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# Physics in Canada
# La Physique au Canada

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Canadian Association of Physicists / Association canadienne des physiciens et physiciennes

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## FEATURING / EN VEDETTE :

ARTICLES RELATED TO THE 2021 CONGRESS, MEDALS AND AWARDS

ARTICLES LIÉS AU CONGRÈS, AUX MÉDAILLES ET AUX PRIX 2021

**Physics in Canada**
*La Physique au Canada*
**Vol. 72, No. 2 (2021)**

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**Front cover**: "Firebending Cool Flames", by Maggie Yang, Victoria Park Collegiate Institute, Toronto ON – Second Place (High School/CEGEP Individual Category), 2019 **Art of Physics competition**. / **Couverture** : « Firebending Cool Flames », par Maggie Yang, Victoria Park Collegiate Institute, Toronto ON - Deuxième place (catégorie individuelle lycée/CEGEP), **concours l'Art de la physique** 2019.

**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 et de physiciennes 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 physicien(ne)s canadien(ne)s auprès du gouvernement, des organismes subventionnaires et auprès de plusieurs sociétés scientifiques internationales. Nous nous faisons le promoteur enthousiaste d'événements et d'activités mettant à l'avant-scène la physique et les physicien(ne)s canadien(ne)s, 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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**The Editorial Board welcomes articles from readers suitable for, and understandable to, any practising or student physicist. Review papers and contributions of general interest of up to four journal pages in length are particularly welcome. Suggestions for theme topics and guest editors are also welcome and should be sent to bjoos@uottawa.ca.**

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

# THE FUTURE OF UNIVERSITY TEACHING

Béla Joós, Editor-in-Chief, *Physics in Canada*

We have lived through some remarkable times since March 2020. They have tested our resilience, and taught us new skills, but they have also reminded us of what we are missing. Many of us are eager to return to less restrictive times. It is also clear that there is no turning back the clock. As restrictions are gradually lifted, a new normal will emerge. The future will not be like pre-pandemic times, and we should actively be involved in shaping it. Each stakeholder should reflect on what would be best for all.

The lockdown has hastened our transition to online work and study mode, that many saw coming but much more gradually. In March 2020, we scrambled as well as we could to salvage the Winter 2020 academic semester, tentatively testing various online teaching and testing tools. By Fall 2020 we were better equipped and hoped that soon we would return to normal. Research laboratories at UOttawa returned with strict safety rules within a few months. Teaching, however, remained online, and still has been for most students entering first year in Fall 2021. It surprised many how long the disruption is lasting. But cool heads knew that there was no easy way out of this, and it is increasingly clear that whether we want it or not the world has profoundly changed.

Fortunately, the transition to a virtual world happened at a time in our civilization when we could function without physically being present at work. Zoom, Teams, Google Meet and other platforms are making it easy to interact, hold meetings and teach. This semester I teach a bimodal class with nearly half the students physically present and the other half following the class online through a zoom link. Asking questions, even for those online, is easy. They either raise their hand (virtually) or put the question in the chat. The loudspeakers in the class project their voice clearly. As to the questions in the chat, either I answer them or, in many cases, they are answered by classmates. That has been a remarkable development arising from the use of the online tool. Online students are more interactive than those in the lecture hall. The lectures are recorded, and my notes, which I produce on my tablet, are posted as pdf files. Students can come or not come to class knowing that they can connect through the zoom link or watch later. I have a trove of recorded demos to use. James Fraser (Queen's U.) argued in a recent seminar titled "Interactive engagement in the remote-teaching era – why we should never go back", that the potentials of online teaching are significant (September 29, 2020, Carleton U.).

Online teaching has many attractions. With increasing financial pressures to deliver undergraduate teaching, universities will be tempted to adopt the format for many classes. There are tremendous cost savings if you do not need to build large lecture halls and equip them with the latest technology. Is an in-person lecture given to hundreds of students, and sometimes up to a thousand, any better than a lecture online? With zoom, students can ask questions anytime using chat, interacting about the questions with fellow students, TAs or the professor. Polls are easy to set up to assess the level of understanding and guide the mastery of the concepts. Managing large undergraduate laboratories is resource intensive. A lot of the introductory training can be done online, and as technology becomes more life-like the experience can only improve.

There will be significant savings, but the loss of a social environment will greatly affect many students. Students need their peers, not only to help them academically, but also to give meaning to their daily challenges, and help them shape the vision of their future. A successful physics program requires in-person hands-on learning, an interactive environment where students motivate each other and gain understanding by talking about concepts and hearing others discuss the concepts in their own words.

The social environment and the personal connections are tremendous motivators. Academics and students will have to ponder carefully how we implement the changes. Arguments will be made to support the transition, in some cases, citing their popularity based on enrolment numbers, which remain strong. However, what many students find convenient, staying within the comfort of their homes to avoid lengthy commutes, may not necessarily be the best for them intellectually. Home comfort and the easy access to information on the web can negatively affect malleable minds and even lead them astray. It is also much harder to get out of a rut when your only comforts are online entertainment. Most of us have really fond memories of campus life. Life-long connections are made in university.

Will we return to a time like the early 20th century when quality in-person education in small groups was the privilege of the wealthy? Is this the end of affordable mass education in person? Will a vibrant campus life become a memory of the past? We will really have to fight back so that we balance the transition to online learning with in-person experiences. The building of a sense of community can only happen when physical bonds are built between individuals.

Students were not the only ones sent home to work. Faculty members and most of the workforce followed suit. It may be worthwhile to discuss the whole question of working on-line in more general terms and beyond the context of academia. Experienced and established employees, including academics, may see many benefits in that work mode, especially if comfortably set up at home. Seminars and meetings can easily be arranged with colleagues around the globe, without the hassle and the costs of travel and lodging. Conferences have been conveniently available online. Some companies have embraced on-line work, seeing benefits not only in the savings they provide, but also in facilitating the recruitment of employees from a larger pool, as on-line work does not require moving the employee and their family, with all the disruptions and new commitments they entail.

Despite the progress made in operating online, how much are we losing and how should the new normal be? Online work lessens the bonds between colleagues and makes it harder to have profound, meaningful conversations. Interactions remain cautious and bonds weak, reducing the attachment to the institution. Online conferences are not memorable nor inspiring.

I do not think that online work is a sustainable way of operating, even in the high-tech industry. Nothing can replace the unplanned exchange of ideas at a meeting, in the corridor outside one's office, over a meal, or at a conference, that can lead to major insight and sometimes changes in paradigm. Moreover, although some students thrive in online teaching, many others struggle. With too many hours spent in front of a screen, motivation can be hard to maintain. When faced with a hard-to-solve problem, the support of peers is precious, especially in the early years at university. With experience, one learns how to use online tools and build a group of peers to exchange ideas and progress together. But the loss of enthusiasm from not having the comfort of relaxing with friends in coffee shops and other venues can be damaging long-term.

