysical atmospheres rely heavily on our knowledge of the spectral signatures of molecules. The mid-infrared spectral region is particularly useful as most molecules are radiatively active in that range i.e. they are able to absorb photons of energy corresponding to transitions between rotational and vibrational (ro-vibrational) energy levels.

The 8-14 μm range presents the additional interest to correspond to an atmospheric spectral window i.e. a part of the electromagnetic spectrum that allows radiation to partially pass through the atmosphere. Molecules absorbing or emitting in that spectral range can be detected by a sensitive instrument if their spectral signature is known.

The spectral signature depends on the probability for a molecule to absorb a photon at a given energy. Because this probability is determined by the geometry and composition of the molecule, each absorption profile is unique for a given species. The spectral signature of molecules in the mid-infrared is usually represented by their absorption cross-section (in cm^2 $molecule^{-1}$) as a function of the wavenumber (in cm^{-1}).

Large molecules (typically six and more atoms) are found in weak abundance in the atmosphere. The pressure mixing ratio of these constituents typically ranges from a few hundreds to a fraction of a ppt (part-per-trillion). However, many of those compounds, particularly those containing C-Cl, C-F and C-Br bonds, have large absorption cross-sections ($>10^{-18}$ cm^2 $molecule^{-1}$) in the mid-infrared atmospheric spectral window. This make these molecules extremely potent greenhouse gases. Hence, most halocarbons have a global warming potential over a horizon of 100 years (GWP_{100}) three to four orders of magnitude larger than CO_2 [1].

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SUMMARY

The acquisition of accurate experimental reference cross-sections on large atmospheric volatile molecules, and particularly halocarbons, is discussed.

Many large polyatomic molecules are now detectable through remote sensing either by ground-based (e.g. Mahieu *et al*. [2]) or satellite missions (e.g. Brown *et al*. [3]). The trend of halocarbons such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) is particularly followed due to their contribution to both climate change and ozone depletion. The processing of remote sensing signals relies heavily on the availability and accuracy of the molecular absorption cross-section reference data. This article will review the method used to acquire and validate these data.

MOLECULAR DATA FOR ATMOSPHERIC REMOTE SENSING

The molecular spectroscopic data used in remote sensing retrieval are usually obtained by laboratory experiments or ab-initio calculations. The line-by-line spectroscopic parameters of small molecules such as CO_2, H_2O, O_3 or CH_4 are included in database like HITRAN [4] or GEISA [5]. From their spectroscopic parameters, synthetic absorption spectra can be generated over a large range of temperature and pressure conditions and compared with remote sensing data to extract the pressure-missing ratio profiles of these atmospheric gases.

Large molecules do not fit into this model. As the number of atoms increases, so does the number of ro-vibrational transitions, making line-by-line ab-initio calculations impractical. Heavier molecules such as halocarbons also have large moment of inertia, which bring the ro-vibrational lines close together. Experimentally, the infrared absorption spectra of such molecules typically appear as broad bands, each of these bands corresponding to the overlapping of multiple individual transitions. An illustration of a heavy molecule broad band can be seen in Fig. 1 with the ozone-depleting compound CFC-113 (1,1,2-trichloro-1,2,2-trifluoroethane). The main features of those spectra correspond to transitions between fundamental modes of vibrations i.e. absorption from the ground vibrational state to a higher vibrational state ($v = 0 \rightarrow v' > 0$). But spectra are complicated even further by the presence of hot bands — temperature-dependent transitions from thermally populated excited vibrational states ($v > 0 \rightarrow v' > v$) — and combination bands resulting from the coupling of fundamental modes. A line-by-line description of each ro-vibrational transition of those molecules is therefore still impossible. This situation is dealt with by providing as reference the absorption cross-section spectra of the large polyatomic molecules, in a range of temperature and pressure suitable for atmospheric simulations.

Theoretical calculation on large molecules is usually limited to the estimation of the spectral position and integrated strength of the absorption bands. Several methods and basis sets are available depending on the complexity of the molecule. Among them, the density functional theory (DFT) method provide results competitive with ab-initio calculations such as 2nd-order Møller-Plesset at a reduced computational cost [7]. The radiative efficiency of a molecule, an essential parameter to determine their impact on the radiative forcing, can be estimated from computational methods when no experimental data are available [1 and references therein]. Theoretical calculations can also nicely complete an experimental investigation by verifying the lack of impurity and by facilitating the detection of conformers (e.g. Le Bris *et al.* [8]). However, it still cannot reasonably be used alone to simulate an absorption cross-section spectrum of a large molecule with an accuracy high enough for remote sensing.

There are therefore strong needs for accurate experimental cross-section spectra of large molecules. Ideally the reference data should be at a resolution high enough so that no feature is missed. This aspect is particularly important on the *Q*-branch of the absorption bands, which can become very sharp as the temperature decreases.

EXPERIMENTAL ACQUISITION TECHNIQUE

Semi-conductor lasers are now able to reach the 8-14 µm portion of the electromagnetic spectrum using technology such as quantum cascade laser. However, a compromise still needs to be made between the spectral range and the resolution of the laser. Therefore, acquisitions of high-resolution experimental absorption cross-sections covering the whole mid-infrared atmospheric spectral window are still dependent on Fourier transform infrared spectroscopy (FTIR).

A Fourier transform spectrometer (FTS) is based on Michelson interferometry. A lightsource is divided by a beamsplitter into two signals of equal intensity. The two beams travel separate paths before being reflected by mirrors and recombined at the beamsplitter. A change in the optical path difference between the two beams is created by moving one of the mirrors. The intensity

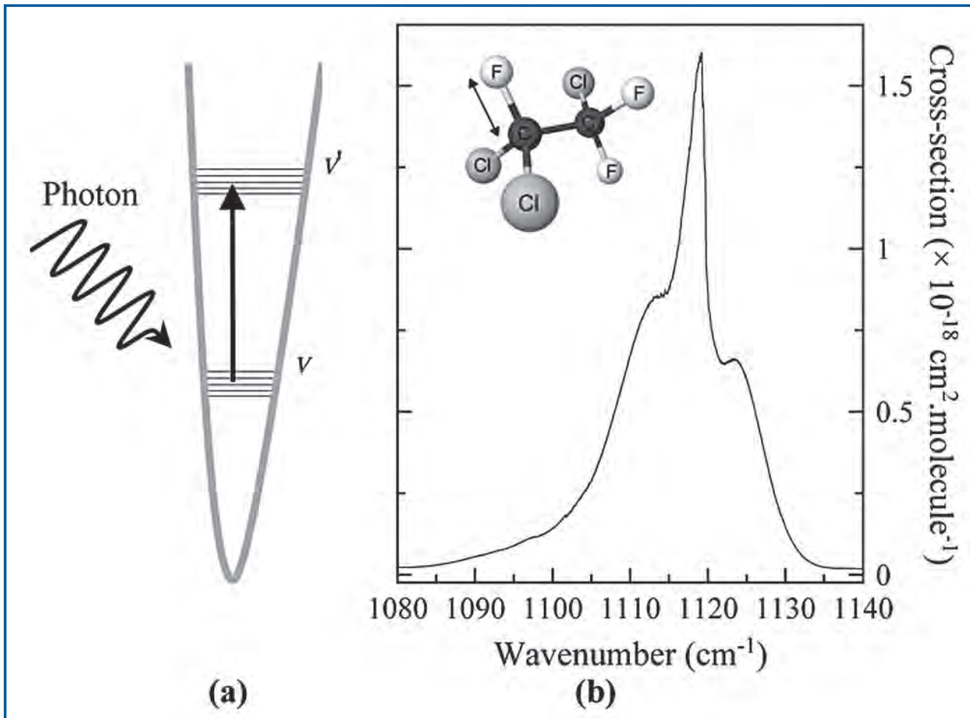

Fig. 1 Absorption of light in the mid-infrared by a large molecule in gaseous phase. (a) The molecule is excited by photo-absorption. Since vibrational energy states are orders of magnitude greater than rotational energy states, the transitions from the rotational levels in the ground vibrational state ($v = 0$) to the rotational levels in an excited vibrational state ($v' > 0$) form a band. (b) C–F stretching vibration on the C_1 conformer of CFC-113 and the broadband associated with this fundamental vibration mode. (Data from Le Bris *et al.* [6])

of the recombined beam is detected as the mirror is moving, which create an interferogram. After a phase correction, the signal output is switched to the frequency domain by a Fourier transform. In a typical mid-infrared configuration, the FTS operates with a thermal source (Globar) and a KBr beamsplitter. The recombined beam is sent to a liquid nitrogen-cooled mercury (MCT) detector. This configuration typically allows to cover a spectral range from the 500's cm^{-1} to the 6000's cm^{-1}.

The gas sample can be either pure or mixed with dry air or nitrogen. Mixed samples broaden the band shapes and give spectra similar to those acquired by remote sensing. Pure vapours allow a better control of the pressure and thus a better accuracy. However, the cross-section spectra need to be processed through a pseudo-line method such as the one developed by Toon *et al*. [9] before being used for atmospheric retrieval.

A stainless steel gas cell equipped with ZnSe windows is positioned along the recombined beam path between the FTS and the detector. For highly absorbing molecules, a very short cell is preferred to prevent nonlinear saturation effects while keeping the gas pressure at a reasonable level for accurate readouts. For atmospheric remote sensing applications, it is often necessary to obtain the absorption cross-sections of gases at low temperature. To avoid condensation on the cell windows, prevent absorption of the source radiation outside of the cell, and protect the hygroscopic KBr beamsplitter, all the elements of the optical paths from the source to the detector must remain under vacuum.

DATA ANALYSIS AND COMPOSITE SPECTRA

In a typical experiment, a baseline spectrum is first obtained from a series of scans taken with an empty cell at a temperature T. The gas sample is then allowed to fill the cell at a controlled pressure P and a second series of scans is taken. The optical depth $\chi_{P,T}$ for each wavenumber is obtained from the experimental data using the Beer-Lambert law:

$$\chi_{P,T}(\upsilon) = \ln\left[\frac{I_{0,T}(\upsilon)}{I_{P,T}(\upsilon)}\right]$$

where υ is the wavenumber in cm^{-1}; $I_{0,T}$ is the light intensity passing through the empty cell (baseline) and $I_{P,T}$ is the light intensity passing through the cell filled with the sample at the pressure P.

The absorption cross section σ_T at a wavenumber υ can then be extracted using the following equation:

$$\sigma_T(\upsilon) = \chi_{P,T}(\upsilon)\frac{T}{T_0}\frac{P_0}{P}\frac{1}{N_L L}$$

where T_0 and P_0 are the standard conditions for temperature and pressure; N_L is the Loschmidt's constant ($N_L = 2.651 \times 10^{22}$ cm^{-3}) and L the length of the cell in cm.

Molecular spectra have usually a large dynamic range. Thus, a set of different gas pressures must be used to get a good signal to noise ratio on the smallest structures while keeping the signal from the strongest bands unsaturated. Thus, the cross-section spectrum of a compound at a given temperature is ideally a composite spectrum retrieved from multiple pressure-dependent scan series.

The optical depths corresponding to excessively optically thin (i.e. noisy) or optically thick (i.e. saturated) environments are eliminated (see Fig. 2). The thresholds on the optical depth are determined empirically. Pressure-induced self-broadening can play a role when working on a pure vapour as sharp features are usually pressure-dependent. In such case, the optical depth no longer varies linearly with the pressure even in the absence of saturation. However, it has been observed [11] that, in that event, a quadratic fit on the optical depth still allows the retrieval of the cross-section at the zero-Torr limit.

SOURCES OF ERRORS AND DATA VALIDATION

FTIR spectra, particularly in the atmospheric spectral range, can be affected by an array of artifacts and practical issues. The

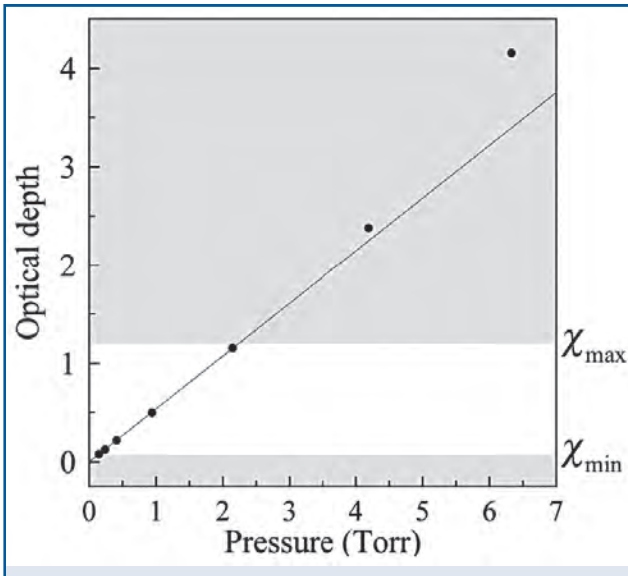

Fig. 2 Calculation of the effective cross-section $\sigma_{T,\nu}$ of perfluorodecalin ($C_{10}F_{18}$) for $\upsilon = 1079.3$ cm^{-1}. In this example, the optical depth $\chi_{P,T}$ varies linearly with the pressure between the threshold values χ_{min} and χ_{max} (white area). The two points in the upper grey area correspond to saturated environments and are eliminated from the calculation. (Data from Le Bris *et al.* [10])

following section presents the most common sources of errors and the methods used to minimize them[1].

One of the main source of uncertainties comes from the variation of the luminance of the thermal source during the scans. As high-resolution FTIR acquisitions can take a considerable amount of time, a drift between the primary baseline and the gas spectra is not uncommon. Left untreated, the drift leads to an improper zeroing of the absorption cross-sections. It is therefore important to adjust the primary baseline (typically built from hundreds of scans) with control baselines of a few dozens of scans taken before and after each cell filling. Depending on the compound being studied, adjustment of the primary baseline can also be done using area of the molecular spectra where no absorption occurs.

Another issue of FTIR spectroscopy is the relative weakness of the optical signal. The source being a black body, the radiation power is constrained by its temperature. This available power is further limited by the iris controlling the spatial coherence. Individual high-resolution acquisitions are therefore often noisy and a large number of scans must be added to obtain a satisfying signal-to-noise ratio. However, because high-resolution data also requires a lengthy displacement of the FTS arm, a compromise must be reach between resolution and acquisition time. Fortunately, for many large molecules, a resolution of 0.02 cm^{-1} does not significantly alter the line shape and is comparable to the resolution used in satellite remote sensing mission such as SCISAT ACE-FTS [12].

The iris itself creates an artifact. To maximize the transmitted power, the iris has to be set close to the source. The warmed-up annulus around the aperture creates an off-axis secondary thermal radiation superimposing to the main source. This leads to distortion of the signal as the aperture size decreases. Fortunately, the warm aperture artifact can be strongly reduced by inserting a second aperture at the focal point of the beam between the FTS and the detector [13].

MCT detectors have a notorious non-linear response to the photon flux. The effect is particularly noticeable on the central peak of the interferogram, which create a baseline offset on the spectrum. The raw interferograms may require corrections before the phase correction and the Fourier transformation. Other errors such as the uncertainty on the pressure and temperature measurements, the sample purity, and the optical path length can usually be easily evaluated and minimized.

The validations of experimental data are performed either by comparison with independent studies when they exist, or as mentioned earlier, with the line positions and integrated band strengths of the theoretical calculations. Another method to verify the quality of the data is to survey the variation of the integrated band strengths with temperature. Although the band shapes are temperature-dependent due to the change of population in the rotational levels of the ground vibrational state, the overall integrated intensities should remain constant. Taking into account all sources of errors, the uncertainties on the experimental total integrated intensity of strongly absorbent gases such as halocarbons at the 95% confidence limit are often below 5%.

1. Some typical issues of Fourier transform spectroscopy such as spectral aliasing or dynamic alignment errors are usually corrected by commercial spectrometers and will therefore not be discussed here.

PRESENT AND FUTURE NEEDS FOR REMOTE SENSING

The phase-out of ozone depleting substances has led to the production and emission of substitute compounds. Among them, hydrofluorocarbons (HFCs) have become the major replacements in many applications. However, their important global warming potential may offset the benefit on the climate of the bans of CFCs and HCFCs [14]. So far, the majority of detections of HFCs have been made either by *in-situ* experiments through the AGAGE (Advanced Global Atmospheric Gases Experiment) network or using flask sampling like the NOAA (National Oceanic and Atmospheric Administration) network. However, molecules such as HFC-134a [15] and HFC-23 [16] are now detectable by satellite measurements. It is likely that, in the near future, more molecules will be added to the list, which will require precise absorption cross-section reference data over a wide range of atmospheric temperatures and pressures.

The study of exoplanet atmospheres, and in particular the search for biosignature gases, represent another exciting new field of investigation. The next generation of ground-based and space-based telescopes, such as NASA's James Webb Space Telescope, will have the capacity to probe the atmosphere of Earth-like planets. The potential for an exoplanet to host life could therefore be assessed by analyzing the presence of gases that are exclusively (or mostly) produced by life on Earth. The standard biosignature gases are small molecules such as O_2, CH_4, N_2O, O_3, which are substantial in the Earth atmosphere. However, it has recently been shown [17] that larger molecules such as ethyl mercaptan, ethanol, isoprene, thioglycol, dimethyl sulfide, toluene, benzene, dimethyl disulfide, dimethyl sulfoxide, fluoroacetone, methyl ethyl ketone, acetone, acetaldehyde, methyl mercaptan, and methyl vinyl ketone can provide similar detectability. A more extended list of potential stable volatile biomarkers has recently been published [18]. The availability of the spectral signature of those large molecules in a relevant range of temperatures and pressures will be essential to assess their utilities as biomarkers and to interpret the atmospheric spectra of exoplanets.

CONCLUSION

Despite their weak abundance in the atmosphere, large volatile molecules and particularly halocarbons, can strongly affect the climate due to their high absorption cross-sections within the mid-infrared spectral window. Large molecules are also very interesting candidates as biosignature tracers in the study of Earth-like exoplanet atmospheres. The new generation of remote sensing instruments will likely allow more and more compounds to be detected. To make the most of these instruments, it will become increasingly necessary to have excellent reference molecules at an appropriate resolution and in a wide range of temperatures and pressures.

ACKNOWLEDGEMENTS

I would like to thank my co-workers and colleagues for their contributions. Financial support from NSERC is gratefully acknowledged.