Over time, as mentioned above, technology will make on-line learning more and more life-like, especially within small groups. Large classes will remain a challenge. Deciding which is better, classes of hundreds online, with elegantly presented polls, or similar ones delivered in a large lecture hall with inspiring teachers, will not be easy. Most students will want the physical presence of peers, to sustain them, inspire them and allow them to make friends. There is no denying, however, that online teaching is here to stay and will only get better. It has the potential to provide virtual learning spaces that will be accessible at the user's convenience. Academics will need to keep control over its evolution so that it remains precisely accessible and an enriching teaching tool, and not driven by cost effectiveness.

As I write, a neighbour just quit his well-paying job in an IT firm, exhausted by the long days spent in front of the screen, working for a corporation, which has decided to go fully online, ignoring basic human needs for interactions, brainstorming, and simple breaks over a coffee or a meal. Decision-makers are likely comfortably installed people satisfied with their online life and having established social and professional circles. Most young adults embarking on their university studies live under different circumstances. They need to discover who they are, what their passions are and how to be productive citizens of this world. They also need to build their social circle, and those things will not happen in front of a screen. Universities are the best place to create an environment for passionate discussions of issues and brainstorming about the challenges facing humanity, and to build one's identity.

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1. Ciara Rickard, What postsecondary classes will look like in 10 years, The Globe and Mail, 16 Nov 2021 p. A15 (2021).

*Comments of readers on this Editorial are more than welcome.*

# L'AVENIR DE L'ENSEIGNEMENT UNIVERSITAIRE

Béla Joós, Rédacteur en chef, *La Physique au Canada*

Depuis mars 2020, nous avons vécu des moments exceptionnels. Ils ont mis à l'épreuve notre résilience et nous ont permis d'acquérir de nouvelles compétences, mais ils nous ont aussi rappelé ce qui nous manquait. Nombre d'entre nous sont impatients de revenir à une époque moins restrictive. Il est également clair qu'il n'est pas possible de revenir en arrière. Au fur et à mesure que les restrictions sont levées, une nouvelle normalité émergera. L'avenir ne ressemblera pas à l'époque prépandémique et nous devrions participer activement à son élaboration. Chaque partie prenante doit réfléchir à ce qui serait le mieux pour tous.

Le confinement durant la Covid a accéléré notre transition vers un mode de travail et d'étude en ligne, que beaucoup voyaient venir, mais de manière beaucoup plus progressive. En mars 2020, nous avons fait de notre mieux pour sauver le semestre académique d'hiver 2020, en testant divers outils d'enseignement et d'évaluation en ligne. À l'automne 2020, nous étions mieux équipés et nous espérions revenir bientôt à la normale. Les laboratoires de recherche de l'Université d'Ottawa sont revenus avec des règles de sécurité strictes en l'espace de quelques mois. L'enseignement, cependant, est resté en ligne, et cela a été le cas pour la plupart des étudiants qui sont entrés en première année à l'automne 2021. La durée des perturbations en a surpris beaucoup. Mais les têtes froides savaient qu'il n'y avait pas de solution facile, et il est de plus en plus clair que, que nous le voulions ou non, le monde a profondément changé.

Heureusement, la transition vers un monde virtuel s'est produite à un moment de notre civilisation où nous pouvions fonctionner sans être physiquement présents au travail. Zoom, Teams, Google Meet et d'autres plateformes facilitent les interactions, les réunions et l'enseignement. Cet automne 2021, j'enseigne dans une classe bimodale où près de la moitié des étudiants sont physiquement présents et l'autre moitié suit le cours en ligne par le biais d'un lien Zoom. Il est facile de poser des questions, même pour ceux qui sont en ligne. Ils lèvent la main (virtuellement) ou posent leur question dans le chat. Les haut-parleurs de la classe projettent clairement leur voix. Quant aux questions posées dans le chat, soit j'y réponds, soit, dans de nombreux cas, ce sont des camarades de classe qui y répondent. Il s'agit là d'une évolution remarquable découlant de l'utilisation de l'outil en ligne. Les étudiants en ligne sont plus interactifs que ceux qui se trouvent dans un amphithéâtre. Les cours sont enregistrés et mes notes, que je produis sur ma tablette, sont publiées sous forme de fichiers pdf. Les étudiants peuvent venir ou ne pas venir en classe, sachant qu'ils peuvent se connecter via le lien zoom ou regarder plus tard. Je dispose d'une librairie de démonstrations filmés durant l'été. James Fraser (Queen's U.) a soutenu, lors d'un récent séminaire intitulé "Interactive engagement in the remote-teaching era - why we should never go back", que le potentiel de l'enseignement en ligne est considérable (29 septembre 2020, Carleton U.).

L'enseignement en ligne présente de nombreux attraits. Compte tenu des pressions financières croissantes exercées sur l'enseignement de premier cycle, les universités seront tentées d'adopter ce format pour de nombreux cours. Il est possible de réaliser des économies considérables en évitant de construire de grands amphithéâtres et de les équiper des technologies les plus récentes. Un cours magistral donné en personne à des centaines d'étudiants, voire à un millier, est-il meilleur qu'un cours magistral en ligne ? Avec zoom, les étudiants peuvent poser des questions à tout moment en utilisant le chat, et interagir sur les questions avec les autres étudiants, les assistants ou le professeur. Les sondages sont faciles à mettre en place pour évaluer le niveau de compréhension et guider la maîtrise des concepts. La gestion de grands laboratoires de premier cycle exige beaucoup de ressources. Une grande partie de la formation initiale peut être effectuée en ligne et, à mesure que la technologie devient plus réaliste, l'expérience ne peut que s'améliorer.

Des économies importantes seront réalisées, mais la perte d'un environnement social affectera grandement de nombreux élèves. Les étudiants ont besoin de leurs pairs, non seulement pour les aider sur le plan académique, mais aussi pour donner un sens à leurs défis quotidiens et les aider à façonner la vision de leur avenir. Un programme de physique réussi nécessite un apprentissage pratique en personne, un environnement interactif où les étudiants se motivent mutuellement et acquièrent une meilleure compréhension en parlant des concepts et en écoutant les autres en parler avec leurs propres mots.

L'environnement social et les relations personnelles sont des facteurs de motivation considérables. Les universitaires et les étudiants devront réfléchir attentivement à la manière dont nous mettrons en œuvre les changements. Des arguments seront avancés pour soutenir la transition, dans certains cas en citant leur popularité basée sur le nombre d'inscriptions, qui reste élevé. Cependant, ce que de nombreux étudiants trouvent pratique, à savoir rester dans le confort de leur logis pour éviter de longs trajets, n'est pas nécessairement ce qu'il y a de mieux pour eux d'un point de vue intellectuel. Le confort de la maison et l'accès facile à l'information sur le web peuvent avoir un effet négatif sur les esprits malléables et même les détourner du droit chemin. Il est également beaucoup plus difficile de sortir d'une ornière lorsque le seul réconfort est le divertissement en ligne. La plupart d'entre nous ont de très bons souvenirs de la vie sur le campus. C'est à l'université que l'on noue des liens qui durent toute une vie.

Reviendrons-nous à une époque comme celle du début du 20e siècle, où l'éducation de qualité en personne et en petits groupes était le privilège des riches ? Est-ce la fin de l'éducation de masse abordable en personne ? Une vie de campus dynamique deviendra-t-elle un souvenir du passé ? Nous devrons vraiment nous battre pour équilibrer la transition vers l'apprentissage en ligne et les expériences en personne. La construction d'un sens de la communauté ne peut se faire que lorsque des liens physiques sont tissés entre les individus.

Les étudiants n'ont pas été les seuls à être renvoyés chez eux pour travailler.  Les membres du corps enseignant et la majeure partie de la main-d'œuvre ont suivi le mouvement. Il peut être intéressant de discuter de la question du travail en ligne de manière plus générale et en dehors du contexte universitaire. Les employés expérimentés et établis, y compris les universitaires, peuvent voir de nombreux avantages dans ce mode de travail, surtout s'ils sont confortablement installés à la maison. Des séminaires et des réunions peuvent facilement être organisés avec des collègues du monde entier, sans les tracas et les coûts de déplacement et d'hébergement. Les conférences sont facilement accessibles en ligne. Certaines entreprises ont adopté le travail en ligne, y voyant de nombreux avantages, non seulement en termes d'économies, mais aussi pour faciliter le recrutement de salariés à partir d'un vivier plus large, car le travail en ligne n'exige pas le déplacement du salarié et de sa famille, avec toutes les perturbations et les nouveaux engagements qu'il implique.

Malgré les progrès réalisés dans le domaine du travail en ligne, que perdons-nous et que devrait être la nouvelle normalité ? Le travail en ligne réduit les liens entre collègues et rend plus difficiles les conversations profondes et significatives. Les interactions restent prudentes et les liens faibles, ce qui réduit l'attachement à l'institution. Les conférences en ligne ne sont ni mémorables ni inspirantes.

Je ne pense pas que le travail en ligne soit un mode de fonctionnement durable, même dans le secteur de la haute technologie. Rien ne peut remplacer l'échange d'idées imprévu lors d'une réunion, dans le couloir à l'extérieur de son bureau, au cours d'un repas ou d'une conférence, qui peut déboucher sur des idées majeures et parfois sur des changements de paradigme. En outre, si certains étudiants s'épanouissent dans l'enseignement en ligne, beaucoup d'autres éprouvent des difficultés. Avec trop d'heures passées devant un écran, la motivation peut être difficile à maintenir. Face à un problème difficile à résoudre, le soutien des pairs est précieux, surtout dans les premières années d'université. Avec l'expérience, on apprend à utiliser les outils en ligne et à constituer un groupe de pairs pour échanger des idées et progresser ensemble. Mais la perte d'enthousiasme liée à l'absence du confort de la détente entre amis dans les cafés et autres lieux de rencontre peut être préjudiciable à long terme.

Au fil du temps, comme indiqué ci-dessus, la technologie rendra l'apprentissage en ligne de plus en plus proche de la réalité, en particulier au sein de petits groupes. Les grandes classes resteront un défi. Il ne sera pas facile de décider ce qui est le mieux, des classes de centaines de personnes en ligne, avec des sondages élégamment présentés, ou des classes similaires dans un grand amphithéâtre avec des enseignants inspirants. La plupart des étudiants souhaiteront la présence physique de leurs pairs, pour les soutenir, les inspirer et leur permettre de se faire des amis. Il est toutefois indéniable que l'enseignement en ligne est là pour durer et qu'il ne fera que s'améliorer. Il a le potentiel de fournir des espaces d'apprentissage virtuels qui seront accessibles à la convenance de l'utilisateur. Les universitaires devront garder le contrôle de son évolution afin qu'il reste précisément accessible et un outil d'enseignement enrichissant, et qu'il ne soit pas uniquement motivé par le rapport coût-efficacité.

À l'heure où j'écris ces lignes, un voisin vient de quitter son emploi bien rémunéré dans une société d'informatique, épuisé par les longues journées passées devant l'écran à travailler pour une entreprise qui a décidé de se mettre entièrement en ligne, ignorant les besoins humains fondamentaux d'interactions, de brainstorming et de simples pauses autour d'un café ou d'un repas. Les décideurs sont probablement des personnes confortablement installées, satisfaites de leur vie en ligne et ayant établi des cercles sociaux et professionnels. La plupart des jeunes adultes qui se lancent dans des études universitaires vivent dans des circonstances différentes. Ils doivent découvrir qui ils sont, quelles sont leurs passions et comment devenir des citoyens productifs de ce monde. Ils ont également besoin de construire leur cercle social, et ces choses ne se feront pas devant un écran. Les universités sont le meilleur endroit pour créer un environnement propice à des discussions passionnées sur des questions et à un brainstorming sur les défis auxquels l'humanité est confrontée, et pour construire son identité.

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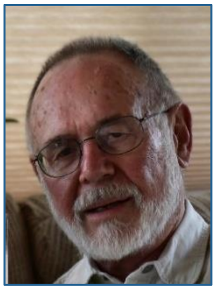
## RÉFÉRENCES

1. Ciara Rickard, 2021, What postsecondary classes will look like in 10 years, The Globe and Mail, 16 nov 2021 p. A15.

*Les commentaires des lecteurs sur cet éditorial sont toujours les bienvenus.*
*NOTE: Le genre masculin n’a été utilisé que pour alleger le texte.*

# ANTON Z. CAPRI (1938-2021)



Anton Zizi Capri (Tony), who was a professor for 30 years in the Department of Physics of the University of Alberta, passed away on June 30th, 2021. Tony was born in 1938 in Czernowitz, Romania. His father was Leon Kapri, Freiherr (Baron) von Mericey. During World War II the family had to flee Romania, first to Germany and then immigrated to Toronto, Canada, in 1949. He first went to St. Paul's School and then Jarvis Collegiate Institute where he finished as valedictorian in 1957. In 1960 he married Skaidrite Kveps whom he had known since high school. He graduated from the University of Toronto in 1961 with a B.A.Sc. in Engineering Physics. He then accepted a position with Kimberley-Clark Corporation in their Pioneering Research Department in Neenah, Wisconsin. The intellectual challenge being inadequate, in 1963 he went to Princeton University as a graduate student in physics. He completed an MA in 1965 and a PhD under Professor Arthur S. Wightman in 1967. He then accepted a postdoctoral position at the University of Alberta. This turned into a visiting professorship in 1968 and then into a tenure track position in 1969 and he remained there until his retirement as a full professor in 1998. He was a professor emeritus ever since.