REFERENCES

1. Ø. Hodnebrog, *et al*., "Global warming potentials and radiative efficiencies of halocarbons and related compounds: A comprehensive review", *Reviews of Geophysics*, **51**, 300-378 (2013).
2. E. Mahieu, *et al*., "Retrieval of HCFC-142b (CH3CClF2) from ground-based high-resolution infrared solar spectra: Atmospheric increase since 1989 and comparison with surface and satellite measurements", *Journal of Quantitative Spectroscopy and Radiative Transfer*, **186**, 96-105 (2017).
3. A.T. Brown, *et al*., "Trends in atmospheric halogen containing gases since 2004", *Journal of Quantitative Spectroscopy and Radiative Transfer*, **112**, 2552-2566 (2011).
4. L.S. Rothman, *et al*., "The HITRAN2012 molecular spectroscopic database", *Journal of Quantitative Spectroscopy and Radiative Transfer*, **130**, 4-50 (2013).
5. N. Jacquinet-Husson, *et al*., "The 2015 edition of the GEISA spectroscopic database", *Journal of Molecular Spectroscopy*, **327**, 31-72 (2016).
6. K. Le Bris, R. Pandharpurkar, and K. Strong, "Mid-infrared absorption cross-sections and temperature dependence of CFC-113", *Journal of Quantitative Spectroscopy and Radiative Transfer*, **112**, 1280-1285 (2011).
7. I. Bravo, *et al*., "Infrared absorption spectra, radiative efficiencies, and global warming potentials of perfluorocarbons: Comparison between experiment and theory", *Journal of Geophysical Research: Atmospheres*, **115**, D24317 (2010).
8. K. Le Bris, *et al*., "Structure and conformational analysis of CFC-113 by density functional theory calculations and FTIR spectroscopy", *Journal of Molecular Spectroscopy*, **243**, 142-147 (2007).
9. G.C. Toon, B. Sen, and A. Kleinboehl, *Derivation of pseudo-lines from laboratory cross-sections*, Jet Propulsion Laboratory n.d. Web 14 September 2016. URL: http://mark4sun.jpl.nasa.gov/data/spec/Pseudo/Readme.
10. K. Le Bris, *et al*., "*Cis*- and *trans*-perfluorodecalin: Infrared spectra, radiative efficiency and global warming potential", *Journal of Quantitative Spectroscopy and Radiative Transfer* (2017), in press, DOI: http://dx.doi.org/10.1016/j.jqsrt.2017.01.011.
11. K. Le Bris, J. McDowell, and K. Strong, "Measurements of the infrared absorption cross-sections of HCFC-141b (CH_3CFCl_2)", *Journal of Quantitative Spectroscopy and Radiative Transfer*, **113**, 1913-1919 (2012).
12. P.F. Bernath, P.-F. Coheur, R. Colin, *et al*., "Atmospheric chemistry experiment (ACE): mission overview", *Geophysical Research Letters*, **32**, L15S01-5 (2005).
13. T.J. Johnson, *et al*., "Removing aperture-induced artifacts from fourier transform infrared intensity values", *Applied optics*, **41**, 2831-2839 (2002).
14. A. Ravishankara, *et al*., *HFCs: A critical link in protecting climate and the ozone layer*, UNEP Synthesis Rep., United Nations Environment Programme, Nairobi, Kenya, 2011.
15. R. Nassar, *et al*., "A global inventory of stratospheric fluorine in 2004 based on atmospheric chemistry experiment Fourier transform spectrometer (ACE-FTS) measurements", *Journal of Geophysical Research: Atmospheres*, **111**, no. D22313 (2006).
16. J.J. Harrison, *et al*., "First remote sensing observations of trifluoromethane (HFC-23) in the upper troposphere and lower stratosphere", *Journal of Geophysical Research: Atmospheres*, **117**, D05308 (2012).
17. S.J. Messenger, *Detectability of biosignature gases in the atmospheres of terrestrial exoplanets*. MSc thesis, Massachusetts Institute of Technology, 2013.
18. S. Seager, W. Bains, and J. Petkowski, "Toward a list of molecules as potential biosignature gases for the search for life on exoplanets and applications to terrestrial biochemistry", *Astrobiology*, **16**, 465-485 (2016).

In 2005, the Division of Nuclear Physics (DNP) created a PhD Thesis Prize competition for best thesis in Experimental or Theoretical Nuclear Physics by any student receiving their PhD degree from a Canadian University in the current or prior calendar year (see http://dnp.phys.uregina.ca/articles/Thesis%20Prize). The DNP is pleased to announce that the recipient of the 2014-15 DNP Thesis Prize is Timothy Friesen. Dr. Friesen was awarded his PhD by the University of Calgary in 2014 for the work "Probing Trapped Antihydrogen: In Situ Diagnostics and Observations of Quantum Transitions". A summary of Dr. Friesen's thesis work appears below.

Probing Trapped Antihydrogen

by Timothy Friesen

The hydrogen atom is one of the most important and best-understood systems in physics. Hydrogen spectroscopy has been invaluable for testing and motivating theory, and the hydrogen spectrum is known to high levels of precision. This makes antihydrogen, the anti-matter counterpart to hydrogen, a natural candidate to test CPT (charge-parity-time) symmetry, the fundamental symmetry between matter and antimatter. In addition, since antihydrogen is electrically neutral, it is an excellent candidate to study whether the gravitational interaction between matter and antimatter is different than that between matter and matter.

The goal of the ALPHA collaboration is to study, and in particular to perform spectroscopy on, antihydrogen atoms trapped in a magnetic neutral atom trap. The ALPHA apparatus consists of a Penning-Malmberg trap for the confinement and manipulation of charged antiprotons and positrons combined with an Ioffe-Pritchard-type neutral atom trap for confinement of antihydrogen (see Fig. 1). The ALPHA apparatus is located in the Antiproton Decelerator (AD) facility at CERN just outside of Geneva, Switzerland. The AD provides low-energy antiprotons (5.3 MeV) to the ALPHA experiment as well as several other experiments dedicated to measurements of antiprotons and antihydrogen. Antihydrogen is formed by mixing antiprotons with a positron plasma produced by a sodium-22-based positron accumulator. The antihydrogen atoms can then be trapped by the magnetic minimum trap, consisting of two superconducting mirror coils and a superconducting octupole magnet, that interacts with antihydrogen's small magnetic dipole moment to create a confining potential of roughly 50 μeV. The trapping of antihydrogen atoms was first demonstrated by ALPHA in 2010 [1] and holding times of 1000 seconds have been achieved [2]. Because the trap depth is low, only 1 or 2 anti-atoms are currently trapped for every 40,000 formed. However, even with few atoms trapped per trial, antihydrogen atoms can be studied by repeating each experiment many times to gather statistics.

Summary

This article describes how the ALPHA experiment measures the magnetic field seen by trapped antihydrogen atoms and how it demonstrated resonant positron spin flip transitions.

One of the biggest challenges facing the spectroscopy of trapped antihydrogen is determining the magnetic field seen by the antihydrogen atoms. Because of the inhomogeneous nature of the magnetic trapping fields, the Zeeman effect will result in a strong spatial dependence of the transition frequencies. External sensors such as Hall probes will only measure the fringe fields of the trapping magnets and internal measurements are complicated by the limited physical access to the antihydrogen trapping volume.

To measure the magnetic field seen by the antihydrogen atoms, ALPHA developed a method for measuring the cyclotron resonance frequency ($f_c = qB/2\pi m$, where q and m are the charge and mass of the electron, respectively, and B is the magnetic field) of an electron plasma [3]. The electron plasma can be positioned along the axis of the Penning trap to measure the magnetic field in different locations in the trap. The most uniform field region, and therefore the region with the most uniform transition frequency for spectroscopy, occurs at the field minimum in the centre of the trap. To maximize the transition probability of a desired transition it is critical to be able to measure this minimum magnetic field to the highest precision possible.

The cyclotron resonance of an electron plasma is determined by monitoring changes in the plasma temperature while a series of microwave pulses are applied at frequencies that scan through the cyclotron resonance. The cyclotron motion of the electrons will be excited by the co-rotating component of the microwave electric field.

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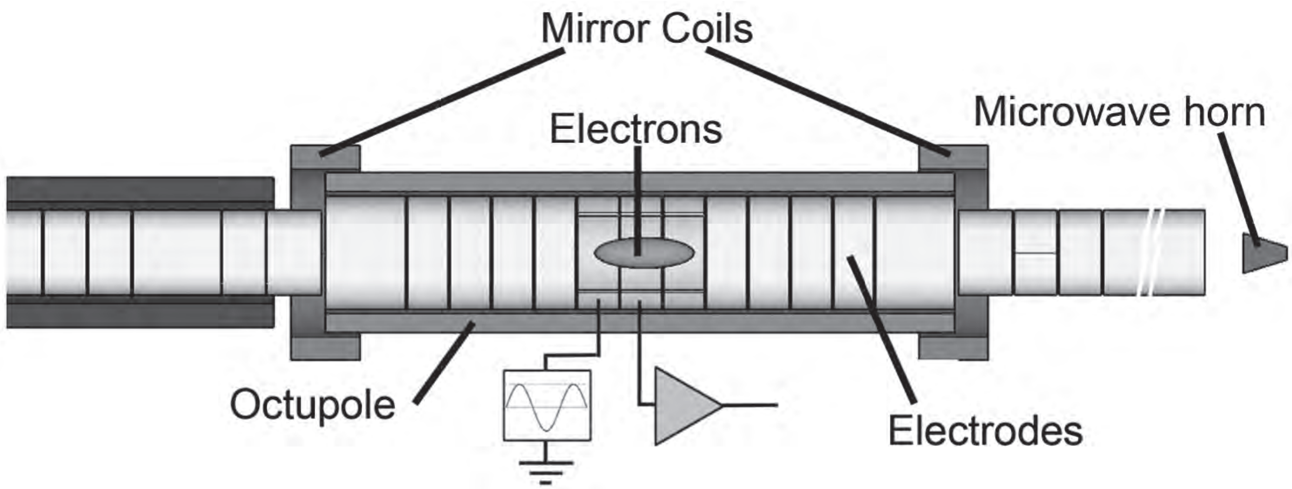


Fig. 1 Sketch of the ALPHA Penning trap and neutral atom trap magnets. A 1 T solenoid (not shown) surrounds the components shown here with the exception of the microwave horn located 1.3 m from the centre of the trap. Also shown is the quadrupole mode excitation drive applied to an electrode on one end of the electron plasma. The subsequent ringing of the plasma is picked up on the centre electrode. The radial extent of the plasma has been exaggerated here for illustrative purposes.

Following each pulse, the energy absorbed by the cyclotron motion will be redistributed by collisions to the remaining degrees of freedom resulting in an increased plasma temperature. To track the plasma temperature changes following each microwave pulse, we monitor the frequency of a normal mode of oscillation of the electron plasma known as the quadrupole mode. This frequency is measured by exciting the motion with a radio-frequency drive applied to one electrode and detecting the image current oscillations on another (see Fig. 1). For small temperature changes the frequency of the quadrupole mode increases linearly with temperature, so by measuring the quadrupole frequency changes as a function of microwave frequency we can find the cyclotron resonance. An example of such a measurement is shown in Fig. 2. With this technique we are able to measure the minimum magnetic field of the antihydrogen trap to roughly 3 parts in 10^4.

Using the electron cyclotron resonance to measure the magnetic field, ALPHA was able to induce and observe the first-ever resonant transitions in antihydrogen by exciting the positron spin resonance transition in antihydrogen's ground state [4]. In a magnetic field, the ground state of antihydrogen is split into two trappable states and two untrappable states. In the high-field limit, the spin of the positron is anti-aligned with the magnetic field in the trappable states and aligned in the untrappable states. Therefore there are two positron spin resonance (PSR) transitions between trappable and untrappable states that can be driven by applying a resonant oscillating magnetic field perpendicular to the magnetic trapping fields. An antihydrogen atom that has undergone this transition will then quickly annihilate on the surrounding electrodes and release charged pions which are detected by a silicon detector as a clear signal of an induced transition.

To establish that resonant PSR transitions were induced, we performed three types of measurements: microwaves on resonance, microwaves off resonance (detuned by -100 MHz), and no microwaves. Each of these measurements had a microwave interrogation time of 180 s which is followed by a quick shutdown of the magnetic trap to detect the annihilation of any remaining atoms. When a PSR transition is induced, the atom should annihilate during the microwave interrogation time rather than when the magnetic trap is shut off. If a transition is not induced, it will not annihilate during the interrogation time (ignoring annihilations on background gas) but when the magnetic trap is shut off.

After performing roughly 100 trials of each experiment (on-resonance, off-resonance, and no microwaves), the overall survival rate of the atoms in the on-resonance set showed a clear decrease compared to the off-resonance experiments. The probability that a statistical fluctuation of the off-resonance survival rate could explain the on-resonance rate is 1×10^{-5} (P-value). In addition, during the interrogation time there was a significant excess of on-resonance events compared to off-resonance events during the first 30 seconds of microwave interaction. This difference corresponds to a P-value of 2.8×10^{-5}. These two data sets combined led ALPHA to conclude that resonant positron spin flip transitions were induced in trapped antihydrogen atoms. This experiment was a proof-of-principle demonstration for antihydrogen spectroscopy rather than a full attempt to accurately measure the transition frequency. However, by demonstrating the difference between on- and off-resonance experiments, the PSR transition frequency has been bounded to within 100 MHz, or 4 parts in 10^3 of the expected hydrogen PSR frequency.

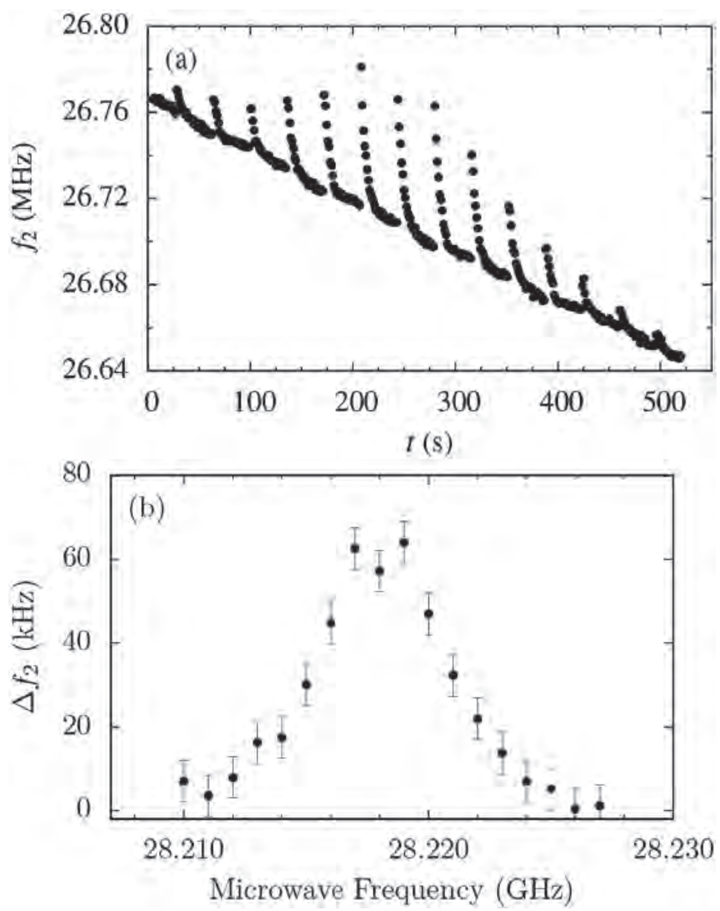


Fig. 2 (a) The quadrupole mode frequency (f_2) evolution of an electron plasma, with a radius of 0.9 mm and consisting of 6.6×10^7 electrons, in a uniform magnetic field while scanning for the cyclotron resonance. The frequency jumps are due to 4 μs microwave pulses at frequencies scanning through the cyclotron resonance frequency. The downward slope of the baseline quadrupole mode frequency is consistent with the slow expansion of the plasma. (b) The cyclotron lineshape is generated by plotting the changes in quadrupole frequency as a function of the frequency of the microwave pulses.

Very recently, the ALPHA collaboration reported another major milestone in antihydrogen research by exciting the two-photon 1S-2S transition for the first time [5], and a similar precision measurement in antihydrogen would provide a stringent test of CPT symmetry.

REFERENCES

1. G.B. Andresen, *et al*., (ALPHA Collaboration), "Trapped Antihydrogen", *Nature*, **468**, 673 (2010).
2. G.B. Andresen, *et al*., (ALPHA collaboration), "Confinement Of Antihydrogen For 1,000 Seconds", *Nat. Phys*., **7**, 558 (2011).
3. C. Amole, *et al*., (ALPHA Collaboration), "In Situ Electromagnetic Field Diagnostics With An Electron Plasma In A Penning–Malmberg Trap", *New J. Phys*., **16**, 013037 (2014).
4. C. Amole, *et al*., (ALPHA Collaboration), "Resonant Quantum Transitions In Trapped Antihydrogen Atoms", *Nature*, **483**, 439 (2012).
5. M. Ahmadi, *et al*., (ALPHA Collaboration), "Observation of the 1S-2S transition in trapped antihydrogen", *Nature*, **541**, 506 (2017).

Report on 2016 CERN Teachers Workshop

by Jeff Goldie, Strathcona High School, Edmonton, AB

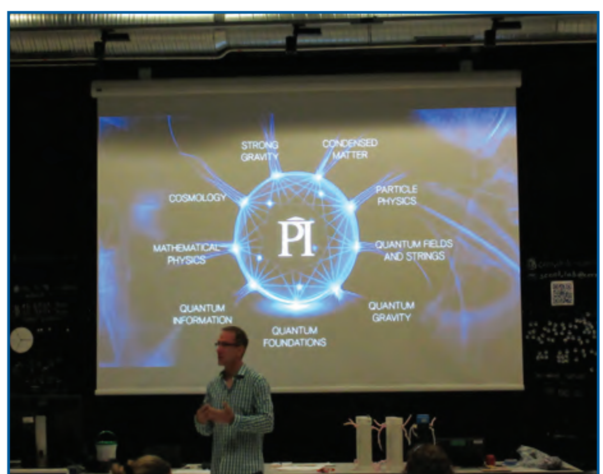
This past spring was a time of more than a little excitement in my life as I was honoured by the Canadian Association of Physicists with an Award for Excellence in Teaching High School/CEGEP Physics (Prairies and Northwest Territories) and subsequently chosen to attend the CERN High School Teachers Programme (HST) in Geneva, Switzerland[1]. The HST, offered each summer by CERN, brings teachers from around the world together for three intensive weeks of lectures, question and answer sessions, hands-on workshops, working group collaborations, and visits to as much of the CERN complex and the Large Hadron Collider (LHC) as is reasonable and safe. This year's HST involved 47 teachers from 38 countries.

Guiseppe Augello (Italy) and Nathalie Sihol (France) working on Acoustic Levitation project

The teachers present at this year's HST arrived with varying familiarity with particle physics, especially at the high-energies that the LHC is operating at, consequently many of the sessions during the first week were directed toward the physics involved in how the LHC operates, and perhaps more importantly, why it is being done. One of the early presentations focussed on the medical applications related to accelerator and detector technology that CERN has been at the forefront of – information that is highly applicable to any high school physics classroom. I greatly appreciated the time and thoughtfulness that each of the presenters devoted to their sessions or tours, and even more to their willingness to entertain and answer questions. This alone was one of the most fulfilling aspects of the programme. I arrived with a notebook full of questions, left with another notebook full of answers, and more importantly to me, even more questions than I had before! Just in case it sounds like all we did was sit and listen there were of course also many breaks in the flow of information to visit key spot of the CERN complex especially S'Cool Lab. This working facility is focussed on delivering hands-on particle physics experiments to high school students from all across Europe and forms a key part of their public outreach program.

S'Cool Lab was also integral to many of the working group collaborations, groups of six teachers collaborating to create educational resources related to CERNs operational goals and projects. Each working group had a primary focus that ranged from working with the Open Data platform, constructing Muon detectors, planning activities using CERNs "Microcosm" display or S'Cool Lab, through to Gender Inclusive teaching. Each group was also tasked with presenting their results to the rest of the groups. It was an excellent opportunity to compare and contrast our varied teaching experiences, and to share ideas with our colleagues. I was constantly amazed at how similar our daily school experiences are regardless of language, culture or even age. I guess no matter where you go students will be students.

The final week of the HST was in some ways the most enjoyable and challenging for the teachers. It started off with a pleasant evening on the CERN patio at a "meet and greet" for fellow Canadians Greg Dick and Dave Fish from the Perimeter Institute (PI). The group was lulled into a false sense of security by the easy going charms of the pair. Little was the group to know that the next day their intellectual world would be shaken to the foundations as Greg and Dave turned on the physics!



Greg Dick introducing the Perimeter Institute workshop

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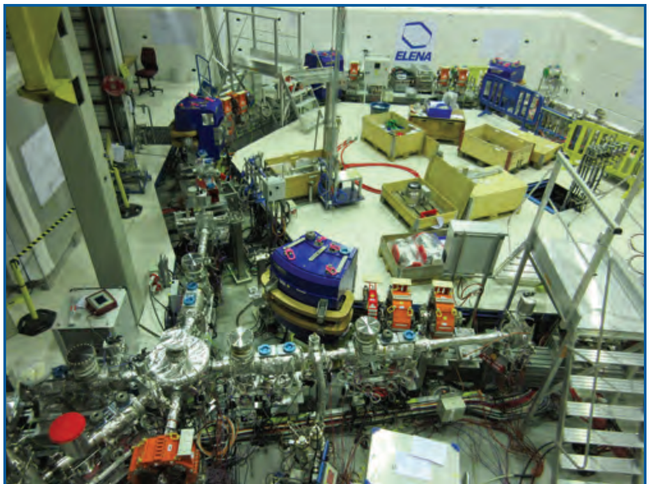
1. Participation in this Workshop is made possible through the Perimeter Physics Education Scholarship and the additional support provided by the Institute for Particle Physics and the CAP HS/Cegep Teachers Award.

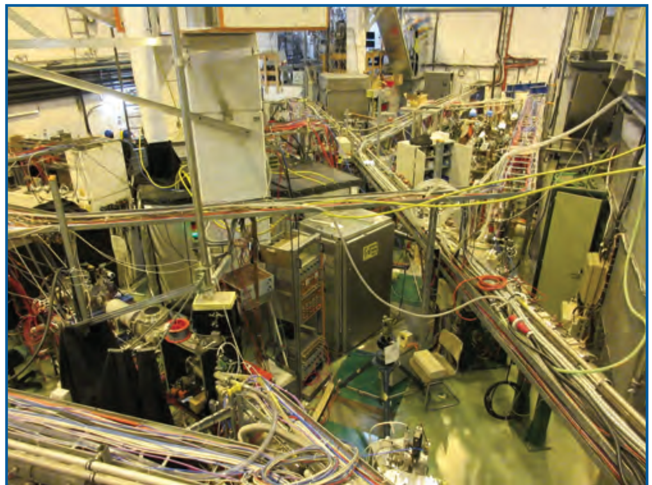
Dave Fish guiding HST group through Curved Spacetime activity

Although many teachers in Canada are familiar with the fantastic learning resources that PI has developed this was the first time that most of the HST group had experienced it. More critically, this was also the first time that they had experienced two experts modelling the type of learning environment that those resources lend themselves to. The phenomenal job that Greg and Dave did in introducing the pedagogy of how to use the PI materials was worth any expense those teachers incurred in getting to CERN. At supper that evening one of the participants offered the wistful observation that Greg and Dave had just made her question everything that she thought was true. The smile that illuminated her face as she also noted that this was going to force her to completely revamp her entire practice reminded me of exactly what a good professional development is intended to do.

From a personal point of view it was also illuminating to hear firsthand about a number of opportunities for teachers and students here in Canada to become involved with researchers and specialists currently active in the field of particle physics. The "BeamLine for Schools" (BL4S) competition presents teams of high school students from around the world with the opportunity to propose and carry out an experiment using the LHC beamline at CERN. Students might spend up to 50 hours learning about particle physics and creating their proposal but the chance for two winning teams (and their coaches) to be onsite at CERN while the experiment is being run is a huge incentive. One neat aspect is that teams do not have to be from a single school and collaborations are most welcome. For more information access <beamline-for-schools.web.cern.ch> or simply type Beamline for Schools into any search engine. A second opportunity is through the International Particle Physics Outreach Group (IPPOG) which offers International Master Classes (http://www.physicsmasterclasses.org). These classes enable high school students, partnered with a local university, to spend an entire day in the month of March exploring the wonders of particle physics. The morning sessions are an introduction to modern particle physics, the afternoon sees the students analyzing actual data from the ATLAS detector searching for a Higgs particle event, and the day culminates with a video conference with participants from around the world so that students can collaborate and share their findings. The IPPOG website (ippog.web.cern.ch) offers a wealth of classroom material, everything from informational posters and brochures through to presentations via their searchable resource list. Either of the BL4S or



Inside the Antimatter Factory



Inside ISOLDE – Radioactive Ion Beam Facility

Master Classes would be an excellent opportunity for physics teachers, and Canadian institutions to get our students excited about fundamental physics research. A third, intriguing opportunity, proposes a test of gravity using antimatter and more information can be accessed by typing projectantimatter.org into any search engine however it seems less likely to be something for the average physics classroom.

One of the last lectures we were privileged to hear was about the possibilities regarding where CERN is headed dependent on advances in technology, and the will of the public to continue to fund such a large scale venture. Reports from previous participants have noted the difficulty related to trying to convey the sheer scale of the network of people, data, and technology that is CERN. It is hard for many people to see the spin-off benefits associated with developing the technologies and infrastructure involved in the LHC, the ATLAS detector, the Compact Muon Solenoid, or the Antimatter factory. It is true that words really don't do these marvels the justice that they deserve. But as educators we can only try. As participants we were encouraged to return to our respective countries and classrooms and strive to instill in our students the knowledge, skills and attitudes about particle physics that make it the grand endeavour that it has been, and will continue to be. For those despairing of the herculean task that this seems to entail I can only offer the observation "The world changes one person at a time" or in our classes, one student at a time!

Neutron Scattering in Canada is at a Turning Point

Canadian scientists need access to world-class infrastructure for cutting-edge and globally competitive research. For many physicists this means using the latest developments in neutron scattering instrumentation.

The Canadian neutron scattering community – encompassing 240 researchers and students from over 40 institutions in 8 provinces – is preparing for renewal, by developing new partnerships for accelerated access to the world's best neutron beam facilities and expertise. World leading facilities like the Spallation Neutron Source and the NIST Centre for Neutron Research in the USA, the Institut Laue-Langevin in France, or the European Spallation Source under construction in Sweden, have much to offer Canadian physicists.

This outward look comes after recent developments at Chalk River Laboratories that foreshadow changes to decades of Canadian leadership in neutron scattering. In the 1950s, Bertram Brockhouse pioneered neutron scattering as a scientific tool for probing materials, and shared the 1994 Nobel Prize in Physics with Clifford Shull of Oak Ridge National Lab (USA). Their methods were replicated around the world and led to the global network of about 20 neutron beam facilities today.

Canadian neutron scatterers also made key contributions to the 2016 Nobel Prize in Physics, awarded to American physicists David Thouless, Duncan Haldane, and Michael Kosterlitz for their theories on topological materials. In 1985, Bill Buyers and others at Chalk River first verified the existence of the 'Haldane gap' in one-dimensional chains of magnetic atoms, a key prediction of the theory. Since then, the study of topological materials has come to dominate frontline research in condensed matter physics.

Today, about 130 researchers from other countries use Canada's facilities for their research, despite the fact that the NRU reactor is the oldest major research reactor in the world. Canada is still among global leaders because we continue to push the limits of what we can learn about materials, making contributions to condensed matter physics, health and life sciences, manufacturing of cars and airplanes, and development of clean energy technologies. You can find many case-studies at http://cins.ca/discover.

But now Canada is at a historic turning point, and the need to form closer ties with foreign facilities is more important than ever. The NRU reactor is scheduled to close permanently on March 31, 2018, marking the end of nearly 70 years of Canadian leadership. In the same year, Canada's only official agreement for privileged participation in a foreign source – the USA's Spallation Neutron Source – will expire.

We must forge formal partnerships with foreign facilities quickly for the next decade. These can be centred on contributions to building and operating beamlines, which can then be leveraged to obtain accelerated access to beam time, and technical and travel support. We should also better exploit the McMaster Nuclear Reactor. Although it has low capacity for neutron scattering today, a CFI-funded beamline for Small-Angle Neutron Scattering (SANS) is being constructed for studying soft materials, as many SANS experiments do not need high flux. With further investments, other capabilities can be added, and the reactor's flux and operating cycle increased.

Success of these partnerships will require a unified vision for a post-2018 future to present to government. The vision should reflect a consensus of all those with interest in using neutron beams as research tools, and notably, one that is supported by university leaders as a priority for Canadian research.

Implementing such a vision is critical, to be able to continue the next decade of research, and to retain a large, active community that can pursue a longer term vision for 2030 and beyond.

Despite the $8B invested globally in neutron sources over the last 20 years, total neutron capacity will shrink as aging reactors close. Without further investment before 2030, the Spallation Neutron Source could become the only major source in North America, while in Europe, only

The Canadian Institute for Neutron Scattering is pursuing international partnerships to ensure that Canadians have access to neutron beam facilities, following the expected closure of the NRU reactor in 2018.

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Opinion

five might remain in operation.[1] Therefore, in the long term Canada should return to the construction and operation of the neutron sources ourselves.

Securing a major investment for the long term – hundreds of millions for a facility focused on neutron beams, or over a billion in a multipurpose NRU-like facility – may be possible when all stakeholders are unified and aligned. One area of emerging alignment, for example, is clean energy technologies: Neutron scattering contributes to advances in nuclear energy along with renewables, and electric or hydrogen-powered vehicles, and Canada has committed to double R&D investment in these areas to achieve the goals of the 2015 Paris Agreement on climate change.[2]

The Canadian Institute for Neutron Scattering is helping coordinate a vision for both time-scales. We're working with several foreign laboratories to construct agreements that provide tremendous scientific incentives for Canadians to conduct their research abroad. For updates on our progress, subscribe at http://cins.ca/.

1. European Strategy Forum on Research Infrastructures. "Strategy Report on Research Infrastructures: Roadmap 2016. http://www.esfri.eu/roadmap-2016

2. http://mission-innovation.net/.

2017 CAP Congress Program Highlights

(Visit http://www.cap.ca/en/congress/2017 for speakers' abstracts and bios.)

Herzberg Public Lecture

Arthur B. McDonald
Department of Physics, Queen's University "Deep, Dark Questions: Neutrinos and Dark Matter at SNO and SNOLAB"
Monday, May 29, 19h30 (the lecture will be preceded by a welcome BBQ for Congress delegates on campus and will be followed by a reception)

Plenary Lecturers

Marcel Franz
Department of Physics and Astronomy at University of British Columbia
Title: From solids with topology to black holes and back
Monday, May 29 at 10h30

Laura Greene (APS President)
Subject: Science Diplomacy
National High Magnetic Field Laboratory at Florida University
Wednesday, May 31 at 17h00

Cecile Fradin
Department of Physics and Astronomy at McMaster University
Title: On the importance of diffusion in biological systems
Wednesday, May 31 at 17h30

Jun Ye
Title: Atomic clock based on quantum matter
University of Colorado / NIST
Thursday, June 1st at 9h15

Chris Quigg
Title: Perspectives and Prospects for High Energy Particle Physics
Fermi National Accelerator Laboratory
Thursday, June 1st at 17h30

Congress Highlights

CAP Presidents Report and Annual General Meeting
Tuesday, May 30, 17h30-19h00

Faits saillants du programme du Congrès de l'ACP 2017

(Visitez le http://www.cap.ca/fr/congres/2017 pour les résumés et biographies des conférenciers.)

Conférence publique Herzberg

Arthur B. McDonald
Département de Physique, Université Queens « Questions sombres et profondes: les neutrinos et la matière sombre au SNO et au SNOLAB »
Lundi 29 mai, 19h30 (la conférence sera précédée d'un barbecue de bienvenue pour les délégués du Congrès sur le campus et suivie d'une réception)

Conférenciers pléniers

Marcel Franz
Université de la Colombie Britannique
Titre: La topologie en physique de la matière condensée
Lundi 29 mai à 10h30

Laura Greene (présidente de l'APS)
Sujet: National High Magnetic Field Laboratory at Florida University
Mercredi 31 mai à 17h00

Cecile Fradin
Université McMaster
Titre: L'importance de la diffusion dans les systèmes biologiques
Mercredi 31 mai à 17h30

Jun Ye
Titre: Horloge atomique basée sur la matière quantique
Université du Colorado / NIST
Jeudi 1er juin à 9h15

Chris Quigg
Titre: Perspectives and Prospects for High Energy Particle Physics
Fermi National Accelerator Laboratory
Jeudi 1er juin, 17h30

Événements spéciaux

Rapport du président de l'ACP et Assemblée générale annuelle
Mardi 30 mai, 17h30-19h00

CEWIP Panel Discussion
Subject: Diversity and Inclusivity within Canadian physics environment
Tuesday, May 30, 13h30-15h00

Professional Practice Development Session
Tuesday, May 30, 19h00-19h45

Poster Session
Wednesday, May 31, 18h00-19h30

Department Leaders Business Meeting
Wednesday, May 31, 19h30

Student-Industry Meet & Mingle
Wednesday, May 31, 19h30

CAP Best Student Oral Competition Finals
Thursday, June 1, 15h30-17h15

Panel de discussion du CEFEP
Sujet: Diversité et Inclusion dans la Physique au Canada
Mardi 30 mai, 13h30-15h00

Session de perfectionnement professionnel
Mardi 30 mai, 19h00-19h45

Session d'affiches
Mercredi 31 mai, 18h00-19h30

Réunion d'affaires des chefs de département
Mercredi 31 mai, 19h30

Rencontre des étudiants et de l'industrie
Mercredi 31 mai, 19h30

Finale de la compétition des présentations orales étudiantes de l'ACP
Jeudi 1er juin, 15h30-17h15

2017 INVITED SPEAKERS / *CONFÉRENCIERS INVITÉS 2017*

(Invited speakers in joint sessions appear after the individual division lists / *La liste des conférenciers invités aux sessions conjointes apparaît après les listes individuelles*)

DASP

David Thompson
Queen's University
Particularities in Geomagnetism and Magnetotellurics

DAMOPC

Gautam Das
Lakehead University
TBA

Rajibul Islam
University of Waterloo
TBA

Amar Vutha
University of Alberta
TBA

Michal Bajcsy
University of Waterloo
TBA

Kyung Soo Choi
University of Waterloo
Building synthetic quantum systems with atoms and photons

Stephen Hughes
Queen's University
Coupling spin photon emitters to an anisotropic nanophotonic vacuum

Xihua Wang
Alberta University
Micro/nanostructure engineering for light management in thin-film solar cells

Marc Dignam
Queen's University
Third Harmonic Terahertz Generation in Bilayer Graphene

Michael Reimer
Queen's University
Nanoscale source of bright entangled photon pairs

Na Young Kim
University of Waterloo
Dynamical Exciton-polaritons

Samuel Beaulieu
INRS/CNRS
High-order Harmonic Generation and XUV Free Induction Decay from Rydberg Wavepackets

DCMMP

David Cory
University of Waterloo
CFREF awards in Quantum Matter at the University of Waterloo

Doug Bonn
University of British Columbia
CFREF awards in Quantum Matter at the University of British Columbia

Alexandre Blais
Sherbrooke University
CFREF awards in Quantum Matter at the Sherbrooke University

Jeff Sonier
Simon Fraser University
TBA

Bruce Gaulin
McMaster University
TBA

DIAP

Michel Laberge
General Fusion, Burnaby
Tokamak compression experiments at General Fusion

Valery Radchenko
TRIUMF
Alpha emitters for cancer therapy

Steffon Luoma
Jannatec Technologies, Mining & Metals
Sensors in mining

Louis Archambault
Université Laval
Designing instruments for monitoring radiation doses delivered to living tissues

DPMB

Caroline Boudoux
Ecole Polytechnique de Montreal
Double-Clad Fiber Couplers – From Laboratory to Market

Michèle Desjardins
University of California
Shedding Light on the Brain: Multimodal Imaging from Two-Photon Microscopy to fMRI-BOLD

Hanna Jankowski
York University
TBA

Gary W. Slater
University of Ottawa
Polymer translocation: some surprising physics learned from Molecular Dynamics Simulations

Carolyn Ren
University of Waterloo
TBA

Cecile Fradin
McMaster University
TBA

William Ryu
University of Toronto
Physics of Behavior: Quantifying and Modelling C. elegans Locomotory Decisions

John Schreiner
Queen's University
TBA

Marc-André Fortin
Université Laval
Gold nanoparticles for dose enhancement in brachytherapy procedures

DNP

Liliana Caballero
University of Guelph
Neutron star mergers: neutrino emission and nucleosynthesis

Sangyong Jeon
McGill University
Characterizing Quark Gluon Plasma - The hottest and densest matter

Mukut Ranjan Kalita
TRIUMF
Search for a permanent electric dipole moment of the Ra-225 atom

Rituparna Kanungo
Saint Mary's University
Exploring exotic phenomena at the drip-lines with reaction spectroscopy at IRIS

Daniel D. Lascar
TRIUMF
Advances in Mass Measurements at TITAN

Dennis Muecher
University of Guelph
Probing Nuclear Shell Evolution using Radioactive Ion Beams at ISOLDE, CERN

Nicholas Scielzo
Lawrence Livermore National Laboratory
Tests of the electroweak interaction from studies of the beta decay of trapped 8Li ions (DNP)

Artemisia Spyrou
NSCL, Michigan State University
Constraining neutron capture rates far from stability and astrophysical implications

DPP

Jean-Michel Guay
University of Ottawa
Paint or not to Paint? That is the plasmonic question...

PPD

Steven Robertson
McGill University
Status of the Belle II experiment

Guillaume Giroux
Queen's University
Status of the PICO experiment

Thomas Lindner
TRIUMF
Status of the T2K experiment

Gilles Gerbier
Queens University
Status of the NEWS experiment

Wolfgang Rau
Queens University
Status of SuperCDMS/Cute

Emma Kuwertz
University of Victoria
Operation and performance of the ATLAS detector in LHC Run-II

Alain Bellerive
Carleton University
Standard Model and Higgs boson studies with the ATLAS detector

Otilia Ducu
Universite de Montreal
Searches for new physics with the ATLAS detector

Isabel Trigger
TRIUMF
Upgrades to the ATLAS detector at the LHC
Pump-probe studies of condensed matter

JOINT DCMMP-DAMOPC

Luyi Yan
University of Toronto
TBA

This list was compiled in early January and is, therefore, incomplete and subject to change. Visit http://www.cap.ca/en/activities/2017-congress-ottawa/invited-speakers for the most recent list.

Cette liste a été compilée au début du mois de janvier. Elle est incomplète et sujette à changement. Veuillez visiter http://www.cap.ca/fr/activities/2017-congress-ottawa/conferenciers-invites.

Science Policy Corner

by Aimee K. Gunther, IQC/U.Waterloo Member, CAP Science Policy Committee

Perhaps it is the beautiful imagery of the Apollo 11 space craft gracefully touching down on the moon, completing over a decade's worth of focused work that inspires so many others to do the same, or at least, in name. In science planning, "moon shots", "initiatives", "road maps" are trendy strategic names of plans with big price tags and lofty goals [1]. Is the Canadian research landscape about to launch its own lunar-sized research initiatives? Is this something we need?

The recently-released Canadian Innovation Agenda from the 2016 consultations (to which CAP submitted recommendations) suggested that further economic growth could come via investment in emerging technologies through: people, technology, and companies. More relevantly, Canadians stressed that the government focus on mission-driven research and innovation ". . . by setting ambitious, big-horizon goals, then making strategic investments and targeting resources in specific areas to fulfill that mission." [2]

What could this mean for physicists? For those within a potential collaborative "moon shot" topic, the Innovation Agenda suggests continued investment in (among other things): the education of highly qualified personnel, growth of technology hubs, and university infrastructure. But what of those institutions outside a technology hub (or "moon shot" mandate)? Will big science facilities have dependable funding mechanisms available? And what of the granting council success rates?

Influx of money or not, science needs long-term consistency in funding. How would the low success rates of grants, and indeed the lower value of many of the grants themselves, affect early career researchers, especially those of an under-represented minority? What happens after the "moon shot" funding is used up? This is where the funding structure results of the Fundamental Science Review will be key.

Le coin de la politique scientifique

par Aimee K. Gunther IQC/U.Waterloo membre, Comité de la politique scientifique de l'ACP

Peut-être est-ce les magnifiques images du vaisseau spatial Apollo 11 alunissant avec grâce qui portent à leur apogée plus de dix années de travail acharné et en incitent tant d'autres à faire de même, du moins en apparence. En planification scientifique, « grands efforts », « initiatives » et « feuilles de route » sont des noms stratégiques branchés, de plans aux factures salées et aux objectifs ambitieux [1]. Le milieu canadien de la recherche est-il sur le point d'entreprendre ses propres initiatives de recherche de taille lunaire? Est-une chose dont nous avons besoin?

Le Programme du Canada pour l'innovation publié récemment et issu des consultations de 2016 (où l'ACP a présenté des recommandations) donne à entendre qu'une croissance économique accrue pourrait venir de l'investissement dans les technologies émergentes si l'on met l'accent sur les gens, les technologies et les entreprises. De façon plus pertinente, les Canadiens ont préconisé que le gouvernement mette l'accent sur la recherche axée sur des missions et sur la promotion de l'innovation « . . .s'il établit des objectifs ambitieux et vastes, puis investit stratégiquement et cible des ressources dans des secteurs précis afin de réaliser ces objectifs [2] ».

Qu'est-ce que cela pourrait signifier pour les physiciens? Pour ceux qui pourraient participer à un « grand effort » collaboratif, le Programme pour l'innovation propose un investissement continu dans (entre autres) : la formation d'un personnel hautement qualifié, l'essor de pôles technologiques et l'infrastructure universitaire. Mais qu'en est-il de ces établissements sans pôle technologique (ou mandat de « grand effort »)? Les grandes installations scientifiques disposeront-elles de mécanismes de financement fiables? Et qu'en est-il des taux de réussite des conseils subventionnaires?