At Princeton, his PhD thesis was on the "External Field Problem for Higher Spin Particles". His co-students included Arthur Jaffe and Jerrold Marsden among others. During his academic career he spent a year as an Alexander von Humboldt Senior Research Fellow at the Max Planck Institute für Physik und Astrophysik, Munich, Germany and since then was frequently invited as a guest professor or research scientist to the following institutions: University of Innsbruck; University of Pisa, University of Milan, University of Trento, Italy; University of Poona, India, Tata Institute of Fundamental Research, Bombay, India; Gifu University, Gifu, Japan. He served as the director of the Theoretical Physics Institute of the University of Alberta.

He also published more than seventy research papers, five books on physics and chapters in several books. His scientific interests included the rigorous study of higher-spin fields, quantum fields in external fields including particle creation in curved spacetime, and constructive quantum field theory. His book "Non-Relativistic Quantum Mechanics" is a model of clarity and of balance between mathematical rigour and physical intuition.  He helped to organize and to edit the proceedings of several of the Lake Louise Winter Institutes and the two NATO Advanced Study Institutes on Particles and Fields held in Banff.

For many years he had collected stories about the life and ideas of physicists in the form of a book which was later published under the title Quips, Quotes and Quanta, which was followed by a second volume. After his retirement, he published several novels of fiction, short stories and even poetry. He was an accomplished mid-Dan level "Go" player and apparently a "kilted" bag-piper. The discussions he engaged in at the departmental coffee were wide-ranging and always lively, and gave the real feel for the life of a physics professor.

To his students and co-researchers, Tony was at first a somewhat intimidating, intellectual authority causing some trepidation in approaching him as a supervisor or collaborator. However, unanimously they reveal his true nature as a warm, friendly, sociable and generous person. He managed to connect with his students and fellow researchers imparting a sense of equality and a spirit of collegiality. His deep knowledge of quantum field theory from the Wightman school had a great influence on his students and colleagues. Personally, the absolutely best course that I ever took in graduate school was from Tony on Jackson level classical electrodynamics. Tony will be sorely missed.

Manu Paranjape, Université de Montréal

(with input from John Beamish, Martin Connors, Valeri Frolov, Karin Fuog, Gebhard Grübl, Dave Henty, Mohsen Razavy, and Rick Sydora)

# DOUBLE ATOMIC ELECTRON EMISSION FOLLOWING THE BETA DECAY OF $^6$HE

Summary: Final charge-state distributions are calculated for the beta decay of $^6$He in a collaborative search for new physics beyond the Standard Model.

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Aaron Bondy received 3rd place in the 2020 CAP Best Overall Student Oral Presentation

## INTRODUCTION

Beta decay has been a very interesting problem in the development of physics. From postulating the neutrino particle, to discovering the nonconservation of parity in the weak interaction, it has been centre stage in the arena of nuclear physics. In particular, in the early days of the electroweak theory, leading up to the Standard Model, beta decay was an important problem that was considered repeatedly ([1] and earlier references therein). A general $\beta^-$ decay has the form

$$A(Z,N) \rightarrow A(Z+1,N-1)+e^- + \bar{\nu} \ , \tag{1}$$

where $Z$ is the nuclear charge and $N$ is the number of neutrons. Two leptons (an electron and an antineutrino) are created, while a neutron changes to a proton. For single beta decay processes, there are two types, differing in how the product lepton spins couple in the aftermath of the decay:

1. Fermi V-type, where $e^-$ and $\bar{\nu}$ are coupled to form a total spin of 0; and
2. Gamow-Teller A-type where $e^-$ and $\bar{\nu}$ are coupled to form a total spin of 1.

The beta decay of $^6$He is predicted to be a pure Gamow-Teller process [2], which has an electron-neutrino correlation coefficient, $a_{e\nu}$, that is equal to −1/3, a quantity which under the present experimental conditions is related to the angle $\theta$, between $e^-$ and $\bar{\nu}$ (see Fig. 1) by

$$W(\theta) \propto 1 + a_{e\nu}\frac{v}{c}\cos\theta \, , \tag{2}$$

where $W(\theta)$ describes the (measurable) angular distribution of observed electrons and $\frac{v}{c}$ is the ratio between the speed of the electrons and the speed of light [3].

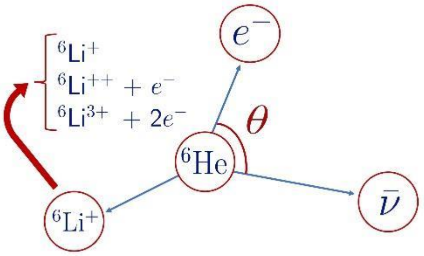

Figure 1. Kinematics of a $^6$He beta decay. The angle θ between the electron and antineutrino is an important property used in testing the Standard Model. The daughter ion, $^6\text{Li}^+$, can undergo any excitation, single- or double-ionization process.

Since the antineutrino in this decay cannot be observed directly [4], it is necessary to reconstruct the kinematics using the momentum of the initial $^6$He atom, along with the other products (the beta particle and the recoiling daughter ion $^6\text{Li}^+$). If in addition one or two atomic electrons boil off (shake-off) resulting in $^6\text{Li}^{++}$ or $^6\text{Li}^{3+}$, this would affect the conservation of momentum relation and must thus be accounted for in deducing $a_{ev}$, the experimental quantity of interest.

Table I compares experimental results [1, 4] with our previous calculations [5] and earlier work by Wauters and Vaeck [6] for the probability of forming the various charge states $^6\text{Li}^{k+}$, $k$ = 1, 2, 3 following beta decay from the ground $^6\text{He}(1s^2\,{}^1S)$ or metastable $^6\text{He}(1s2s\,{}^3S)$ states. Unless experiment and theory are brought into agreement for these probabilities, we cannot confidently interpret the experimental results to deduce $a_{ev}$. For both states shown in Table I, the probabilities for excitation (forming excited $^6\text{Li}^+$) and single ionization ($^6\text{Li}^{++}$) compare well. For double ionization ($^6\text{Li}^{3+}$), though, there is a huge disagreement (~2 orders of magnitude) for both initial states. This discrepancy is what we seek to resolve in the present work.