Qu'il y ait apport de capitaux ou non, la science a besoin d'une stabilité de financement à long terme. En quoi le faible taux de réussite des subventions et, en fait, la valeur moindre d'un grand nombre d'entre elles affecteront-ils les chercheurs en début de carrière, notamment ceux d'une minorité sous représentée? Qu'arrive-t-il après épuisement des fonds du « grand effort »? C'est là que les résultats de la structure de financement de la Revue fédérale des sciences seront clés.

SCIENCE POLICY CORNER

Not to diminish the significance of these potential encompassing research and innovation topics, but there are always trade-offs. Will a flashy and highly marketable, government-driven research initiative be better or worse for physics in Canada? In the coming months and years, we shall see.

References

1. *Nature*, **541**, 450-453 (26 January 2017), doi: 10.1038/541450a.
2. Canadian Innovation Agenda, https://www.ic.gc.ca/eic/site/062.nsf/eng/h_00051.html.

Ce n'est pas pour réduire l'importance de ces sujets possibles englobant la recherche et l'innovation, mais il y a toujours des compromis à faire. Une initiative de recherche gouvernementale tape-à-l'œil et hautement prisée, axée sur la recherche, sera-t-elle meilleure ou pire pour la physique au Canada? Les mois et les années qui viennent nous le montreront.

Références

1. *Nature*, **541**, 450-453 (26 janvier 2017), doi:10.1038/541450a.
2. Programme d'innovation du Canada, https://www.ic.gc.ca/eic/site/062.nsf/fra/h_00051.html.

Would you like to know more about the CAP's role in shaping science policy? Are you interested in getting involved? In either case, please feel free to get in touch (kris@mun.ca).

Aimeriez-vous en savoir davantage sur le rôle de l'ACP dans l'orientation de la politique scientifique? Êtes-vous intéressé à jouer un rôle actif? Dans l'un et l'autre cas, n'hésitez pas à communiquer avec nous (kris@mun.ca).

NEWS

NEWS FROM THE CANADA SCIENCE POLICY CENTRE (CSPC)

SCIENCE POLICY AWARD OF EXCELLENCE - YOUTH CATEGORY

The CSPC is proud to continue last year's highly successful Science Policy Award of Excellence - Youth Category which follows in the spirit of our 2013 Young Generation Award. Do you have a creative idea for a government policy or program that you would like to share with those who can make it happen? Well, sharpen your evidence and put together an application by Friday, July 21st.

NOUVELLES DU CENTRE DE LA POLITIQUE SCIENTIFIQUE CANADIENNE (CPSC)

PRIX D'EXCELLENCE EN POLITIQUES SCIENTIFIQUES CANADIENNES – JEUNE GÉNÉRATION

La CPSC est fière de présenter à nouveau cette année le Prix d'excellence en politiques scientifiques – Jeune génération, qui a connu un énorme succès l'année dernière et qui est dans l'esprit de notre Prix Jeune génération de 2013. Vous avez une idée pour une politique ou un programme gouvernemental que vous aimeriez partager avec les personnes qui ont le pouvoir de changer les choses? Alors, préparez vos arguments et présentez une proposition avant le vendredi 21 juillet.

Proposals should be connected to one or more of the themes of the 2017 Canadian Science Policy Conference (CSPC 2017). One prize will be awarded to the most compelling evidence-based policy idea. The winner will receive free admission to the conference, accommodation for two nights in Ottawa (November 1-3, 2017), and will have the opportunity to present the policy proposal at the conference.

For more details please click here: http://sciencepolicy.ca/cspc-2017-science-policy-award-excellence-youth-category

To check out a selection of the 2016 applications, download the PDF here: http://sciencepolicy.ca/sites/default/files/cspc_award_-_submissions_0.pdf

Les soumissions devraient être liées à au moins un thème de la Conférence de la politique scientifique canadienne 2017 (CPSC 2017). Un prix sera remis pour l'idée de politique fondée sur des données probantes la plus percutante. Le gagnant aura droit à un laissez-passer pour la conférence, ainsi que de l'hébergement pour deux nuits à Ottawa (1er au 3 novembre 2017), et aura l'occasion de présenter sa proposition de politique dans le cadre de la conférence.

Pour de plus amples détails, veuillez cliquer ici : http://sciencepolicy.ca/fr/prix-dexcellence-en-politiques-scientifiques-canadiennes-de-la-cpsc-2017-jeune-generation.

Pour consulter une sélection des propositions de 2016 (disponible en anglais seulement), veuillez cliquez ici : http://sciencepolicy.ca/sites/default/files/cspc_award_-_submissions_0.pdf.

UPCOMING CSPC EVENTS

Science Policy Lecture Series

Be on the lookout for the announcement of the next Science Policy Lecture Series.

If your organization is interested in hosting or sponsoring any symposium or lecture series please contact CSPC at info@sciencepolicy.ca

ÉVÉNEMENTS DU CPSC À VENIR

Série de conférences sur les politiques scientifiques

Soyez à l'affût pour plus de détails de la prochaine série de conférences sur les politiques scientifiques.

Si votre organisation souhaite animer ou parrainer un symposium ou une conférence de la série, veuillez communiquer avec le CPSC à info@sciencepolicy.ca,

ARE YOU CELEBRATING CANADA'S 150TH ANNIVERSARY? BRING YOUR EVENT TO CSPC 2017!

CSPC is inviting all those in the science and innovation community who are planning for the celebration of Canada's 150th anniversary to consider having their functions/ forums/ gala dinners/ receptions/ awards or any other celebration event at CSPC 2017.

To know more about this contact the CSPC at info@sciencepolicy.ca

For more information, email us at info@sciencepolicy.ca

VOUS CÉLÉBREZ LE 150E ANNIVERSAIRE? PRÉSENTEZ VOTRE ÉVÉNEMENT DANS LE CADRE DE LA CPSC 2017!

Le CPSC invite tous les individus qui font partie de la communauté des sciences et de l'innovation qui planifient célébrer le 150ième anniversaire à tenir leurs fonctions/ forums/soupers/remises de prix/etc., dans le cadre de la CPSC 2017.

Pour en apprendre davantage, veuillez communiquer avec le CPSC à info@sciencepolicy.ca

Pour de plus amples renseignements, écrivez-nous par courriel à l'adresse info@sciencepolicy.ca

REPORT OF OUTGOING PRESIDENT / *RAPPORT DU PRÉSIDENT SORTANT*

(JUNE/*JUIN* 2015 – JUNE/*JUIN* 2016)

BY/*PAR* ADAM J. SARTY

I write this Report now more than half-way into the 2016-17 "CAP year" under the leadership of the current CAP President, Richard MacKenzie. This Report is meant to provide you – the Canadian physics community – with a brief snapshot/overview of CAP activities based upon my one-year tenure as your President; this task is made challenging by the reality that the activities of the CAP, and the CAP office and staff, have been quite dynamic and in flux (in exciting and positive ways), both throughout this reporting period, and flowing into the months since last June. But, I will report here focusing on the June 2015-June 2016 year, drawing primarily upon the report I gave prior to our CAP Annual General Meeting during Congress 2016 at the University of Ottawa last June – and I will leave discussion of all the continuing activities and changes within the CAP since last June for a future report by Richard MacKenzie (when there will be even more to report!).

Let me begin with the most obvious: this was an amazing/outstanding year for international recognition of Canadian physics! Long-serving CAP member, Art MacDonald (SNOLAB/Queen's University), was announced as a joint recipient of the Nobel Prize in Physics, together with Takaaki Kajita (University of Tokyo) "for the discovery of neutrino oscillations, which shows that neutrinos have mass". The announcement of this Nobel Prize in October 2015 was followed closely that November by the news that the Sudbury Neutrino Observatory (SNO) Collaboration shared the 2016 Breakthrough Prize in Fundamental Physics, valued at $3 million, with T2K/K2K and three other international collaborations (Super Kamiokande, KamLAND, and Daya Bay) "for the fundamental discovery of neutrino oscillations, revealing a new frontier beyond, and possibly far beyond, the standard model of particle physics." Both SNO and T2K/K2K boast significant involvement from Canadian scientists across the country, including a host of CAP individual, departmental, and institutional members (SNO and TRIUMF). These very high profile awards for Canadian physics were accompanied by an impressive list of other national and international awards for CAP members (as can be seen with a review of the News Archives on the CAP's website), all of which served to shine the spotlight on the great work of Canadian physicists – congratulations once again to Art MacDonald and to all the (many) award winners.

As this Report will be based upon my "state of the CAP" report from the AGM, this represents my own view of CAP activities, priorities, and status as of my term's end, as opposed to a more dogmatic outline of the full myriad of CAP activities – those activities can all be found on our www.cap.

Au moment de rédiger le présent rapport, la deuxième moitié de « l'année 2016-2017 de l'ACP » s'est amorcée sous la direction de l'actuel président de l'ACP, Richard MacKenzie. Ce rapport vise à vous – la collectivité canadienne de la physique – fournir un bref coup d'œil/aperçu des activités de l'ACP pendant mon année à titre de président; cette tâche est rendue difficile du fait que les activités de l'ACP, ainsi que de son bureau et de son personnel, ont été assez dynamiques et changeantes (d'une manière positive et stimulante), tant au long de la présente période de rapport que depuis juin dernier. Mon compte rendu portera toutefois surtout sur l'année « juin 2015 – juin 2016 », puisant principalement au rapport remis avant l'assemblée générale annuelle (AGA) de l'ACP, au congrès tenu en 2016 à l'Université d'Ottawa en juin dernier – et je laisserai l'examen de toutes les activités permanentes et des changements apportés à l'ACP depuis ce mois-là pour un futur rapport de Richard MacKenzie (il y aura alors une matière plus abondante à traiter!).

Commençons par le plus significatif: ce fut une année étonnante et remarquable pour la reconnaissance internationale de la physique au Canada! On a annoncé que M. Art MacDonald (SNOLAB/Université Queen's), depuis longtemps membre de l'ACP et co-lauréat du Prix Nobel de physique avec Takaaki Kajita (Université de Tokyo) « pour la découverte des oscillations de neutrinos, montrant que ceux-ci ont une masse ». L'annonce de ce prix Nobel en octobre 2015 a été suivie dès novembre par la nouvelle que la Collaboration de l'Observatoire de neutrinos de Sudbury (SNO) partageait le Prix d'innovation 2016 en physique fondamentale (Breakthrough Prize), évalué à 3 millions de dollars, avec la collaboration T2K/K2K et trois autres collaborations internationales (Super Kamiokande, KamLAND et Daya Bay) « pour la découverte fondamentale des oscillations de neutrinos, révélant les limites du modèle normal de la physique des particules et les repoussant peut-être très loin ». SNO et T2K/K2K jouissent toutes deux de la participation de nombreux scientifiques de partout au Canada, dont une foule de personnes, départements et établissements membres de l'ACP (SNO et TRIUMF). Ces prix très prestigieux pour la physique au Canada s'accompagnaient d'une liste impressionnante d'autres prix nationaux et internationaux pour les membres de l'ACP (comme le révèle l'examen des nouvelles archivées sur le site Web de l'ACP), qui ont tous servi à braquer les projecteurs sur les grands travaux des physiciens canadiens – à nouveau, mes félicitations à Art MacDonald et à tous les (nombreux) lauréats de prix.

Comme le présent rapport reposera sur le compte rendu « état de l'ACP », présenté à l'assemblée générale annuelle (AGA), cela représente mon point de vue sur les activités, les priorités et l'état de l'ACP à la fin de mon mandat, et non un aperçu plus dogmatique de l'ensemble des activités de l'ACP –

ca website (which is currently about to undergo a facelift . . . but that's for next year's report, and I will try not to get ahead of myself). With that introduction, and caveat, I continue:

WHO IS THE CAP / WHAT DOES THE CAP DO?

People

Following a long process in previous year(s) to update and modernize the governance structure and bylaws of the CAP, this year was our first full year under this new structure. The CAP organization is led by a volunteer Board of Directors that is informed by input from larger Advisory Council comprised of about 50 physicists spanning the geographic and disciplinary range of our membership. Our Board Executive for the year were David Lockwood (Treasurer), Stephen Pistorius (Vice-President Elect), Richard MacKenzie (Vice President), and Bob Fedosejevs (Past President), and myself; the full Board included 7 other Directors: Donna Strickland (Academic Affairs), Jens Dilling (International Affairs), Andreas Warburton (Student Affairs), Mike O'Neill (Professional Affairs), Marcello Pavan (Communications), Kris Poduska (Science Policy), and Steven Rehse (Member Services). We were assisted by our professional and dedicated staff members to facilitate the day-to-day operations of our Association – our Executive Director, Francine Ford **(celebrating her 25th Anniversary in her role as our CAP Executive Director this past June!)**; our Program Manager, Danielle Legault; our part-time Membership Coordinator, Chantal Éthève-Meek; our part-time Web-master, Chris Brûlé; and our part-time Communications intern, Jenny Kliever. All of these people serve our Membership of approximately 1500 – roughly 700 of whom are full members, 240 are graduate student members, 180 are undergraduate student members, 60 are departmental members, 6 are institutional members and 8 are corporate members. We remain conscious of the reality that the large majority of our membership are academically-oriented physics researchers, based at universities or government laboratories, and we continue to investigate potential future opportunities to make better connections with physicists working in the private sector, as well as high school and CEGEP physics teachers.

Finances

The CAP financial situation remains reasonable, but the Board continued to keep a watchful eye as we balanced market fluctuations with our desire to make strategic spending investments for the Association. The CAP investment portfolio is well managed and continues to grow through dividend income (by June 2016, it was recovering in overall market value). The membership revenue is stable, and the 2015 Congress held at U. of Alberta showed an essentially breakeven financial result. Our annual financial statements showed our *Physics in Canada* magazine as a net expense, but this was primarily a result of our last issue in 2015 not getting mailed out before the December fiscal year-end, and so had to be accounted for in the 2016 finances. As a result of some

lesquelles peuvent toutes être consultées sur notre site Web (qui doit bientôt subir une cure de rajeunissement. . .mais je laisse cela pour le rapport de l'an prochain et j'essaierai de ne pas trop m'avancer). Poursuivons après cette introduction et mise en garde.

QU'EST-CE QUE L'ACP / QUE FAIT L'ACP ?

L'équipe

À la suite d'un long processus amorcé au cours des années passées en vue de mettre à jour et de moderniser la structure de gouvernance et les règlements de l'ACP, cette année est la première passée entièrement sous la nouvelle structure. L'organisme qu'est l'ACP est dirigé par un conseil d'administration bénévole informé par l'apport du grand conseil consultatif, composé d'environ 50 physiciens qui couvrent l'ensemble du territoire et des disciplines de notre effectif. Cette année, notre conseil de direction était formé de David Lockwood (trésorier), Stephen Pistorius (vice-président élu), Richard MacKenzie (vice-président), Bob Fedosejevs (ancien président) et moi-même; le conseil complet comprenait sept autres administrateurs : Donna Strickland (Affaires académiques), Jens Dilling (Affaires internationales), Andreas Warburton (Affaires étudiantes), Mike O'Neill (Affaires professionnelles), Marcello Pavan (Communications), Kris Poduska (Politique scientifique), et Steven Rehse (Services aux membres). Notre personnel professionnel et dévoué nous a aidés à faciliter la marche courante de l'Association – notre directrice exécutive, Francine Ford **(qui a célébré son 25e anniversaire à titre de directrice exécutive de l'ACP en juin dernier!)**; notre chef de programmes, Danielle Legault; notre coordonnatrice de l'adhésion (à temps partiel), Chantal Éthève-Meek; notre webmestre à temps partiel, Chris Brûlé; et notre interne aux communications (à temps partiel), Jenny Kliever. Toutes ces personnes servent notre effectif d'environ 1500 membres – dont quelque 700 membres à part entière, 240 étudiants de cycles supérieurs, 180 étudiants du premier cycle et 60 membres départementaux, ainsi que 6 établissements membres et 8 membres corporatifs. Nous sommes biens conscients de la réalité que la vaste majorité de nos membres sont axés sur la recherche en physique, œuvrant dans des laboratoires universitaires ou gouvernementaux, et nous continuons d'examiner les possibilités d'établir de meilleures relations avec les physiciens du secteur privé et avec les professeurs de physique au secondaire et au cégep.

Finances

La situation financière de l'ACP demeure raisonnable, mais le conseil est resté vigilant au moment où nous pesions les fluctuations du marché face à notre volonté de faire des placements stratégiques pour l'Association. Le portefeuille de ces placements est bien géré et continue de croître grâce aux revenus en dividendes (en juin 2016, sa valeur globale sur le marché s'est rétablie). Les recettes tirées des adhésions sont stables et le congrès de 2015, tenu à l'Université de l'Alberta, a atteint des résultats essentiellement équilibrés. Dans nos états financiers annuels, notre revue *La physique au Canada* a affiché une dépense nette, mais cela tient principalement au fait que notre dernier numéro de 2015 n'avait pas été posté avant la fin de l'exercice en décembre et, de ce fait, a dû être strategic spending initiatives, coupled with an overall market downturn affecting the value of our investments for the past two years, the CAP showed a net loss of ~$57k for FY2015, following a loss of ~$25k in FY2014 (but noting we had positive gains of $61k and $24k for FY2013 and FY2012, respectively). The CAP holds ~$490k in investment funds, with about $200k of that in "general reserves".

The long list of Regular Activities

While I promised at the beginning of this Report that it will not be a dogmatic outline of the full myriad of CAP activities, I believe it is important for us to be reminded (at least in a brief list form) of several important activities which have become embedded in the lexicon defining "what the CAP is":

- *Running our Annual Congress*: June 2015 at the University of Alberta, and June 2016 at the University of Ottawa; this annual conference draws 500-700 of us each year, providing a unique opportunity for the Canadian physics community to network, collaborate, share research and teaching ideas and methodology, discuss issues with university physics department heads and chairs, and liaise with NSERC and CFI representatives. This Congress also offers graduate students the opportunity to present their research and to compete for the best student oral or poster presentation.
- *Publishing Physics in Canada*: our unique magazine focusing on Canadian physics.
- *Overseeing the Annual Lecture Tour*: ensuring that top CAP member researchers make "the tour" to speak to undergraduate physics students throughout the country.
- *Overseeing Prize Exams*: member-developed exams delivered by volunteer members and Friends of CAP around the country to both high school students, and to undergraduate students – allowing top young physics enthusiasts to demonstrate their skills and be recognized for early excellence in understanding.
- *The CAP Medals and Awards Program*: peer review of nominations to recognize top Canadian physicists in various research disciplines, in service, and in teaching physics at secondary and post-secondary levels.
- *Public Policy Initiatives and Government Advocacy*: with the help of an active and knowledgeable Science Policy Committee, the CAP has been becoming more and more effective at being the voice of Canadian physics to the federal government (through pre-budget submissions, appearing before Standing Committees of the House of Commons, meeting with MPs) and to federal funding agencies (with close communications and liaising with NSERC and, more recently, with CFI).
- *Oversight of P.Phys. and Professional Affairs*: an active committee continuing to advocate for the professionalization of the physics practice in Canada.
- *Support for student Conferences*: supporting the Canadian Undergraduate Physics Conference (CUPC), and the Canada-America-Mexico (CAM) physics conference for graduate students.

comptabilisé en 2016. Par suite de certaines initiatives de placement stratégique, conjuguées à un repli global du marché qui affecte la valeur de nos placements depuis deux ans, l'ACP a affiché une perte nette de ~57k$ pour l'exercice 2015, après une perte de ~25k$ dans l'exercice 2014 (compte tenu cependant de gains de 61k$ et de 24k$ pour les exercices 2013 et 2012, respectivement). L'ACP détient ~490k$ en fonds de placements, dont environ 200k$ dans la « réserve générale ».