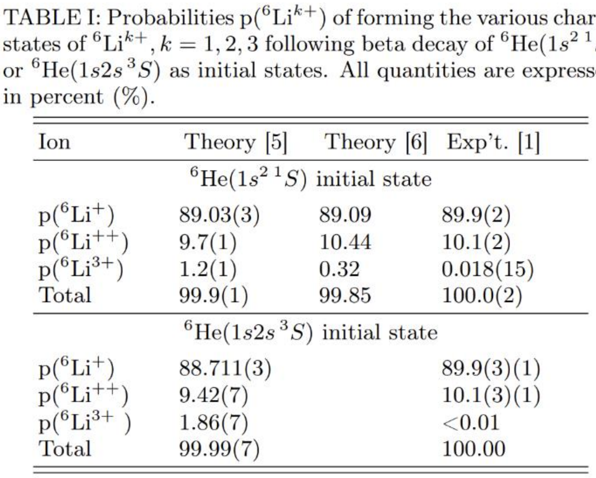

TABLE I: Probabilities p($^6\text{Li}^{k+}$) of forming the various charge states of $^6\text{Li}^{k+}$, $k = 1, 2, 3$ following beta decay of $^6\text{He}(1s^2\,{}^1S)$ or $^6\text{He}(1s2s\,{}^3S)$ as initial states. All quantities are expressed in percent (%).

| Ion | Theory [5] | Theory [6] | Exp't. [1] |
|---|---|---|---|
| | $^6\text{He}(1s^2\,{}^1S)$ initial state | | |
| p($^6\text{Li}^+$) | 89.03(3) | 89.09 | 89.9(2) |
| p($^6\text{Li}^{++}$) | 9.7(1) | 10.44 | 10.1(2) |
| p($^6\text{Li}^{3+}$) | 1.2(1) | 0.32 | 0.018(15) |
| Total | 99.9(1) | 99.85 | 100.0(2) |
| | $^6\text{He}(1s2s\,{}^3S)$ initial state | | |
| p($^6\text{Li}^+$) | 88.711(3) | | 89.9(3)(1) |
| p($^6\text{Li}^{++}$) | 9.42(7) | | 10.1(3)(1) |
| p($^6\text{Li}^{3+}$) | 1.86(7) | | <0.01 |
| Total | 99.99(7) | | 100.00 |

## WAVE FUNCTIONS

Although the two-electron Schrödinger equation, with Hamiltonian (in atomic units),

$$H = -\frac{1}{2}\nabla_1^2 - \frac{1}{2}\nabla_2^2 - \frac{Z}{r_1} - \frac{Z}{r_2} + \frac{1}{r_{12}}\,, \tag{3}$$

is not exactly solvable, the solutions can be approximated by various methods including the Hartree-Fock and configuration-interaction methods. Our work employs the much more accurate (e.g. [8]) Hylleraas wave functions

$$\Psi(\mathbf{r}_1, \mathbf{r}_2) = \sum_{t=1}^{2} \sum_{i,j,k} a_{ijk}^{(t)} r_1^i r_2^j r_{12}^k e^{-\alpha^{(t)} r_1 - \beta^{(t)} r_2} \times \mathcal{Y}_{l_1,l_2,L}^{M} \pm \text{exchange}\,, \tag{4}$$

that are essentially exact for bound states for all practical purposes, where $\{a_{i,j,k}^{(t)}\}$ and $\{\alpha^{(t)}, \beta^{(t)}\}$ are respectively the linear and nonlinear variational parameters. In Eq. 4, $r_1 = \boldsymbol{r}_1$ and $r_2 = \boldsymbol{r}_2$ are the radial positions of electrons 1 and 2, $r_{12} = |\boldsymbol{r}_1 - \boldsymbol{r}_2|$ is the interelectronic distance, and $\mathcal{Y}_{l_1,l_2,L}^{M}$ is the vector coupled spherical harmonic for a state with *L, M* quantum numbers. The eigenstates, called pseudostates, provide a discrete variational representation of the entire (bound + continuum) spectrum. Three important features of Hylleraas wave functions are that:

- They yield by far the most accurate wave functions for bound states.
- The discrete and complete basis set of pseudostates is computationally easier to deal with the infinity of Rydberg / continuum states.
- The pseudostates contain complete information about both the bound states and the scattering states, at least in the region of space near the nucleus.

The downside of the method is that each two-electron pseudostate represents an unresolved linear combination of both charge states $^6$Li$^{++}$ and $^6$Li$^{3+}$ for $E > 0$, as illustrated by the crosshatch pattern in Fig. 2 where the two scattering continua overlap.

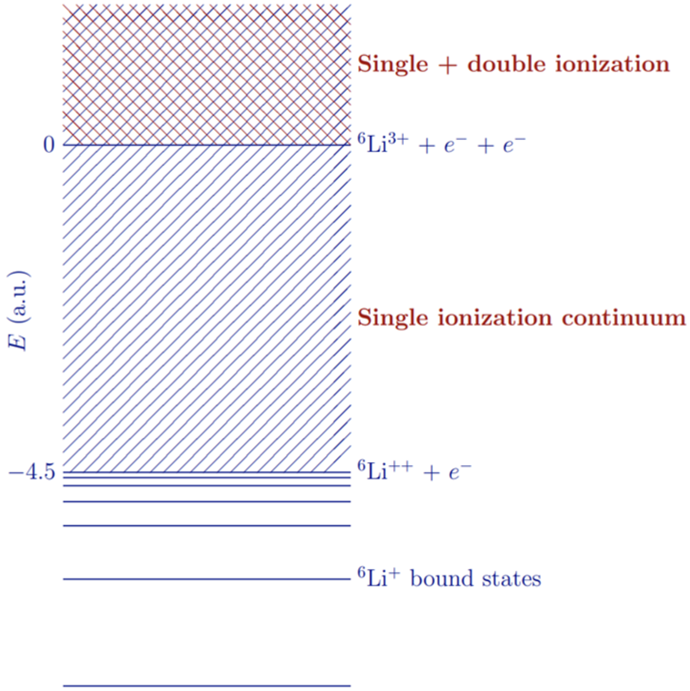

Figure 2. Energy level diagram for $^6$Li$^+$ following beta decay. For *E > 0*, the single ionization continuum overlaps the double ionization continuum. This work seeks to resolve the fractional contribution from the two charge states.

## RESULTS

Our previous work [5] calculated the $^6$Li$^+$ daughter ion probabilities using these Hylleraas wave functions and made use of the sudden approximation (SA), which assumes that the change in nuclear charge from $Z = 2$ to $Z = 3$, due to the beta decay, is instantaneous. The SA is thought to be justified on the basis that the actual time taken for the change in nuclear charge is $\sim 10^{-18}$ s, which is many orders of magnitude smaller than the relaxation time of the atomic electrons in the new Coulomb potential. Couratin *et al.* estimated that for the case of single-electron $^6$He$^+$, the SA alters the estimated that for the case of single-electron $^6$He$^+$, the SA alters the transition probabilities only at the 1% level [7].

According to the SA, the initial helium wave function $\psi(^6\mathrm{He})$ is expanded in terms of the complete set of states $\psi_n(^6\mathrm{Li}^+)$ according to

$$\Psi(^6\mathrm{He}) = \sum_n c_n \Psi_n(^6\mathrm{Li}^+)\,. \tag{5}$$

The expansion coefficients, $c_n$, have the interpretation of probability amplitudes, and their squares, as probabilities in

$$\mathrm{p}(E_n) = c_n^2 = |\langle \Psi(^6\mathrm{He}) | \Psi_n(^6\mathrm{Li}^+) \rangle|^2\,, \tag{6}$$

which gives the probability of transition to a daughter ion state with energy En following the decay. Our previous work partitioned the energy bins as indicated in Fig. 2, where (in a.u.) $E_+ < -4.5$, $-4.5 < E_{++} < 0$, and $E_{3+} > 0$ define bound, singly, and doubly ionized states, respectively. Although the first two energy bins unambiguously identify the charge state, the $E > 0$ criterion could correspond to either single- or double-ionization, since one electron can feasibly be emitted with a large surplus of energy. This is the physical reason for the overlapping crosshatch region for $E > 0$ in Fig. 2.

In order to remedy this problem, we have constructed projection operators that can be used to resolve the states with $E > 0$ into $^6$Li$^{++}$ or $^6$Li$^{3+}$, depending on whether single or double ionization boundary conditions are satisfied. To do this we took the following approach:

1. Form a complete set of one-electron pseudostates
2. Take their (anti)symmetrized products to form a complete set of two-electron pseudostates
3. Use these product states as the basis for a projection operator that will act on the $\psi_n$($^6$Li$^+$) Hylleraas eigenfunctions with $E_n > 0$

The crucial part of the method is in step 2. In forming product states, we retain knowledge of what the charge state is of the two-electron system. This is because for each of the two one-electron states in step 1, the energy does unambiguously determine the charge state. However, in forming product states, we have neglected the electron-electron interaction, and hence have lost some information on the total energy. Fortunately, we have [9] accounted for this via perturbation corrections. We find that it is a completely negligible effect for present accuracy.

So, with two-electron wave functions that have well-defined boundary conditions in hand, we form the projection operator that will partition the previously overlapping $E > 0$ region:

$$P = \sum_{n_{3+}} |\, n_{3+}\rangle\langle n_{3+}\,| , \tag{7}$$

where $\{n_{3+}\}$ denotes those product wave functions corresponding to double ionization. Of course, we also have $Q$, formed as the sum of everything else, and satisfying $P + Q = 1$. The corrected probabilities (with $p(E_n)$ from Eq. (6)) that we report are calculated as:

$$\mathrm{p}^*(E_n) = \langle \Psi_n(^6\mathrm{Li}^+) \mid P \mid \Psi_n(^6\mathrm{Li}^+)\rangle \times \mathrm{p}(E_n)\,. \tag{8}$$

The finer details of our method have been omitted here (for the sake of brevity), but the interested reader can consult Ref. [9]. Our new results (in Table II) reduce the discrepancy between theory and experiment by an order of magnitude. Thus, there indeed was some $^6$Li$^{++}$ masquerading as $^6$Li$^{3+}$ in [5], as shown in Fig. 2; however, the $^6$Li$^{3+}$ results still disagree by an order of magnitude for both starting states. This indicates that there is work left to be done on the problem.

TABLE II: Resolved $^6\mathrm{Li}^{3+}$ formation probabilities for each initial state following beta decay. All quantities are expressed in percent (%).

| He state | $p(^6\mathrm{Li}^{3+})$ | | |
|---|---|---|---|
| | Theory [5] | Present work | Exp't [1, 4] |
| $^6\mathrm{He}(1s^2\,{}^1S)$ | 1.2(1) | 0.35(5) | 0.018(15) |
| $^6\mathrm{He}(1s2s\,{}^3S)$ | 1.86(7) | 0.53(7) | <0.01 |
| $^6\mathrm{He}(1s2s\,{}^1S)$ | | 0.56(6) | |

## CONCLUSIONS

The projection operator formalism has reduced the discrepancy with experiment by almost an order of magnitude and, as developed, can be investigated for potential use in to a range of atomic physics problems involving two electron continuum phenomena (e.g. double photoionization of He). Concerning the remaining discrepancy between theory and experiment (assuming that it is indeed on the theoretical side), one possibility would be to correct for the SA by solving the TDSE, where a time-dependent potential will be introduced in place of a step-function to model the beta particle.

## ACKNOWLEDGEMENTS

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# 2021 STUDENT COMPETITIONS / COMPÉTITIONS ÉTUDIANTS 2021

The CAP would like to thank and congratulate everyone that participated in this year's 2021 CAP Virtual Congress and Best Student Presentation Competition, from the ~325 student competitors and 81-member judging team, to everyone who attended the talks and visited the posters. Your support and participation was vital to the success of the event.

As always, this year was met with a series of fantastic poster and oral presentations and all presenters should be proud of their hard-work and accomplishments!

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| PARTICLE PHYSICS | |
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# CREATING A SUPERFLUID CRYSTAL IN HELIUM-3

**SUMMARY**: When confined to a thickness smaller than one-hundredth of a human hair, superfluid helium-3 forms a strange new state of matter; a superfluid crystal.

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Pramodh Senarath Yapa received 2nd place in the 2021 CAP Best Overall Student Oral Presentation

## THE LIQUID TO SOLID PHASE TRANSITION

In a seminal paper published in 1937 [1], the great Soviet physicist Lev Davidovich Landau decried the scientific discourse surrounding the liquid-solid phase transition. He wrote: "One even finds the strange statement that there is no essential difference at all between liquids and crystals, and that continuous transitions between them are possible. However, liquids differ essentially from crystals in that they are isotropic in contrast to anisotropic crystals. Every transition from a crystal to a liquid or to a crystal of a different symmetry is associated with the disappearance or appearance of some elements of symmetry." With these fateful words, Landau set the stage for our modern classification of phase transitions as symmetry-breaking processes. However, Landau probably would not have imagined that this same classification could lead to a state of matter which blurs the liquid-solid distinction: a superfluid crystal.