La longue liste des activités régulières

Au début du présent rapport, j'ai promis que ce ne serait pas un aperçu dogmatique de l'ensemble des activités de l'ACP, mais je crois qu'il est important de rappeler (au moins par une liste brève) plusieurs activités importantes qui font maintenant partie intégrante du lexique définissant « ce qu'est l'ACP » :

- *La tenue de notre congrès annuel*: en juin 2015 à l'Université de l'Alberta, et en juin 2016 à l'Université d'Ottawa; cette rencontre annuelle attire de 500 à 700 d'entre nous chaque année, offrant à la collectivité canadienne de la physique une occasion unique de se réseauter, de collaborer, d'échanger des idées et méthodes de recherche et d'enseignement, de discuter de questions avec les directeurs des départements universitaires de physique et d'assurer une liaison avec les représentants du CRSNG et de la FCI. Le congrès offre aussi aux étudiants de cycles supérieurs l'occasion de présenter leurs recherches et de rivaliser pour la meilleure présentation étudiante orale ou sur affiche.
- *Publication de La Physique au Canada*: notre revue unique axée sur la physique au Canada.
- *Coordination de la Tournée annuelle des conférenciers*: veiller à ce que les principaux chercheurs membres de l'ACP fassent la « tournée » en vue de s'adresser aux étudiants du premier cycle en physique de partout au pays.
- *Encadrement d'examens*: conçus par des membres et administrés tant aux étudiants du secondaire qu'à ceux du premier cycle par des membres bénévoles et Amis de l'ACP de partout au pays – permettant aux meilleurs jeunes enthousiastes de la physique de faire valoir leurs talents et de faire reconnaître leur excellence hâtive sur le plan de la compréhension.
- *Programme de médailles et de prix de l'ACP*: examen des candidatures par les pairs pour faire reconnaître les grands physiciens canadiens dans diverses disciplines de recherche, dans les services et dans l'enseignement de la physique aux niveaux secondaire et postsecondaire.
- *Initiatives de politiques publiques et défense de nos intérêts auprès du gouvernement*: avec l'aide du Comité de la politique scientifique à la fois actif et averti, l'ACP est devenue de plus en plus efficace à se faire la voix de la physique au Canada auprès du gouvernement fédéral (par ses mémoires pré-budgétaires, sa comparution devant les Comités permanents de la Chambre des communes, ses rencontres avec des députés) et les organismes de financement fédéraux (communication étroite et liaison assurée avec le CRSNG et, tout récemment, la FCI).
- *Contrôle du titre Phys. et des Affaires professionnelles*: comité actif qui ne cesse de travailler à la professionnalisation de la pratique de la physique au Canada.
- *Appui aux conférences d'étudiants*: appui à la Conférence canadienne des étudiants de physique et à la Conférence de physique Canada-États-Unis-Mexique pour les étudiants de cycles supérieurs.

- *Providing framework for support on International Committees*: particularly providing a mechanism for representation on Commissions of the International Union of Pure and Applied Physics (IUPAP); and the newly-facilitated Canadian partnership with the Asia-Pacific Centre for Theoretical Physics (APCTP), based in Pohang, South Korea.
- *Interfacing with the University Physics Departments across Canada*: annual meeting with department heads/chairs and institutional member leaders, and a regular survey of departments to ascertain trends and issues.
- *News Bulletins & News Flashes to Members / Press Releases*: providing methods of ensuring the Canadian physics community can share in all the good news and activities affecting Canadian physics.
- *Other Divisional Activities*: such as PhD thesis prizes for particular discipline Divisions, support for plenary speakers and divisional best student oral or poster presentation competitions at the annual Congress, support for discipline-based Canadian conferences, etc.

With that impressive summary list (from which I am sure to have missed other relevant activities), I challenged CAP members during my June AGM presentation (and I challenge you again now) to ponder the question:

WHAT DO CANADIAN PHYSICISTS THAT ARE NOT CAP MEMBERS THINK THE CAP IS / AND WHAT THE CAP DOES?

This is an important question for us as an Association to try and understand, since we want to expand our membership, reaching particularly physicists working outside of academia, but also physicists within academia who are choosing not to join the CAP. Our Department surveys reveal that we are graduating several hundred new undergraduate and graduate physics students each year, and yet our membership has remained steady at around 1500 for years . . . where are all these new physicists going, and why don't they see the CAP as relevant?

It is hard for us, as CAP members, to answer the question because we aren't the target audience. However, I can present paraphrased anecdotes from my own experience trying to tease out the answer to those questions (perhaps you will recognize these comments):

- *I'm not sure what the CAP does . . .*
- *The CAP just has that annual Congress thing, right?*
  - *I don't need to go to Congress, I go to APS meetings*
  - *My research colleagues don't go to Congress, so I don't go*
  - *So, the CAP doesn't really get me anything*
- *I can just join the APS*

- *Encadrement de l'appui au sein des comités internationaux*: en particulier, assurer un mécanisme de représentation au sein des commissions de l'Union internationale de physique pure et appliquée; et le partenariat récent du Canada avec le Centre de physique théorique pour l'Asie et le Pacifique, de Pohang en Corée du Sud.
- *Interface avec les départements universitaires de physique de tout le Canada*: assemblée annuelle avec les directeurs de départements et les dirigeants membres d'établissements, et sondages réguliers auprès des départements pour cerner les tendances et les problèmes.
- *Bulletins de nouvelles et messages d'information aux membres / communiqués de presse*: offrir des moyens de pouvoir faire part, à la collectivité canadienne de la physique, de toutes les bonnes nouvelles et activités qui concernent la physique au Canada.
- *Autres activités des divisions*: les prix de thèses de doctorat dans les divisions de disciplines particulières, l'aide aux conférenciers aux séances plénières et à la meilleure présentation étudiante orale ou sur affiches par division au congrès annuel, l'appui aux conférences canadiennes de disciplines particulières, etc.

Fort de cette liste brève mais impressionnante (où, j'en suis sûr, manquent d'autres activités pertinentes), j'ai mis les membres de l'ACP au défi, dans mon exposé de juin à l'AGA (et je vous enjoins à nouveau), de réfléchir à la question suivante:

QU'EST L'ACP AUX YEUX DES PHYSICIENS CANADIENS QUI N'EN SONT PAS MEMBRES / ET QUE FAIT L'ACP ?

Voilà une question qu'il nous importe de comprendre, à titre d'Association, car nous voulons grossir notre effectif et atteindre en particulier les physiciens qui travaillent hors du secteur universitaire, mais aussi les physiciens de ce secteur qui choisissent de ne pas adhérer à l'ACP. Nos sondages auprès des départements révèlent que nous diplômons chaque année plusieurs centaines de nouveaux étudiants des premier et deuxième cycles en physique, et pourtant notre effectif stagne à environ 1500 membres depuis des années . . . où donc ces nouveaux physiciens vont-ils, et pourquoi ne voient-ils pas la pertinence de l'ACP?

Pour nous, à titre de membres de l'ACP, il est difficile de répondre à la question, n'étant pas la groupe cible. Je puis toutefois vous citer des anecdotes personnelles paraphrasées et tenter d'en dégager la réponse à ces questions (peut-être reconnaîtrez-vous ces propos) :

- *Je ne sais pas vraiment ce que l'ACP fait . . .*
- *L'ACP vient tout juste de tenir ce congrès annuel, n'est-ce pas?*
  - *Je n'ai pas besoin d'aller au congrès, j'assiste aux réunions de l'American Physical Society (APS)*
  - *Mes collègues de recherche ne vont pas au congrès, alors, moi non plus*
  - *Alors, l'ACP ne m'apporte vraiment rien*
- *Je puis simplement adhérer à l'APS*

We need to ensure that non-CAP-member Canadian physicists know what we actually ARE doing. To do so, we need to make sure we ourselves know what the CAP does (refer, for example, to the summary list just above for a start!), and we need to continually ask ourselves whether we are doing the "right things" – the things that Canadian physicists would like to see a national professional association do. Luckily, the CAP has indeed been well aware of these issues, thought hard about them, and expressed our response in the form of our Strategic Plan released in 2014. SO:

WHO DO WE SAY WE WANT TO BE / WHAT DO WE SAY WE WANT TO DO?

Our answers to those questions have been articulated in the CAP 5-Year Strategic Plan for 2014-2018 (which is prominently featured on the front page of our CAP website), where we boldly state the CAP Vision:

The Canadian Association of Physicists strives to unleash the full potential of physics and physicists for the benefit of Canada.

A detailed implementation strategy for this Plan was developed in the 2014-15 year, and we started down the road in 2015-16 to trying to keep up with that plan. I think it is important to remind ourselves of the 4 primary Goals which we established in the Strategic Plan:

1. To Strengthen the Profession of Physics
2. To Improve the Visibility of Physics and Physicists in Canada through excellence in Communications
3. To effectively Advocate at all levels the Value of Physics and Physicists
4. To achieve Organizational and Operational excellence to provide Services in an Effective, Efficient, and Transparent manner

WHAT NEXT?

Given all I've written above, I can summarize in 3 points:

- The CAP DOES do a lot – engages in many programs and initiatives to support and advocate for physics in Canada.
- But it's not clear that we are doing the RIGHT things, or the things Canadian physicists want the CAP to do (nor is it clear Canadian physicists know what we actually do now).
- We have a great Strategic Plan that clearly articulates **who we want to be** and **what we want to do**.

On the road to implementing our Strategic Plan over the 2015-16 year, we found ourselves continually running into many tasks that focused on **communications** to various stakeholders. This pointed us in a very clear direction to address "what next?":

1. To achieve the Strategic Plan Goals, the CAP had to recognize that we are primarily a **Communications organization**.

Il nous faut veiller à ce que les physiciens canadiens non-membres de l'ACP sachent ce que nous FAISONS vraiment. À cette fin, nous devons nous assurer de savoir nous-mêmes ce que l'ACP fait (pour commencer, reportez-vous à la liste brève ci-dessus, par exemple!), et sans cesse nous demander si nous faisons les « bonnes choses » – celles que les physiciens canadiens aimeraient voir accomplir par une association professionnelle nationale. Heureusement, l'ACP a en effet été bien consciente de ces problèmes, y réfléchissant longuement, et elle a traduit notre réponse dans son Plan stratégique publié en 2014. Alors:

QUI DISONS-NOUS VOULOIR ÊTRE / QUE DISONS-NOUS VOULOIR FAIRE ?

Nos réponses à ces questions sont énoncées dans le Plan stratégique quinquennal de l'ACP pour 2014-2018 (qui occupe une place prééminente dans la page d'accueil du site Web de l'ACP), où nous formulons clairement la Vision de l'ACP:

L'Association canadienne des physiciens et physiciennes s'emploie à faire valoir la pleine puissance de la physique et des physiciens au bénéfice du Canada.

Une stratégie détaillée de mise en œuvre de ce Plan a été élaborée au cours de l'exercice 2014-2015 et nous avons commencé en 2015-2016 à tenter de respecter ce plan. Il est important, à mon avis, de rappeler les quatre objectifs premiers que nous avons établis dans le Plan stratégique:

1. Renforcer la profession de la physique
2. Accroître la visibilité de la physique et des physiciens au Canada par l'excellence dans les communications
3. Défendre efficacement à tous les niveaux la valeur de la physique et des physiciens
4. Atteindre l'excellence sur les plans de l'organisation et du fonctionnement afin d'assurer les services d'une façon efficace, efficiente et transparente

QUELLE EST LA PROCHAINE ÉTAPE ?

Étant donné tout ce qui précède, je puis résumer en trois points:

- L'ACP FAIT effectivement beaucoup – elle réalise de nombreux programmes et initiatives pour appuyer et défendre la physique au Canada.
- Mais il n'est pas clair si nous faisons les Bonnes choses, ou les choses que les physiciens canadiens veulent voir faire à l'ACP (il n'est pas clair, non plus, si les physiciens canadiens savent ce que nous faisons déjà).
- Nous avons un plan stratégique fantastique qui énonce clairement **qui nous voulons être** et **ce que nous voulons faire**.

La mise en œuvre de notre Plan stratégique, au cours de l'exercice 2015-2016, nous a amenés à expédier sans cesse les nombreuses tâches entourant les **communications** à divers intervenants et, très clairement, à nous demander « quelle est la prochaine étape? »:

1. Pour atteindre les objectifs du Plan stratégique, l'ACP a dû reconnaître qu'elle est avant tout un **organisme de communication**.

2. There were so many items related to communications in our Implementation Plan, that we needed HELP (external/professional) to assess our communications needs (with reference to our Strategic Plan and current activities), and guide us in a plan to address these Communication Needs to allow us to "get where we want to be" according to our Plan.

Therefore, during this year, after a Request for Proposals (RFP) process, the CAP engaged a communications specialist (Dr. Gina Grosenick) to conduct a Communications Needs Assessment as it relates to the CAP's overall operations and our Strategic Plan. This Needs Assessment identified 10 clear communication goals from our Plan, identified 10 distinct audiences to whom the CAP would like "to talk", provided a gap analysis to point to our specific communications deficits, and concluded with an outline of a Communications Plan to rectify the gaps and move us directly towards achieving a large number of the goals and tasks enumerated in our Strategic Plan. The Executive Summary of the Communication Needs Assessment is available from the CAP website.

Moving forward following this very thoughtful and well-researched assessment, it became clear at the end of my term as CAP President that the CAP sits at a cross-roads. Our Association must choose between either: investing in a new communications initiative to move the CAP toward truly meeting the Goals outlined in our Strategic Plan (a real investment, of real dollars – involving adding a communications professional to our office staff, for example); or, working within our status quo resource allocation and making the choice to re-focus/reduce the CAP program of activities (since we are currently over-stretched, and cannot continue status quo without stopping some activities).

The response at the June 2016 AGM seemed to support the CAP making the decision to make the investment, to take a risk, and seriously look at following the advice presented in the Communications Needs Assessment – it truly seemed like a clear way forward which will move us in a meaningful way toward realizing the Goals of our Strategic Plan, and with that, creating a stronger and more relevant CAP (with hopefully a larger membership, too!). I'm happy to say that the CAP Board has agreed with this and since the end my term has approved and proceeded in this direction. . .but I will leave that for this year's President, Richard MacKenzie, to report on in the future ☺.

I will conclude by acknowledging the great work done over the 2015-16 year by our partner "charitable arm of the CAP", the CAP Foundation (CAPF). Now functioning at arms-length from the CAP with its own governance structure, but remaining closely connected with the CAP Board, the CAPF worked diligently at finding its own path to enhancing charitable contributions toward the mission of the CAP. Most notably, leading up to the 2016 Congress at the University of Ottawa, the CAPF secured a matching donation from the Carswell Family Foundation (founded by CAP Past President, Allan Carswell) and launched the ***Ignite the Spark*** campaign, raising funds prior to the Congress and then culminating with a special Donor Reception with Art MacDonald as part of our

2. Notre Plan de mise en œuvre comportait tellement de points reliés aux communications qu'il nous fallait de l'AIDE (de l'extérieur/professionnelle) pour évaluer nos besoins en communications (par rapport à notre Plan stratégique et aux activités en cours) et nous guider vers un plan visant à combler ces besoins de façon à nous permettre « d'atteindre ce que nous voulons être », selon notre Plan.

Aussi, pendant cette année, après avoir lancé une demande de propositions, l'ACP a retenu les services d'une spécialiste en communication (Dre Gina Grosenick) pour évaluer les besoins en communications ayant trait au fonctionnement global et au Plan stratégique de l'ACP. Cette évaluation a permis de cerner dans notre plan 10 objectifs clairs en matière de communication et 10 publics distincts que l'ACP aimerait « atteindre », une analyse de carences révélant nos lacunes particulières sur le plan des communications, et se conclue par un plan de communication visant à combler les lacunes et à nous amener directement à réaliser un grand nombre des objectifs et tâches énoncés dans notre Plan stratégique. Le résumé de cette évaluation des besoins en communication peut être consulté sur le site Web de l'ACP.

Dans la foulée de cette évaluation fort sérieuse et bien documentée, il m'est apparu clairement à la fin de mon mandat à la présidence de l'ACP que l'Association est à la croisée des chemins. Elle doit opter : soit entreprendre une nouvelle initiative en matière de communication afin d'amener vraiment l'ACP à réaliser les objectifs énoncés dans son Plan stratégique (un placement réel, en dollars réels – ce qui suppose l'ajout d'un professionnel des communications à son personnel de bureau, par exemple); soit s'en tenir aux ressources dont elle dispose déjà et opter pour une réorientation/réduction de son programme d'activités (car l'ACP utilise plus que pleinement ses ressources et ne peut s'en tenir au statu quo sans abandonner certaines activités).

La réponse à l'AGA de juin 2016 semblait appuyer l'ACP dans sa décision de faire ce placement, de prendre un risque et de veiller sérieusement à suivre le conseil formulé dans l'Évaluation des besoins en communication – cela semblait clairement être la voie à suivre pour avoir les moyens de réaliser les objectifs de notre Plan stratégique et, en outre, de créer une ACP plus forte et plus pertinente (ayant aussi un effectif qu'on espère élargi!). Je suis heureux de dire que le conseil de l'ACP a donné son aval et, depuis la fin de mon mandat, a approuvé et pris cette orientation. . .mais je laisserai au président de cette année, Richard MacKenzie, le soin de faire rapport sur la question dans l'avenir ☺.

Je conclus mon propos en reconnaissant le magnifique travail fait au cours de l'exercice 2015-2016 par notre partenaire, « l'organisme caritatif de l'ACP » qu'est la Fondation de l'ACP (FACP). La FACP, qui est maintenant indépendante de l'ACP et a sa propre structure de gouvernance mais demeure étroitement reliée au conseil de l'ACP, s'est employée avec diligence à trouver sa propre voie pour rehausser les dons de charité destinés à la mission de l'ACP. Tout particulièrement, avant le congrès de 2016 à l'Université d'Ottawa, elle a obtenu un don jumélé de la Carswell Family Foundation (fondée par l'ancien président de l'ACP, Allan Carswell) et lancé la campagne ***Allumer la flamme***, recueillant des fonds avant le congrès et aboutissant à une réception spéciale en l'honneur

BUREAU DE L'ACP

Congress-closing Special Recognition Gala held at Ottawa's Shaw Centre (with a special appearance, and words of praise for Canadian physics, from His Excellency The Right Honorable David Johnston, Governor General of Canada). We can expect to hear more from the CAPF in the coming year, and I encourage everyone to participate in their initiatives. I also encourage everyone to consider making a donation to this charitable foundation before the end of March 2017 as donations received above those made in the previous year are eligible for a matching donation.

I will conclude by saying Thank You to all CAP members. The CAP functions with a small and dedicated professional staff, and an army of volunteer[1] physicists from around the country, to continue a long list of activities designed to promote, advocate and recognize Canadian physics and physicists. As we choose to invest a little more to reach our true vision of what the CAP can – and should - be, and to reach out to more of the Canadian physics community to join with us on that vision, I am confident that the CAP will remain a successful and relevant professional association for all of Canadian physics.

des donateurs avec Art MacDonald dans le cadre de notre Gala spécial de reconnaissance clôturant le congrès, tenu au Centre Shaw d'Ottawa (avec la présence spéciale de Son Excellence le Très Honorable David Johnston, Gouverneur général du Canada, qui y a louangé la physique au Canada). Nous pouvons compter entendre parler de la FACP à nouveau au fil de la prochaine année, et je vous encourage tous à prendre part à ses initiatives. Je vous encourage aussi à songer à faire un don à cet organisme caritatif avant à la fin de mars 2017, car les dons ajoutés à ceux de l'année précédente peuvent donner lieu à des dons équivalents.

En conclusion, L'ACP poursuit une longue liste d'activités visant à promouvoir, défendre et reconnaître la physique et les physiciens au Canada. Je tiens à remercier tous les membres de l'ACP, dont la marche est assurée par un personnel professionnel et dévoué peu nombreux et par une armée de physiciens bénévoles[1] de partout au pays. En choisissant d'investir un peu plus afin de réaliser notre véritable vision de ce que l'ACP peut – et devrait - être, et de convaincre une plus grande partie de la collectivité canadienne de la physique de se consacrer à cette vision, je suis confiant que l'ACP demeurera une association professionnelle fructueuse et pertinente pour l'ensemble de la physique au Canada.

1. If you are interested in helping the CAP with any of its programs or activities, please contact the CAP Executive Director, Francine Ford, at cap@uottawa.ca or any member of the CAP Board of Directors or Advisory Council (full list is available under About Us on the CAP website, www.cap.ca).

1. Si vous être intéressé à aider l'ACP dans un de ses programmes ou activités, veuillez communiquer avec la directrice exécutive de l'ACP, Francine Ford, à cap@uottawa.ca, ou avec tout membre du conseil d'administration ou du conseil consultatif de l'ACP (voir la liste complète sous l'onglet « À propos de l'ACP », du site Web de l'ACP: www.cap.ca).

PhD Physics Degrees Awarded in Canadian Universities*
Doctorats en physique décernés par les universités canadiennes*

December 2015 to december 2016 / Décembre 2015 à décembre 2016

Brock University

KOROBANIK, J., "The Effects of Magnetic Dilution and Applied Pressure on Several Frustrated Spinels", (F. Razavi), June 2016, now searching for employment in Ottawa, ON, Canada.

OSPADOV, E., "Theory and Application of a Pure-sampling Quantum Monte Carlo Algorithm", (S. Rothstein), June 2016, now a Postdoctoral Fellow at the University of Western Ontario, London, ON, Canada.

TAHERI, M., "The Structural, Magnetic an Thermal Studies of $Ce_{1-x}Eu_xCrO_3$ Nano-Powders", (F. Razavi), June 2016, now searching for employment in Calgary, AB, Canada.

PSHENITSIN, D., "Conservation laws of magneto-hydrodynamics and their symmetry transformation properties", (S. Anco, T. Wolf and A. Odesski), October 2016.

VAN OOSTEN, B., "A Multi-Scale Molecular Dynamic Approach to the Study of the Outer Membrane of the Bacteria Psudomonas Aeruginosa PA^{01} and the Biocide Chlorhexidine", (T. Harroun), October 2016, now a Postdoctoral Fellow at Brock University, St. Catharines, ON, Canada.

Carleton University

BEAUCHESNE, H., "Possible Avenues in Supersymmetry and Naturalness", (T. Gregoire), October 2016.

LACEY, J., "Cross Section Measurements of the Higgs Boson in the Diphoton Decay Channel Using Proton-Proton Collision Data Recorded by the ATLAS Detector at Centre-of-Mass Energies of 7 TeV and 8 TeV", (A. Bellerive), February 2016.

MIKSYS, N., "Advancements in Monte Carlo Dose Calculations for Prostate and Breast Permanent Implant Brachytherapy", (R. Thomson), October 2016.

PILKINGTON, T., "Dark Matter and Collider Phenomenology of Large Electroweak Scalar Multiplets", (H. Logan), October 2016.

POURMOGHADDAS, A., "Quantitative Imaging With a Pinhole Cardiac SPECT CZT Camera", (G. Wells), May 2016.

*This list includes all information submitted to the CAP office by 2017 January 21.

**La liste comprend l'information reçue au bureau de l'ACP jusqu'au 21 janvier 2017.*

Concordia University

BAHRAMI, S., "The Higgs triplet model: mixing in the neutral sector, vector-like fermions, and dark matter", (M. Frank), October 2016, now a Postdoctoral Fellow at McGill University, Montreal, QC, Canada.

SHARMA, B., "Development of semiempirical models for metalloproteins", (G. Lamoureaux), October 2016, now a Postdoctoral Fellow at Concordia University, Montreal, QC, Canada.

Dalhousie University

COOPER, M., "Interpreting satellite remote sensing observations using a chemical transport model: implications for processes affecting tropospheric nox and ozone", (R. Martin), May 2017, now pursuing a Postdoctoral Fellowship at Dalhousie University, Halifax, NS, Canada.

KARAHKA, M., "Physics in high electric fields", (J. Kreuzer), May 2017, now a Teaching Assistant at Dalhousie University, Halifax, NS, Canada.

McGill University

ARCHAMBAULT, S., "Search for very-high-energy gamma-ray emission from primordial black holes with veritas", (D. Hanna), October 2016, now pursuing a Postdoctoral Fellowship at Chiba University, Chiba, Japan.

BEAUDOIN, F., "Understanding and suppressing dephasing noise in semiconductor qubits", (W. Coish), October 2016, now pursuing a Postdoctoral Fellowship at Dartmouth College, Hanover, NH, USA.

BEAUPEUX, M., "Physical aspects of morphogenesis: coupled oscillators and tissue kinematics in vertebrate embryos", (P. Francois), October 2016, now an associate at Morgan Stanley, Montreal, QC, Canada.

CHEAIB, R., "A search for the decay of a B meson into a kaon and a tau lepton pair at the BaBar experiment", (S. Robertson), May 2016, now pursuing a Post Doctoral Fellowship at the University of Mississippi, Oxford, MS, USA.

FARRELL, A., "Using external fields to control topological insulators and topological superconductors", (T. Pereg-Barnea), October 2016, now a data scientist at Capital One, Richmond, Virginia, USA.

GRIFFIN, S., "VERy TRenDy: the VERITAS transient detector", (M. Dobbs), February 2016, now pursuing a Postdoctoral Fellowship at McGill University, Montreal, QC, Canada.

HAAG, A., "Potential-driven surface stress of a cantilever-based sensor", (P. Grutter), October 2016, now travelling around the world.

KLOTZ, A., "DNA polymer physics in complex nanofluidic environments", (W. Reisner), February 2016, now a Postdoctoral Research Associate at the Massachusetts Institute of Technology (MIT), Cambridge, MA, USA.

LEE, S., "System radiobiology modelling of radiation induced lung disease", (I. El Naqa and J. Seuntjens), October 2016, now pursuing a Post Doctoral Fellowship at the Memorial Sloan Kettering Cancer Center, New York, New York, USA.

LEMONDE, M., "Reaching the single-photon strong coupling regime in optomechanical cavities", (A. Clerk), May 2016, now pursuing a Postdoctoral Fellowship at TU Wien, Vienna, Austria.

PAPACONSTADOPOULOS, P., "On the detector response and the reconstruction of the source intensity distribution in small photon fields", (J. Seuntjens), May 2016, now a Medical Physics Resident at the Jewish General Hospital, Montreal, QC, Canada.

PAQUET, J., "Characterizing the non-equilibrium quark-gluon plasma with photons and hadrons", (C. Gale), February 2016, now pursuing a Post Doctoral Fellowship at Stony Brook University, Stony Brook, New York, USA.

RYU, S., "Integrated description of heavy ion collisions at RHIC and the LHC", (S. Jeon), October 2016, now pursuing a Postdoctoral Fellowship at the Frankfurt Institute for Advanced Studies (FIAS), Frankfurt, Germany.

SCHNEIDER, A., "Nonlinear information processing in early vestibular pathways", October 2016, now searching for employment.

SCHUMACHER, Z., "Time-domain Kelvin probe force microscopy for local ultra-fast decay time measurements", (P. Grutter), October 2016, now travelling around the world.

STOEBE, M., "Measurement of the inclusive isolated prompt photon cross-section in proton-proton collisions at vs = 8 TeV with the ATLAS detector", (B. Vachon), May 2016, now an R&D Manager and Executive Assistant at Pyramid Computer GmbH, Freiburg, Germany.

VUJANOVIC, G., "Exploring the dynamics of strongly interacting media with dilepton tomography", (C. Gale), February 2016, now pursuing a Postdoctoral Fellowship at the Ohio State University, Columbus, Ohio, USA.

McMaster University

DEHGHAN-KOOSHKGHAZI, A., "Theoretical Study of Inhomogeneous Polymeric Systems", (A. Shi), September 2016, now a Data Scientist at Indellient Inc., Oakville, ON, Canada.

DIENER, R., "Standard Model Naturalness from Dark Vortices & Codimension-2 Braneworlds", (C. Burgess), March 2016, now a Defence Scientist at Defence Research and Development Canada, Ottawa, ON, Canada.

HASAN, F., "Numerical Study of the Dynamical Casimir Effect & its Classical Analogue in a Double Cavity", (D. O'Dell), April 2016, now a Machine Learning Engineer at GradeSlam, Montreal, QC, Canada.

HUANG, W., "Theoretical Studies of Unconventional Superconductivity in SR2RuO4", (C. Kallin), August 2016, now a Post Doc at the Institute of Advanced Studies at Tsinghua University, Beijing, China.

KLASSEN, M., "Simulating Radiative Feedback and the Formation of Massive Stars", (R. Pudritz), January 2016, now a Chief Data Scientist & Co-Founder at Paladin:Paradigm Knowledge Solutions, Calgary, AB, Canada.

MILADINOVIC, N., "The Abraham-Minkowski Controversy & the He-McKellar-Wilkens Phase", (D. O'Dell), December 2016, now a Sessional Lecturer at McMaster University, Hamilton, ON, Canada.

MEMORIAL UNIVERSITY

ALODHAYB, A.N., "Development of Calix[4]arene-Functionalized Microcantilever Array Sensing System for the Rapid, Sensitive and Simultaneous Detection of Metal Ions in Fresh Water", (L. Beaulieu), June 2016, now a Per-Course Instructor at AlJouf University, Saudi Arabia.

KHATAMI, M.H., "Membrane-Active Protein Interactions with Phospholipid Bilayers", (V. Booth and I. Saika-Voivod), October 2016, now searching for employment.

ZHANG, D., "Opto-Microfluidic Devices with Femtosecond Laser Microfabrication", (Q. Chen), October 2016, now an Application Scientist with Sciencetech Inc., London, ON, Canada.

POLYTECHNIQUE MONTRÉAL

BAVANDSAVADKOUHI, R., "Synthesis and Chemical and Morphological Characterization of Ruthenium-Based Nanoparticles", (E. Sacher/A. Yelon), December 2016, now searching for employment in Canada.

BOSTANI, A., "Design and Implementation of Apodized and Unapodized Frequency Converters in Bulk Aperiodically Poled Nonlinear Material", (R. Kashyap), June 2016, now a Reliability Engineer at Ciera Compagny, Québec, QC, Canada.

DE MONTIGNY, E., "Instrumentation optique pour l'identification per- opératoire des tissus durant les chirurgies de la thyroïde", (C. Boudoux), August 2016, now an Software Engineer at Alazar Technologies, Pointe-Claire, QC, Canada.

ÉTHIER-MAJCHER, G., "Contrôle optique de qubits liés à des centres isoélectroniques d'azote dans le GaAs", (S. Francoeur), August 2016, now a Postdoctoral Fellow at the Cambridge University, Cambridge, UK.

GHALI, H., "Optical Microcavities for Real-Time Detection of Bacteria", (Y.-A. Peter/P. Bianucci), June 2016, now a Postdoctoral Fellow at the Concordia University, Montreal, QC, Canada.

LACHAÎNE, R., "Ingénierie de nanoparticules plasmoniques robustes pour la génération de bulles par laser en vue d'applications biomédicales", (M. Meunier), Novembre 2016, now an Optical system designer and laser processing at Dental Wings, Montréal, QC, Canada.

MADORE, W.-J., "Imagerie optique pour le diagnostic du cancer de l'ovaire", (C. Boudoux/N. Godbout), December 2016, now a Postdoctoral Fellow at the CHUM Centre for Research, Montreal, QC, Canada.

MAHJOUB, M., "Développement d'une méthode de Monte Carlo dépendante du temps et application au réacteur de type CANDU-6", (J. Koclas), Décembre 2016, now a Lecturer at the Polytechnique Montréal, Montreal, QC, Canada.

MEHDI ZADEH, F., "Étude thermo-hydraulique de l'écoulement du modérateur dans le réacteur CANDU-6", (A. Teyssedou and S. Étienne), June 2016, now a Postdoctoral Fellow at the Institut supérieure de l'Aéronautique et de l'espace, Toulouse, France.

POIRIÉ, T., "Caractérisations tribomécaniques in situ de couches minces hybrides pour l'optique ophtalmique', (J.-E. Klemberg-Sapieha and L. Martinu), Décember 2016, now searching for employement in Canada.

ST-JEAN, P., "Dynamics of Exicitonic Complexes Bound to Isoelectronic Centers: Toward the Realization of Optically Adressable Qubits", (S. Francoeur), September 2016, now a Postdoctoral Fellow at the Centre National de la Recherche Scientifique, CNRS, Paris, France.

VANIER, F., "Nonlinear Optics in Chalcogenide and Tellurite Microspheres for the Generation of Mid-Infrared Frequencies", (Y.-A. Peter), December 2015, Now a Research Officer at the National Research Council Canada, Boucherville QC, Canada.

QUEEN'S UNIVERSITY

BECERRA, R., "Optical properties of chiral thin films and microparticles", (K. Robbie), November 2016, now an Optical Coating Specialist at L-3 WESCAM, Don Mills, ON, Canada.

BROWN, J., "Using phase-space localized basis functions to obtain vibrational energies of molecules", (T. Carrington), November 2016, now a Postdoctoral Fellow at Temple University in Philadelphia, USA.

DAVID-URAZ, A., "Investigating the potential magnetic origin of wind variability in OB stars", (G. Wade/D. Hanes), November 2016, now a Postdoctoral Fellow at Florida Institute of Technology, Melbourne, Florida, USA.

SHOKRALLA, S., "Comprehensive characterization of measurement data gathered by the pressure tube to calandria tube gap probe", (T. Krause/J. Morelli), November 2016, now Sr. Advisor - Model Development at Ontario Power Generation, ON, Canada.

SHULTZ, M., "Rotational evolution and magnetospheric emission of the magnetic early B-type stars", (G. Wade/D. Hanes), November 2016, now a Postdoctoral Fellow at Uppsala University, Uppsala, Sweden.

RYERSON UNIVERSITY

GONG, P., "Novel ultrasound transmission and reconstruction techniques for synthetic transmit aperture imaging", (Y. Xu and M. Kolios), June 2016, now pursuing a Postdoctoral Fellowship at the Mayo Clinic, Rochester, MN, USA.

MARAGHECHI, B., "Feasibility of non-invasive thermometry in hyperthermia regime using harmonics generated by nonlinear ultrasound wave propagation", (J. Tavakkoli, M. Kolios), October 2016, now pursuing a Postdoctoral Fellowship at the Grand River Hospital, Kitchener, ON, Canada.

RAZANI, M., "Development of optical coherence tomography technique for clinical diagnostics and monitoring", (M. Kolios), October 2016, now pursuing a Postdoctoral Fellowship at the Ryerson University, Toronto, ON, Canada.

SCHELKANOVA, I., "Development of the numerical aperture gated, spatially resolved, diffuse reflectance imaging architecture for subsurface imaging of microvasculature", (A. Douplik), June 2016, now currently unemployed.

SIMON FRASER UNIVERSITY

EJTEMAEE, S., "Dynamics of trapped Ions near the linear-zigzag sctructural phase transition", (P. Haljan), January 2016, now pursuing an industrial Postdoctoral Fellowship at Dwave systems, Burnaby, BC, Canada.

EMADI, M., "Radiative and pionic decays of heavy-light Mesons using HISQ quarks", (H. Trottier), January 2016, now currently employed at Semios Bio Technologies, Vancouver, BC, Canada.

MONTOYA, E., "Spin pumping and spin transport in magnetic heterostructures", (B. Heinrich), May 2016, now a Postdoctoral Fellow at the University of California - Irvine, Irvine, CA, USA.

TRENT UNIVERSITY

MOHANAN, A, "Mitigating Cold Flow Problems of Biodesel: Strategies with Additives", S. Narine, January 2016.

UNIVERSITÉ DE SHERBROOKE

FORGUES, J.-C., « Étude du bruit de grenaille dans un conducteur simple: observation d'enchevêtrement, de compression d'états à deux modes et du quatrième cumulant des fluctuations statistiques dans le courant émis par une jonction tunnel », (B. Reulet), Janvier 2016, maintenant chargé de cours à l'Université de Sherbrooke, Sherbrooke, QC, Canada.

GRISSONNANCHE, G., « Une fable de phases en interaction dans les cuprates supraconducteurs contée par le transport thermique », (L. Taillefer), Mars 2016, maintenant chargé de cours et travailleur autonome à Clermont-Ferrand, France.

REYMBAUT, A., « Universalité du crossover de Mott à demi-remplissage et effets de la répulsion coulombienne aux premiers voisins sur la dynamique supraconductrice des isolants de Mott dopés aux trous », (A.-M. Tremblay), Janvier 2016, maintenant un Professionnel de recherche à l'Université de Sherbrooke, Sherbrooke, QC, Canada.

ROBERGE, B., Étude optique et magnétique des composés RVO3", (S. Jandl), Janvier 2016, maintenant un Stagiaire postdoctoral à l'Université de Sherbrooke, Sherbrooke, QC, Canada.

ROY-GUAY, D., Magnétométrie vectorielle à base de centre colorés dans le diamant, M. Pioro-Ladrière (D. Morris), Octobre 2016, maintenant un Stagiaire postdoctoral à l'Université de Sherbrooke, Sherbrooke, QC, Canada.

UNIVERSITY OF ALBERTA

BAHRAMIAN, A., "Behavior of Low-Mass X-Ray Binaries and their Formation in Globular Clusters", (C. Heinke), November 2016.

BAKER, M., "Hyperfine Splitting in Non-Relativistic Bound States", (A. Penin), November 2016.

BUTT, A., "Search for Microscopic Black Holes in Multi-Jet Final-States Using Multiple Single-Jet Triggers with ATLAS Detector with 8 TeV Proton-Proton Collisions at the Large Hadron Collider", (D. Gingrich), November 2016.

CHANDLER, C., "Realistic Models for Polarons", (F. Marsiglio), November 2016.

ELSHAMOUTY, K., "Characteristics of Neutron Stars from X-Rays Observations", (C. Heinke), November 2016.

HEALEY, M., "Computational Study of a-Synuclein Structure and Druggability", (J. Tuszynski), November 2016.

IBRAHIM, A., "Separating Simultaneous Seismic Sources using Robust Inversion of Radon and Migration Operators", (M. Sacchi), June 2016.

JEON, J., "Novel Transport Properties in Spatially Confined La0.3Pr0.4Ca0.3MnO3 Thin Films", (K. Chow, R. Marchand), November 2016.

OMIYINKA, T., "Search for a Superfluid Phase of Parahydrogen: Exploring the Effect of Confinement", (M. Boninsegni), November 2016.

PAVLOVSKII, K., "Mass Transfer from Giant Donors", (N. Ivanova), June 2016.

POURESLAMI ARDAKANI, E., "Regional Geophysical Study of the Athabasca Region, Northeastern Alberta: Implications for Geothermal Development", (D. Schmitt), November 2016.

ROSAS BONILLA, J., "Three-Dimensional Thermal Structure of Subduction Zones", (C. Currie), November 2016.

SIBLEY, L., "The SNO+ Liquid Scintillator Response to Low-Energy Electrons and its Effect on the Experiment's Sensitivity to a Future Neutrinoless Double Beta Decay Signal", (A. Hallin), November 2016.

VAEZI, Y., "Applications of Seismic Interferometry in Microseismic Monitoring", (M. van der Baan), November 2016.

UNIVERSITY OF BRITISH COLUMBIA

ADOLPHS, C., "Extensions beyond standard models", (M. Berciu), September 2016.

BITTER, M., "Quantum coherent control of laser-kicked molecular rotors", (V. Milner), November 2016.

CAPSONI, M., "On-surface self-assembly and characterization of a macromolecular charge transfer complex by scanning tunneling microscopy and spectroscopy", (S. Burke), September 2016.

CHEN, H., "Validation and optimization of myelin water imaging in a preclinical model of spinal cord injury", (Kozlowski, Piotr), May 2016.

FOELL, C., "Luminescent properties of Pb-based (PbX) colloidal quantum dots (CQDs) in vacuum, on silicon and integrated with a silicon-on-insulator (SOI) photonic integrated circuit (PIC)", (J. Young), November 2016.

FONSECA, E., "Mass and Geometric Measurements of Binary Radio Pulsars", (I. Stairs), November 2016.

GOLDSBURY, R., "White dwarf populations in globular clusters", (H. Richer), May 2016.

GUNTON, W., "Photoassociation and Feshbach resonance studies in ultra-cold Gases of ^{6}Li and Rb atoms", (K. Madison), May 2016.

GUTIERREZ, A., "Cold antihydrogen experiments and radial compression of antiproton clouds in the ALPHA apparatus at CERN", (W. Hardy), February 2016.

KOLB, P., "The TRIUMF nine-cell SRF cavity for ARIEL", (R. Kiefl and N. Merminga), May 2016.