## SUPERFLUID HELIUM-3

The superfluid behaviour of helium-3 was discovered in 1972 by David Lee, Doug Osheroff and Bob Richardson, for which they later won the Nobel Prize in Physics. Cooling the helium-3 down to a temperature roughly two thousandth of a degree above absolute zero, they discovered that the liquid suddenly began to flow without any friction. This was many decades after the same phenomenon was discovered in helium-4, the more common isotope of helium. This delay was because helium-3 is a fermion, and must first form a Cooper pair to transition into its superfluid phase. The Cooper pairing in helium-3 results in a much more fragile state than that of bosonic helium-4, and thus helium-3 requires lower temperatures for superfluidity.

The Cooper pairing also means that there can be many different phases of superfluid helium-3; in the language of Landau, the symmetry group of helium-3 is larger than helium-4, and can be broken into many distinct sub-groups. In the laboratory setting, it was established that the phase diagram of bulk superfluid helium-3 contained only two thermodynamically stable phases – the A and the B phases.

But as experimental techniques and nanotechnology became more sophisticated, physicists began to wonder about the confined phases of superfluid helium-3: can you make new phases by restricting the geometry of the container in which the superfluid lives?

## STRIPES OR POLKA DOTS?

In 2007, a theory paper by Anton Vorontsov and Jim Sauls [2] considered this exact situation: confining the superfluid into a slab. The effect of this confinement is that the top and bottom surfaces interfere with the Cooper pairs, leading to reduced superfluidity. Vorontsov and Sauls found that this interference could be counteracted by the superfluid forming a periodic density variation along the plane. As it is the density of the Cooper pairs that is varying, this is referred to as a pair-density wave (PDW) state. At a small enough slab thickness, they predicted that the stable state of the superfluid would be a PDW varying along one direction, while remaining homogeneous in the other in-plane direction. Due to this pattern of density variation, it was dubbed a ‘stripe phase’. This stripe phase and other superfluid PDW states are unusual as they are zero-viscosity liquids, but also show the periodic density modulations which we expect to see in solids - a superfluid crystal!

In 2019 and 2020, two experimental groups tested this theoretical prediction. The first, a collaboration between Royal Holloway University of London and Cornell University [3], put the superfluid into a 1.1 µm slab and found an experimental signature of a PDW phase. But what they found was inconsistent with a stripe phase; the PDW had to vary along both in-plane directions, making it a two-dimensional PDW. Instead of a ‘stripe phase’, they saw something like a ‘polka dot’ phase.

In 2020, the experimental group led by Prof. John Davis at the University of Alberta performed a series of experiments [4] mapping out the entire temperature-pressure phase diagram for three different slab thicknesses between 600 nm and 1.1 µm. Their phase diagrams showed that this new phase was stable in all of the slabs, and appeared sandwiched between the A and B phases.

So by early 2020, experiments had made clear that it is a two-dimensional (2D) pair density wave state which shows up in a confined geometry. But then this begged a couple of questions from the theory side: why is this 2D pair-density wave stable? And what is the actual crystal structure of this pair density wave? Is it a polka dot, which has a triangular symmetry? Or would it have the symmetry of a square lattice?

## A TRIANGULAR SUPERFLUID CRYSTAL

These questions about the stability and structure of the PDW were what we tackled in in our recent work [5]. We did this using an old idea proposed by Landau called ‘weak crystallization’, which relies on Ginzburg-Landau (GL) theory to construct a theory of the crystallization transition. GL theory is based on a quantity called the order parameter and in helium-3, the order parameter is a 3 × 3 matrix:

$$A_{\mu j} = \begin{bmatrix} A_{11} & A_{12} & A_{13} \\ A_{21} & A_{22} & A_{23} \\ A_{31} & A_{32} & A_{33} \end{bmatrix}$$

To understand this superfluid order parameter, we need to understand that helium-3 is a spin-triplet, *p*-wave superfluid. This means that the spin and the orbital angular momentum of the Cooper pairs are both equal to 1: *s* = 1, *l* = 1. This means that the Cooper pairs have 3 sub-states for each projection of the spin and orbital angular momentum. We need separate order parameters for each of these sub-states, and thus there are 3 × 3 or 9 independent complex-valued order parameters for the superfluid helium-3. The $\mu$ indices in the $A_{\mu j}$ matrix are for the spin, and the $j$ for the orbital angular momentum. To look for a PDW phase, we ask if it is energetically favourable for this order parameter to be modulated spatially.

We first calculated which combinations of order parameter components (known as ’collective modes’) would energetically favour a periodic density variation. The energy cost for each mode should vary with the wavelength of the variation, and we can produce a plot like Figure 1 which plots the energy cost for each mode along the y-axis and the wavevector along the x-axis.

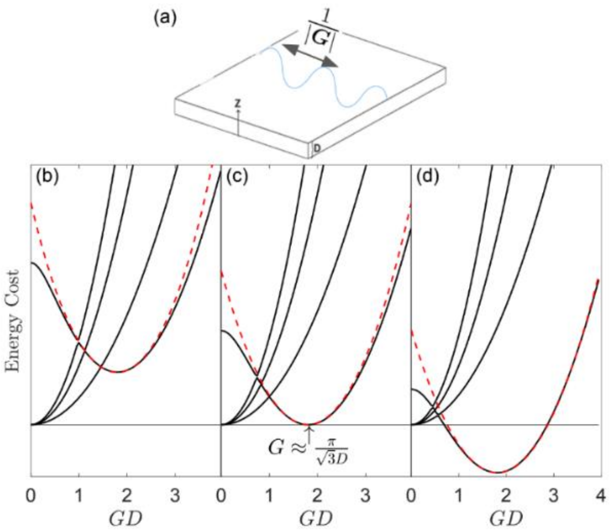

Figure 1. (a) Schematic depiction of the slab and the wavevector of the density variation, G. (b) – (d) show how a mode softens at a finite value of the wavevector as we reduce the thickness of the slab.

This theory also let us predict the crystal structure of this PDW phase - it must have the symmetries of a triangular lattice, also known as the $D_6$ symmetry group. The symmetry is triangular because of a specific (cubic) term in the Ginzburg-Landau free energy which forces the basis vectors of the PDW’s reciprocal lattice to add up to zero in triangles.