KOROBENKO, A., "Control of molecular rotation with an optical centrifuge", (V. Milner), September 2016.

MCKENZIE, R., "Fluctuations and phase transitions in quantum Ising systems", (P. Stamp), September 2016.

NARIMANI, A., "Cosmological tests of gravity", (D. Scott), September 2016.

RABIDEAU, C., "Holographic entanglement entropy: structure and applications from noncommutative field theories to energy conditions", (J. Karczmarek), September 2016.

SABELLA Garnier, P., "Geometry from quantum mechanics: entanglement, energy conditions and the emergence of space", (J. Karczmarek), September 2016.

SMYTH, D., "Numerical Holographic Condensed Matter", (M. Rozali), May 2016.

STORTZ, G., "Development of a Small Animal MR Compatible PET Insert", (V. Sossi), May 2016.

URIBE, C., "SPECT/CT quantification of Lu-177 for dosimetry in radionuclide therapy treatments of neuroendocrine tumors", (A. Celler), May 2016.

UNIVERSITY OF CALGARY

ABDALLAH, M.H., "Time Dependence of the RXTE X-ray Spectrumof Hercules X-1", (D. Leahy), November 2016.

DHAND, I., "Multi-Photon Multi-Channel Interferometry for Quantum Information Processing", (B. Sanders), June 2016.

KHAZALI, M., "Applications of Atomic Ensembles for Quantum Information Processing and Fundamental Tests and Quantum Physics", (C. Simon), November 2016, now a Research Assistant at the, University of Calgary, Calgary, AB, Canada.

MARTIN, E., "Modeling complex systems as dynamical networks", (J. Davidson), June 2016, now a business owner.

McGEACHY, P., "Optimization in Radiation Therapy: Applications to Brachytherapy and Intensity Modulated Radiation Therapy", (R. Khan), June 2016, now following a Medical Residency in Winnipeg.

MIVEHVAR, F., "Cavity-Induced Synthetic Gauge Potentials", (N.M. Ahmadi), June 2016.

NARASIMHACHAR, V., "Quantum Resource Theories for Thermodynamics, Reference Frames, and Uncertainty", (G. Gour), November 2016.

PULWICKI, J., "Dynamics of Plant Growth: A theory based on Riemannian Geometry", (D. Hobill), June 2016, now a Postdoctoral Fellow in France.

RAGHOONUNDUN, A., Exact Solutions for Compact Objects in General Relativity", (D. Hobill), June 2016.

SINCLAIR, N., "Optical quantum memory and signal processing using a rare-earth-ion-doped ", (W. Tittel), June 2016, now a Postdoctoral Fellow at the University of Calgary, Calgary, AB, Canada.

ZAHEDINEJAD, E., "Machine Learning for Designing Fast Quantum Gates", (B. Sanders), June 2016.

UNIVERSITY OF GUELPH

EMAMI, S., "Biophysical Studies of Human Aquaporin 1 Structural Insights by Solid-State NMR and Mechanism of Inhibition by Mercury", (V. Ladizhansky and L. Brown), January 2016, now in search of employment.

GRZETIC, D., "Connecting structure evolution and chain diffusion in dense polymeric systems using dynamical self-consistent field theory", (R. Wickham), June 2016, now a Postdoctoral Fellow at the University of California, Santa Barbara, CA, USA.

SCHMIDT, M., "NMR Studies of Liquid Disordered and Liquid Ordered Phas Coexistence in Model Membranes", (J.H. Davis), June 2016, now a Postdoctoral Fellow at the Simon Fraser University, Burnaby, BC, Canada.

WARD, M., "Solid-state NMR investigations of transmembrane proteins - new approaches for signal enhancement and in situ studies of anabaena sensory rhodopsin", (V. Ladizhansky), June 2016, now a Postdoctoral Fellow at the Utrecht University, Utrecht, Netherlands.

UNIVERSITY OF MANITOBA

CHOWDHURY, U., "A cooler penning trap to cool highly charged radioactive ions and mass measurement of 24Al", (G. Gwinner), October 2016, now pursuing a Postdoctoral Fellowship at SNOLAB in Sudbury, ON, Canada.

COBUS, L., "Anderson localization and anomalous transport of ultrasound n disordered media", (J.H. Page), May 2016, now pursing a Postdoctoral Fellowship at the Institut Langevin, ESPCI ParisTech in Paris, France.

COLLISTER, R., "Towards atomic parity violation at the francium trapping facility", (G. Gwinner), February 2016, now pursuing a Postdoctoral Fellowship at CERN, Geneva, Switzerland.

DESAUTELS, R., "Mediating the exchange coupling and anisotropy in nanoscale magents via interfacial interactions'", (J. van Lierop), February 2016, now pursuing a Postdoctoral Fellowship at Oak Ridge National Laboratory, Oakridge, TN, USA.

FU, L., "Spintronic sensor based microwave imaging", (C-M. Hu), October 2016.

MCCOWAN, P., "In vivo patient dose verification of volumetric modulated arc therapy including stereotactic body radiation treatment applications using portal dose images", (B. McCurdy), May

2016, now a Radiotherapy Physics Resident at CancerCare Manitoba, Winnipeg, MB, Canada.

SUN, H., "An investigation into the use of scattered photons to improve 2D position emission tomography (PET) functional imaging quality", (S. Pistorius), February 2016, now the CEO of Soph Medical Solutions in China.

WEST, J., "The connection between supernova remnants and the galactic magnetic field", (S. Safi-Harb), October 2016, now pursing a Postdoctoral Fellowship at Dunlap Institute for Astronomy & Astrophysics, Toronto, ON, Canada.

University of New Brunswick

WATSON, C., "GPS Ttotal Electron Content Techniques for observing the sturctures and dynamics of the high-latitude Iionosphere", (T. Jayachandran), December 2015, now pursuing a Postdoctoral Fellowship at the National Center for Atmospheric Research (NCAR), Boulder, CO, USA.

University of Ottawa

ALHARBI, A., "High-order Harmonic Spectroscopy of Cyclic Organic Molecules", (R. Bhardwaj-Vedula), October 2016, Faculty member at King Abdulaziz City Abdulaziz City for Science and Technology (KACST), Riyadh, Saudi Arabia.

ALSHEHRI, A., "Micro-and Nanostructuring of Polymers by Femtosecond Laser Pulses", (R. Bhardwaj-Vedula), December 2016, Faculty member at King Khalid University, Abba, Saudi Arabia.

LU, Y., "Study of the Kerr Phase-Interrogator and its Applications", (X. Bao), December 2015, now an Assistant Professor at the National Defense University, China.

NEJADSATTARI, F., "Theoretical & Experimental Studies of Electronic, Magnetic and Hyperfine Interacton Properties of Novel Compounds", (Z. Stadnik), April 2016, now a Research Associate in the Department of Physics, University of Ottawa, Ottawa, ON, Canada.

NKANTA, J.E., "Modelling & Characterization of Laterally-Coupled Distributed Feedback Laser and Semiconductor Optical Amplifier", (T. Hall), June 2016.

PAYEUR, A., "Oscillations and Gain Control in Sensory Systems", (A. Longtin), March 2016, now a Postdoctoral fellow at the University of Ottawa Brain and Mind Research Institute, Ottawa, ON, Canada.

RAJAI, P., "Measurement of Refractive Index & Thickness of Multi layer Systems Using Fourier Domain Optical Coherence Tomography", (R. Munger), October 2016.

VAMPA, G., "Role of Electron-Hole Recollisions in High Harmonic Generation from Bulk Crystals", (P. Corkum), October 2016, now a Postdoctoral fellow at the Stanford University, Stanford, CA, USA.

University of Saskatchewan

ELASH, B., "The Aerosol Limb Imager", (A. Bourassa), October 2016, now an Analyst at MacDonald,Dettwiler and Associates, Richmond, BC, Canada.

FRIAS, W., "Plasma Instabilities in Hall Thrusters", (A. Smolyakov), January 2016.

ISERHIENRHIEN, B., "On the origin of Close-Range E Region Echoses Observed by Super-DARN Hf Radars in the Mid- and High Latitudes", (JP. St-Maurice), April 2016, now Self Employed at BIRO Overseas Study and Support Services Inc. Saskatoon, SK, Canada.

JOHNSON, Neil, "Characterization of Epitaxial Silicene", (A. Moewes), May 2016, now searching for a Postdoctoral fellowship position.

LITT, S., "Ion Thermal and Nonlinear Effects in Hall Plamas", (A. Smolyakov), January 2016, now a Sessional Lecturer at the University of Saskatchewan, Saskatoon, SK, Canada.

WANG, Z., "Hidden World: Higgs, Dark Matter & Conformal Symmetry", (T. Steele), July 2016, now a Postdoctoral fellow at CP3, Perimeter Institute, Waterloo, ON, Canada.

YONG, X., "Theoretical study on the phase transition and chemical reaction of selected materials at high pressure", (J. Tse), December 2016, Research fellow, Institute of high performing computing, Agency for Science techology and research, Singapore.

ZHAO, Jianbao, "Study of Mg2Si-based Thermoelectric Materials, (J. Tse), April 2016, now a Science Associate at Canadian Light Source, Saskatoon, SK, Canada.

University of Toronto

ANDRES, H., "Northern High Latitude Climate Variability of the Last Millenium", (W.R. Peltier), March 2016, now a Postdoctoral fellow at the Memorial University, St. John's, NL, Canada.

COOK, A., "Double Pervoskites with Strong Spin-Orbit Coupling", (A. Paramekanti), November 2016, now a Postdoctoral fellow at the University of Zurich, Zurich, Switzerland.

DMOCHOWSKI, G., "The End of N-Scheme", (A. M. Steinberg), June 2016, now a Postdoctoral fellow at the Princess Margaret Cancer Center, Toronto, ON, Canada.

DYER, E., "Sahel and Congo Basin Precipitation: Variability and Teleconnections", (D.B.A. Jones), November 2016, now a Postdoctoral fellow at the Oxford University, Oxford, UK.

FIELD, R., "Photoinduced Spin Crossover in Single Crystal [FeΠ (BPY)^3](PF6)2", (J.R.D. Miller), November 2016, now a Postdoctoral fellow at the University of Toronto, Toronto, ON, Canada.

HALLAJI, M., "Weak Value Amplification of a Post-Selected Single Photon", (A.M. Steinberg), June 2016, now a Manger in the Market Risk Measurement department of Scotiabank, Toronto, ON, Canada.

HARRIS, E., "Bayesian Inference Framework for the Analysis of Biological Systems Applied to RNA Activation in Human Cells", (D.R. McMillen), November 2016, now the CEO of Yazabi Predictive Inc, Toronto, Ottawa, ON, Canada.

HWANG, K., "Novel Quantum Phases in Correlated Electron Systems", (Y.B. Kim), November 2016, now a Postdoctoral fellow at the Ohio State University, Columbus, OH, USA.

KINGHORN-TAENZER, J., "Study of the Higgs boson produced in association with a weak boson and decaying to WW* with a same sign dilepton and jets final state in $\sqrt{s}=8$TeV pp collisions with ATLAS detector at the LHC", (P.E. Savard), June 2016, now a Postdoctoral fellow at the Tel Aviv University, Israel.

OLSEN, K., "Temperature and Pressure Retrievals and Mitigation of the Impact of Dust for a High-Resolution Fourier Transform Spectrometer Mission to Mars ", (K. Strong), June 2016, now a Researcher at the "Laboratoire de Météorologie Dynamique, Centre national de la recherche scientifique", Paris, France.

POTNIS, S., "Tunneling Dynamics of a Bose-Einstein Condensate", (A.M. Steinberg), June 2016, now a Postdoctoral fellow at the University of Toronto, Toronto, ON, Canada.

RUSSO, M., "Magnetized Astrophysical Flows", (C. Thompson), June 2016, now a Postdoctoral fellow at the University of Toronto, Toronto, ON, Canada.

SCHAFFER, R., "Quantum Spin Liquids in Kitaev and Kagome Systems", (Y.B. Kim), November 2016.

SUTTON, A., "Electronic States of Heavy Fermion Materials", (S.R. Julian), June 2016, now a Cyber Analytics Consultant at Deloitte, Toronto, ON, Canada.

TANG, Z., "Measurement-Device-Independent Quantum Cryptography", (H.K. Lo), November 2016, now a Software engineer in the Private sector, Vancouver, BC, Canada.

TIAN, Y., "Exploring Many Body Interactions with Raman Spectroscopy", (K.S. Burch), June 2016, now a Research Fellow at Nanyang Tech. University, Singapore.

VENKATARAMAN, V., "Perspectives from *ab-initio* and tight-binding: Applications to transition compounds and superlattices", (H.-Y. Kee), June 2016, now a Data Scientist at Capital One, North York, ON, Canada.

WATT-MEYER, O., "The Role of Standing and Travelling Waves in Stratosphere-Troposphere Coupling", (P.J. Kushner), November 2016, now a Postdoctoral fellow at the University of Washington, Seattle, WA, USA.

ZOU, J., "Picosecond Infrared Lasers (PIRL): Applications in Biodiagnostics and Towards Quantitative Mass Spectrometry", (R.J.D. Miller), June 2016, now a Software Verification Specialist, SCIEX, Vaughan, ON, Canada.

University of Waterloo

ARRAZOLA, J., "Practical Quantum Communication", (N. Lutkenhaus), June 2016, now a Postdoctoral Research Fellow at the Centre for Quantum Technologies, Singapore.

BRENNA, W., Thermodynamics and Universality in Anisotropic Higher Curvature Spacetimes", (R. Mann), October 2016, now working at SED Systems, Saskatoon, SK, Canada.

CHAI, Y., "Surface Dynamics, Glass Transition, and Crystallization of Atactic Polystyrene", (J. Forrest), October 2016, now a Postdoctoral Fellow at the University of California, Berkley, CA, USA.

FARNSWORTH, S., "Standard Model Physics and Beyond from Non-Commutative Geometry",

(R. Myers), June 2016, now a Postdoctoral Fellow at the Max Planck Institute for Gravitational Physics, Potsdam, Germany.

FISHER, K., "Photons & Phonons: A room-Temperature diamond quantum memory", (R. Resch), October 2016, now working in the Department of Physics at the University of Toronto, Toronto, ON, Canada.

FOSTER, W., "Motion Management for Lung Cancer Radiotherapy: Employing the Convolution Model for Patient Specific Margin Selection", (R. Barnett and E. Osei), June 2016, now a Product Manager at Acumyn Inc, Kitchener, ON, Canada.

FUREY, N., "RxCxHxO and space-time independent particle physics", (A. Kempf), June 2016.

HENDERSON, R., "Nanoscale Physics of Surfactant Gene Delivery", (Z. Leonenko), June 2016, now a MD/MBA Student at University of Saskatchewan, Saskatoon, SK, Canada.

JOCHYM-O'CONNOR, T., "Novel Methods in Quantum Error Correction", (R. Laflamme), October 2016, now working at the California Institute of Technology, Pasadena, CA, USA.

KAISER, S., "Quantum key distribution devices: How to make them and how to break them", (T. Jennewein), October 2016, now a Postdoctoral Fellow at the Macquarie University, Sydney, Australia.

KAMIAB, F., "Neutron Stars, the Exotica from Modifying General Relativity to Strong Magnetic Fields", (N. Afshordi), June 2016, now a Quantitative Developer at AssetMetrix GmbH, Munich, Germany.

KHOUQEER, G., "In Vitro NMR Study of Magnetization Exchange at Low Field and Proteoglycan-Depletion at High Field in Articular Cartilage", (H. Peemoeller), October 2016, now an Assistant Professor at Al-imam Mohammad Ibn Saud University, Riyadh, Saudi Arabia.

LAMY-POIRER, J., Exact Results in Supersymmetric Gauge Theory', (J. Gomis /D. Gaiotto), October 2016.

MEYER-SCOTT, E., "Heralding Photonic Qubits for Quantum Comunication", (T. Jennewein), June 2016, now a Postdoctoral Fellow at the University of Paderborn, Paderborn, Germany.

RIED, K., "Causal Models for a Quantum World", (R. Spekkens and K. Resch), October 2016, now a Postdoctoral Fellow at the University of Innsbruck, Innsbruck, Austria.

SANDERS, Y., "Characterizing Errors in Quantum Information Processors", (R. Laflamme and F. Wilhelm-Mauch), October 2016, now a Postdoctoral Fellow at the Macquarie University, Sydney, Australia.

SARAVANI, M., "Aspects of Nonlocality: from Particles to Black Holes", (N. Afshordi and R. Sorkin), October 2016, now a Research Associate at the University of Nottingham, School of Mathematical Sciences, Nottingham, UK.

SILVA, J., "Exact Results in Gauge Theories", (R. Myers and P. Vieira), June 2016.

University of Western Ontario

ABEDIN, A., "Formation and past evolution of the meteoroid complex of Comet 96P/Machholz", (P.G. Brown and P. Wiegert), December 2016, now a Demonstrations Coordinator at University of Western Ontario, Ontario, London, ON, Canada.

CYR, I., "The geometry and density of B-emission star disks from statistical analysis and numerical simulations", (C.E. Jones), December 2016.

EZUGWU, S., "Nanoscale thermal and electronic properties of thin films of graphene and organic polyradicals", (G. Fanchini), December 2016.

GRZENIA, B., "The circumstellar environments of B-emission stars constrained by optical interferometry", (C.E. Jones), December 2016.

HOU, R., "Optical characterization of anisotropic interfaces", (F. Lagugne-Labarthet), June 2016.

MARTINEZ, T., "High Resolution Spectroscopy of the Hyades Giants", (D.F. Gray), December 2016.

MCCULLOUGH, E., "A new technique for interpreting depolarization measurements using the CRL atmospheric lidar in the Canadian High Arctic", (R.J. Sica), June 2016, now a researcher at Dalhousie University, Halifax, NS, Canada.

PATEL, P., "The Inner, Gaseous Disks of Herbig Be Stars", (A. Sigut and J. Landstreet), June 2016, now an Outreach Coordinator CPSX at the Western University, London, ON, Canada.

RAHMANI, S., "What governs star formation in galaxies? A modern statistical approach", (P. Barmby), October 2016.

RAJABI, F., "Dicke's Superradiance in Astrophysics", (M. Houde), February 2017, now a Research Assistant at the University of Western Ontario, London, ON, Canada.

SHANNON, M., "The spectral variability of astronomical PAHs", (E. Peeters), October 2016.

TAMMOUR, A., "Insights from Unsupervised Clustering and Composite Spectral Analysis Into the Physical Properties Driving Emission and Absorption in Quasar UV/Optical Spectra", (S. Gallagher), June 2016.

VULIC, N., "X-ray Populations in the Local Group: Insights with Hubble & Chandra", (P. Barmby and S. Gallagher), October 2016, now a Postdoctoral Fellow at at the NASA Goddard Space Flight Centre, Geenbelt, MD, USA.

YE, Q., "Aging comets and their meteor showers", (P.G. Brown), October 2016, now a Postdoctoral Astronomer at the California Institute of Technology, Pasadena, CA, USA.

York University

CAPRA, A., "Testing CPT and Antigravity With Trapped Antihydrogen at LPHA", (S. Menary), February 2016, now a Research Associate at TRIUMF, Vancouver, BC, Canada.

CHAJET, L., "Disc Winds and Line-Width Distributions in Active Galactic Nuclei", (P. Hall), February 2016, now searching for employment.

ESHELMAN, E., "Stand-Off Detection of Organic Compounds On Mars Using Ultraviolet Raman-Spectroscopy and Time-Resolved Laser Inducted Fluorescence", (M. Daly), June 2016, now a Postdoctoral Fellow at the Jet Propulsion Laboratory, Pasadena, CA, USA.

FITZAKERLEY, D., "Antihydrogen Via Two-Stage Charge Exchange", (E. Hessels), February 2016, now a Laboratory Technician at the McMaster University, Hamilton, ON, Canada.

HASHEMI POUR, B., "Multiscale Modelling of Molecules and Continuum Mechanics Using Bridging Scale Method", (G. Zhu), October 2016, now a Sessional Lecturer at York University, Toronto, ON, Canada.

PALACINO CAVIEDES, G., "Search for Magnetic Monopoles in 8 TEV Centre-of-Mass Energy Proton-Proton Collisions with the Atlas Detector at the LHC", (W. Taylor), February 2016, now a Postdoctoral Fellow at the University of Indiana, Bloomington, Indiana, USA, but based at CERN, Geneva, Switzerland.

ROGERSON, J., "The Variability of Outflows in Active Galactic Nuclei", (P. Hall), October 2016, Educator, Telus Spark, Calgary, AB, Canada.

SCHENK, G., "On The Role of Projectile Electrons in an Independent Electron Model Description of Dressed-Ion Impact on Atoms", (T. Kirchner), October 2016, now Searching for employment in Germany.

WURTZ, M., "Higgs and Heavy Meson Lattice Spectroscopy", (R. Lewis), February 2016, now a Financial Risk Manager, Prism Valuation, Toronto, ON, Canada.

The list of PhD Degrees awarded in the following universities will be included in the next issue (No. 2) :

La liste des doctorats décernés par les universités suivantes sera incluse dans le prochain numéro (no. 2) :

Brock University, Carleton University, McGill University, Queen's University, Simon Fraser University, University of Alberta, and/et University of Victoria

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L'Association Canadienne des physiciens et physiciennes invite cordialement à devenir membre toute corporation et institution intéressée. Renseignements disponibles auprès de la directrice exécutive au cap@uottawa.ca.

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Books may be requested from the Book Review Editor, Richard Marchand, by using the online book request form at http://www.cap.ca. You must be a residing in Canada to request a book.

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.

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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.

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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

Conformal Methods in General Relativity, Juan A. Valiente Kroon, Cambridge University Press, 2016; pp. 622; ISBN: 978-1107033894; Price: 143.95.

Hadrons at Finite Temperature, Samirnath Mallik & Sourav Sarkar, Cambridge University Press, 2016; pp. 262; ISBN: 978-1107145313; Price: 119.55.

The Invention of Time and Space: Origins, Definitions, Nature, Properties, Patrice F. Dassonville, Springer, 2016; pp. 176; ISBN: 978-3319460390; Price: 121.02.

The New Ecology: Rethinking a Science for the Anthropocene, Oswald J. Schmitz, Princeton University Press, 2016; pp. 256; ISBN: 9780691160566; Price: 43.95.

SENIOR LEVEL

Combustion Waves and Fronts in Flows: Flames, Shocks, Detonations, Ablation Fronts and Explosion of Stars, Paul Clavin and Geoff Searby, Cambridge University Press, 2016; pp. 720; ISBN: 978-1107098688; Price: 218.95.

Cosmic Magnetic Fields, Philipp P. Kronberg, Cambridge University Press, 2016; pp. 294; ISBN: 978-0521631631; Price: 160.95.

Hadrons at Finite Temperature (2nd copy), Samirnath Mallik & Sourav Sarkar, Cambridge University Press, 2016; pp. 262; ISBN: 978-1107145313; Price: 119.55.

Maxwell's Enduring Legacy: A Scientific History of the Cavendish Laboratory, Malcolm Longair, Cambridge University Press, 2016; pp. 650; ISBN: 978-1107083691; Price: 57.24.

SAMIRNATH MALLIK & SOURAV SARKAR, HADRONS AT FINITE TEMPERATURE (2ND COPY), Cambridge University Press, 2016; pp. 262; ISBN: 978-1107145313; Price: 119.55.

SUPERSYMMETRY, SUPERGRAVITY, AND UNIFICATION (CAMBRIDGE MONOGRAPHS ON MATHEMATICAL PHYSICS), Pran Nath, Cambridge University Press, 2016; pp. 536; ISBN: 978-0521197021; Price: 94.99.

SUPERSYMMETRY, SUPERGRAVITY, AND UNIFICATION (CAMBRIDGE MONOGRAPHS ON MATHEMATICAL PHYSICS) - 2ND COPY, Pran Nath, Cambridge University Press, 2016; pp. 536; ISBN: 978-0521197021; Price: 94.99.

THE STRUCTURE AND DYNAMICS OF CITIES: URBAN DATA ANALYSIS AND THEORETICAL MODELING, Marc Barthelemy, Cambridge University Press, 2017; pp. 278; ISBN: 978-1107109179; Price: 94.99.

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.

ELECTRICITY AND MAGNETISM by Edward Purcell, Cambridge University Press, 2013, pp: 484, ISBN: 978-107-01360-5, price 70.00.

This second edition was first published in 1985, and is based on the first edition first published in 1963. This textbook in its variety of editions is widely used for Electricity and Magnetism courses at the undergraduate level. It was originally written as part of a series of four courses that formed the core of the Berkeley undergraduate physics degree. It should be noted that there is a third edition by Purcell and Morin, that has been updated with additional examples and the use SI units instead of the cgs units of this second edition. The book would be good for a second year undergraduate physics course, where the students are already getting some exposure to vector calculus in concurrent math courses. I would place its level as being slightly simpler than that of Griffiths, "Introduction to Electrodynamics," but above the typical first year textbook treatment.

The first chapter largely covers electric fields from point charges and continuous charge distributions, and introduces Gauss' law. There are sections on electrical energy, force on a layer of charge and energy associated with the electric field that feel a bit out of place, but otherwise the description is excellent. The addition of the examples in the third edition are very welcome.

The second and third chapters present the electric potential, and electric fields around conductors which includes capacitance of different arrangements of conductors. The treatments of both of these is very well done. The fourth chapter on electric currents builds up to DC circuits from a fundamental level.

Chapter five describes the electric field from a moving point charge, in a way I haven't seen in other introductory textbooks. It assumes that students already have some familiarity with special relativity and derives what the electric field from a moving charge looks like. The description is again very well done, and leads to a picture of what the electric field around an accelerating charge looks like.

Chapters six and seven introduce the magnetic field and electromagnetic induction respectively. Inductance and circuits with inductive components are introduced near the end of chapter seven.

The eighth chapter is on alternative current circuits, and is done using complex impedance and admittance as it should be at this level.

Chapter nine introduces the displacement current, and Maxwell's equations in differential form. Electromagnetic waves are then shown to result from these equations. Plane wave propagation and the power density in electromagnetic waves is described.

Chapters ten and eleven describe electric field in matter and magnetic fields in matter respectively. The exposition again proceeds from fundamental physics arguments, starting from the electric dipole for electric fields in matter, leading to a description of dielectrics in capacitors. Magnetization and ferromagnetic materials are also introduced.

In summary this textbook introduces electricity and magnetism in a nice logical order. Electricity and magnetism is of course the favourite first application of the vector calculus methods in a physics course, and the text does a good job of introducing the mathematics as it is being used, rather than in a separate introductory chapter with just the math. The figures are simple grey scale but are well done, and augment the description of the concepts which are presented in a practical and pedagogical way. I would recommend the third edition over this edition, due to the additional examples provided, and the use of SI units.

Blair Jamieson
University of Winnipeg

INCOMING ASTEROID! WHAT COULD WE DO ABOUT IT by Duncan Lunan, Springer, 2013, pp: 390, ISBN 146148748X (ISBN 13: 9781461 487487), price 54.12.

Once in a while, we get smacked on the head by one of the millions of Near Earth Objects (NEOs) that cross our planet's orbital trajectory. One of those bolides created quite a commotion in Russia a few years ago; the Chelyabinsk meteor was an atmospheric phenomenon due to a small asteroid entering the atmosphere at a shallow angle, at speeds of 19-20 km/s over Russia in February 2013. Exploding catastrophically in mid-air, it generated a shower of smaller meteorites and a detonation shock wave, releasing about 2PJ of energy, or 500kT of TNT, nearly 30 times Hiroshima! The small object measured approximately 20 m in diameter and weighted some 12 kT. No fatalities were reported, but one thousand people were injured.

On the other end of the scale, the Chixhulub impact in Yucatan, which coincided with the geological Cretaceous–Paleogene boundary (K–Pg boundary) around 66 million years ago, was 500 times larger and released more than 400 ZJ (Zeta Joules) - or over a billion times the energy of the atomic bombings of Hiroshima and Nagasaki. Leading to one of the six major planetary extinction events in earth's history, accompanied with the passing away of 75% of all planetary biota.

At impact, most of the kinetic energy is transformed into a detonation. The pock marks and craters on the face of the earth and the moon tell us that statistically, a small meteorite under 5 m will reach us every 10 years. A larger one in the 100m range will occur every 11 ky and a 1km diameter impactor will reach us every half million years or so.

We have yet to record a death from a meteorite impact, although statistically there is a probability of one person for every 200,000, being hit in a lifetime! The record of injuries in the 2013 Russian airburst is a potent indicator of meteoritic risk.

As a planetary scientist by trade and passion, and having participated in multiple NASA closed workshops on the subject of deflecting asteroids off earth's trajectory and other associated conferences in the 80s, I was very much interested in reviewing this book. My interest was further stimulated from witnessing a sub-meter airburst last fall, while driving to my cottage in the Laurentians, and from having a friend who co-founded Planetary Resources, a US West coast start-up bent on mining NEO bodies. The first event served as a reminder that the comfort of the recent time spell without incident is not representative of an abatement in overall risk, and while it is true that we have been living through a quiet large meteoritic period, the real probability of an impact has nonetheless not decreased with time. This is the very theme of Incoming Asteroid! What could we do about it? by Duncan Lunan.

The author's interest in the subject stems from a project within ASTRA (the Association in Scotland to Research into Astronautics) the Scottish equivalent of the British Astronautical Society, in the 80s. The intemporally relevant question he asks is 'what would we do if we knew there was going to be an asteroid impact in ten years' time or less?'. The main scenario being considered is an impactor of 1kilometer emanating from the asteroid belt. The key factor in the question is the 10 yr period, thus an impending as opposed to a putative impact. If lower than 10 years, the impact more or less becomes a *fait accompli*, and if much longer (for instance crossing many decades) then the urgency for immediate action would not exist. Lunan tells us first and foremost, that effecting changes in human behaviour necessitates a sense of urgency. As such, a NEO impact has an advantage over climate change, as the potential to instill panic in the population, is present and rapid.

The author proposes 3 *possible courses of action*: 1. We do nothing, 2. we attempt to deflect the incoming boulder using various push-out-of-way techniques, or 3. we try to blow the asteroid to kingdom come. The sci-fi aficionados, within the scientific community, will readily identify the two later options as being Hollywoodian in nature. As a matter of fact, I also saw movies treating of the first option as well. The book then discusses the political will to proceed to an action-oriented scenario.

This is where Lunan discusses the possible reactions of leaders. Would a post-factual president not believe in the impending disaster and decide to revert to option 1., and do nothing? Akin, metaphorically, to the slowly evolving meta climatic problems we are now facing. Possibly not, according to our optimistic writer, because of the economic benefit of spending trillions on removing the threat would enable us to develop more rapidly key value-added technologies and, *de facto*, become a planetary civilisation which could exploit the planetary resources bounty.

Although published by Springer in their mechanical engineering series, Lunan's book is really meant for the larger readership in hope of raising, within the public and policy maker, the spectre of an impactor's menace into actionability band - the media analogy of raising an electron to the valence band. It is, as such, recommendable and largely a good read. The oft flashbacks to the Sci-fi culture are not distractive and are quite enjoyable. The book is filled with historical references, those that one can forget in the fog-of-science, those brought back a lot of found memories to me.

Richard Boudreault, P. Phys.

Experimental Studies of Neutrino Oscillations by Kajita, Takaaki, World Scientific Publishing, 2016, pp: 98, ISBN 978-981-4759-26-7, price 46.80.

In 2015 Takaaki Kajita and Arthur B. McDonald were awarded the Nobel Prize in Physics for the discovery of neutrino oscillations. To celebrate his achievement, World Scientific Publishing released **Experimental Studies of Neutrino Oscillations** which is a collection of papers by Kajita. These papers were previously published in various conference proceedings between 2000 and 2009. Because Kajita heads the Super-Kamiodande (Super-K) collaboration, the book predominantly presents results from the Japanese neutrino observatories.

The book summarizes the current status of the neutrino oscillation measurements and discusses the next-generation experiments. Neutrino oscillations were discovered by the Kamiokande detector (1988) when the measured ratio of muon to electron neutrinos from the atmosphere fell well below predicted values. This deficit could be explained by neutrino flavour oscillations which implies that neutrinos have nonzero mass. Ten years later, the larger Super-K detector measured the zenith angle dependence of the neutrino flux. The deficit of downward-moving muon neutrinos that travel 15 km from the upper atmosphere to reach the detector was minimal, whereas a large deficit was found for upward-moving muon neutrinos that travelled 12800 km through the earth before being detected. The Super-K data showed that muon neutrinos were oscillating to either tau neutrinos or hypothetical sterile neutrinos (neutrinos that interact with matter only via the gravitational force).

The collaboration was able to place experimental bounds on the flavour mixing angle and the mass-squared difference. Kajita also explains how the Sudbury Neutrino Observatory (SNO) and the Japanese experiment kamLAND studied the deficit of solar electron neutrinos. These measurements gave evidence of electron neutrino oscillations and led to experimental bounds on a second mixing angle and mass difference.

In the most recent Super-K measurements, the collaboration has searched for evidence of either solar or atmospheric neutrinos oscillating to sterile neutrinos. So far, there is no experimental evidence in favour of the sterile neutrino. The Tokai to Kamioka (T2K) experiment uses an intense beam of accelerator-produced neutrinos that is directed to Super-K 295 km away. T2K is currently trying to measure the third mixing angle which is thought to be very small. The collaboration will also attempt to find evidence of CP violation by looking for differences between neutrino oscillations and anti-neutrino oscillations. This project may require an even larger detector, called Hyper-Kamiokande. In addition to searching for CP violation, the next generation neutrino experiments will also attempt to determine the ordering of the mass eigenstates.

Experimental Studies of Neutrino Oscillations by Kajita provides a nice summary of the current state of neutrino oscillation physics and the goals of the next generation experiments. The conference papers included in the collection do not provide a lot of experimental details, but rather focus on the results of the measurements and their implications. Because the seven papers occur over a relatively short time, there tends to be substantial repetition. Overall the book is an interesting read, but someone interested in the past, present, and future of experimental neutrino oscillation physics may get more value out of a good review article.

Jake Bobowski
University of British Columbia Okanagan

Join the Fun
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Art of Physics Competition

You are invited to enter the competition (open or high school categories) by capturing in a photograph a beautiful or unusual physics phenomenon and explaining it in less than 200 words in terms that everyone can understand.

The emphasis of this contest is not so much on having a high level of physics comprehension as it is on being able to explain the general principle behind the photograph submitted. Individual (open and high school) and high school class entries are invited up until April 15 each year (see http://www.cap.ca/en/activities/art-physics for entry form and rules). Please note that all entries must be original artwork produced by the participant.

Winning entries will form part of our Art of Physics exhibition which may be on display at the Canada Science and Technology Museum, and may appear as a cover on our publication, *Physics in Canada*. They will also be posted on our Art of Physics website at http://www.cap.ca.

We hope you will take advantage of this opportunity to explore the art of physics by submitting entries for the next competition.

Reflection in Glass

2nd Place (IYL2015 Category) - 2015 competition

by Jonathan Lew,
Burnaby, British Columbia
(see http://www.cap.ca/aop/aop/Reflection2015.html)

Concours l'Art de la physique

Vous êtes invités (es) à participer (aux catégories ouverte ou école secondaire) en photographiant un phénomène physique magnifique, ou particulier, et en rédigeant un court texte explicatif de moins de 200 mots, en termes simples et à la portée de tous.

L'accent de ce concours est de pouvoir expliquer le principe général de la photo soumise plutôt que de démontrer un niveau élevé de compréhension de la physique. L'échéance pour les inscriptions individuelles ouvert et école secondaire) et scolaires (voir formulaire d'inscription/règlements à http://www.cap.ca/fr/activites/lart-de-physique) est fixée au 15 avril chaque année. Notez bien que toutes les inscriptions doivent être des oeuvres originales du participant ou de la participante.

Les soumissions gagnantes feront partie de notre exposition L'Art de la physique au Musée des sciences et de la technologie du Canada et auront une chance de paraître sur la couverture d'un numéro de *La Physique au Canada*. Elles seront également affichées sous la rubrique L'Art de la physique du site web de l'ACP à l'adresse suivante: http://www.cap.ca.

Nous espérons que vous profiterez de cette occasion d'explorer l'art de la physique en soumettant une oeuvre pour la prochaine compétition.

Physics in Canada
La Physique au Canada

To Come *À venir*

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No.3 Physics Outreach / *L'engagement communautaire de la physique*

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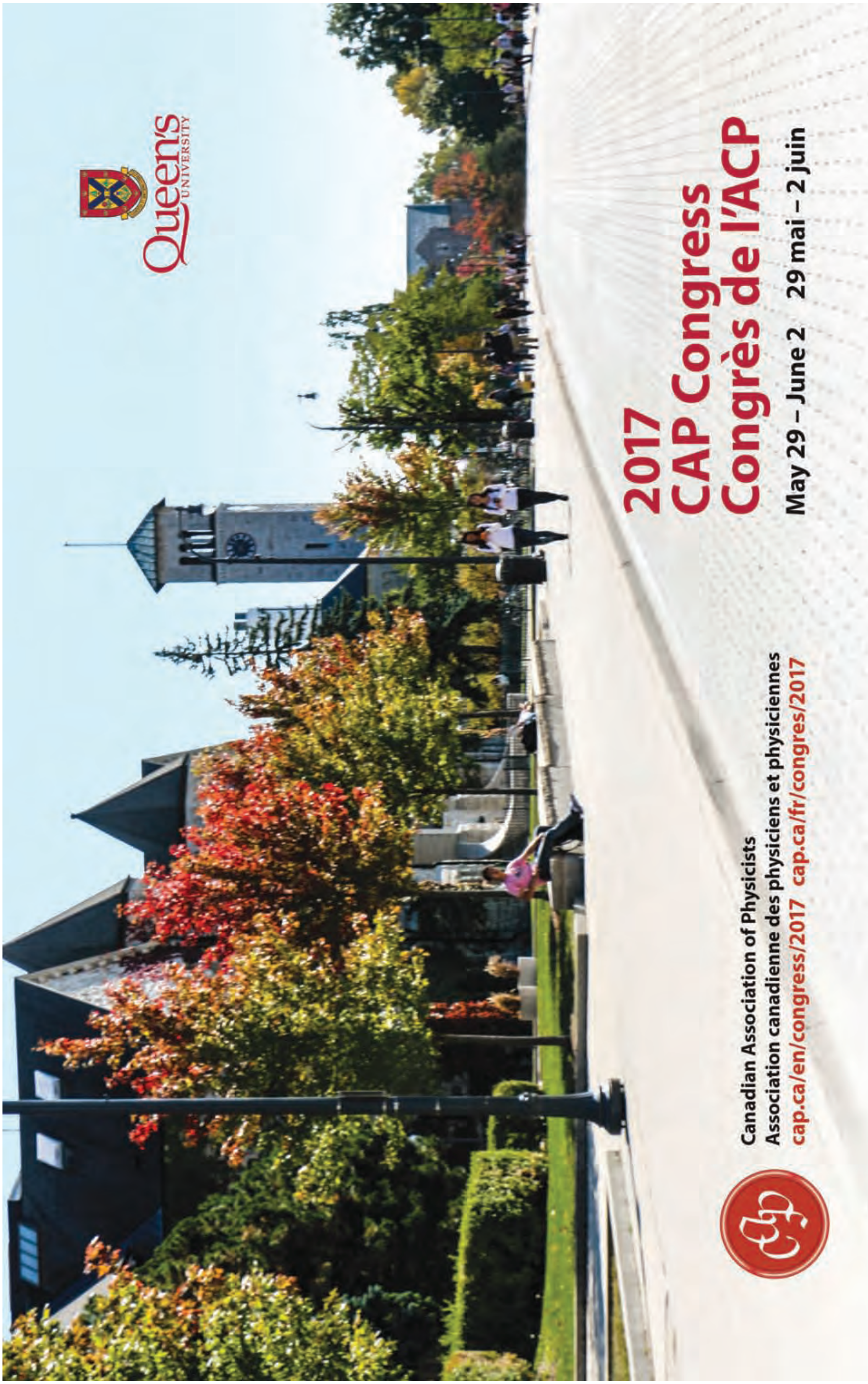

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