## RESULTS

Shown in Figure 2 is our computed phase diagram for a slab thickness D = 300 nm. The blue region corresponds to the B phase under confinement, the planar-distorted B (PDB) phase; the red region corresponds to the A phase, which is unmodified from its bulk order parameter structure; and the grey region corresponds to the new PDW phase. We also show the data points for the calculated critical temperatures, $T_1*$ and $T_2*$ where the mode softens, and $T_{PDW}$, the temperature where the phase transition occurs. $T_{PDW}$ is very close to the mode softening temperatures and is thus indistinguishable from them on the plot. Qualitatively similar results are obtained for the thicknesses studied in experiment, but the PDW region is smaller.

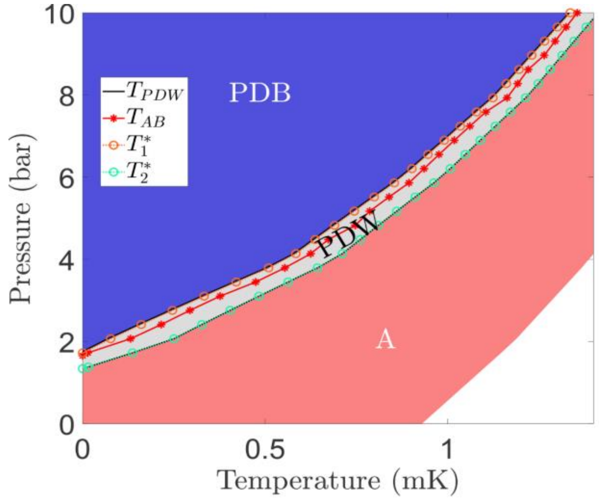

Figure 2. Calculated phase diagram of superfluid helium-3 when confined to a slab thickness D = 300nm.

For the crystal structure of this PDW, as the order parameter is a 3 × 3 matrix, we were able to compute the structure as it would appear in each of those 9 components. But of these 9 components, we found that there were three dominant terms, each with a different spatial structure as shown in Figure 3.

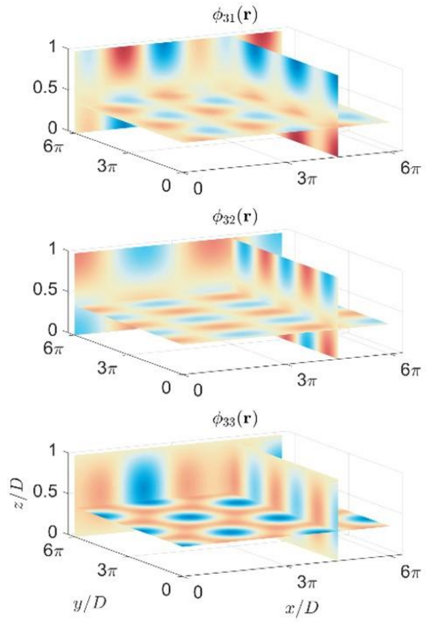

Figure 3. The three dominant superfluid crystal structures. These appear in the bottom row of the order parameter matrix ($\mu$ = 3) with $A\mu j = A\mu j + \varphi\mu j$ . Here $A\mu j$ is the background homogeneous superfluid order parameter.

## CONCLUSION

In summary, we have proposed a mechanism which explains why a two-dimensional pair-density wave state appears in confined superfluid helium-3. This mechanism allows us to compute the phase diagram under confinement, which qualitatively matches experimental results. We are also able to predict the dominant crystal structures of this emergent superfluid crystal using this theory. In the future, we hope to calculate the properties of this state and the experimental signatures of its crystal structure.

## ACKNOWLEDGEMENTS

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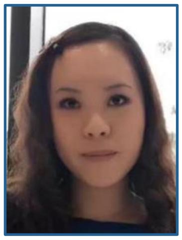
# MODEL OF MAGNETIC MONOPOLE PRODUCTION IN HEAVY-ION ULTRAPERIPHERAL COLLISIONS AT THE LHC

**SUMMARY**: A Monte Carlo model has been implemented and used to compute the kinematics and production rates of magnetic monopoles in heavy-ion ultraperipheral collisions at the LHC.



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Wen-Yi Song received 1st place in the 2021 CAP Best Overall Student Poster Presentation

## INTRODUCTION

A magnetic monopole, an object that emits a radial magnetic field, does not exist in classical electrodynamics. Yet, in 1931, Dirac postulated the existence of particles with magnetic charges [1] and proved their consistency with quantum mechanics given their charges are integer multiples of the fundamental magnetic charge ($g_D$). This result implies that the existence of such a magnetic monopole would explain the quantization of electric charge.

High-energy particle colliders have been on a quest to discover stable Dirac monopoles, which have no substructure and would be created in pairs to conserve magnetic charge. Recently these searches have been conducted with proton-proton collisions at CERN's Large Hadron Collider (LHC). The monopole production rates are predicted by benchmark models, such as the fusion of photons radiated by the colliding protons. However, the LHC not only collides protons but also heavy ions, which produce large electromagnetic fields as they move at ultrarelativistic velocities. Ultraperipheral collisions, where the ions pass each other with no direct interaction, could produce magnetic monopoles from the radiated photons via the photon fusion mechanism.

## HEAVY-ION ULTRAPERIPHERAL COLLISIONS

Heavy-ion collisions are characterized by the distance between the colliding ions transverse to their directions of motion. In ultraperipheral collisions (UPC), where the distance $b$ is larger than twice their radii $R_A$, the photons radiated from the ions undergo the photon-fusion process while the ions are left intact (see Figure 1). The strong electromagnetic fields propagate as low-momentum photons, as described in the equivalent photon method by Weizsäcker and Williams [2, 3].

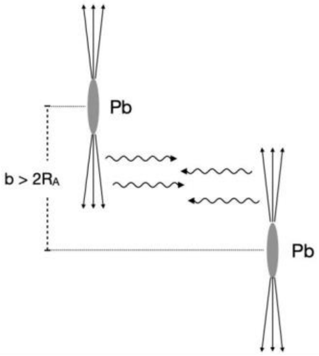

Figure 1. Depiction of propagation of photons radiated by colliding heavy ions, such as lead, in ultraperipheral collisions.

Listed in Table 1 are several collision systems considered at the LHC design beam energy of 7 TeV, where the ions are fully stripped with no remaining electrons. Only the protons in the ions are accelerated, hence, the effective collision energy, denoted as the nucleon-nucleon center-of mass energy $\sqrt{s_{NN}}$ is proportional to the charge-to-mass ratio $Z/A$. Consequently, $\sqrt{s_{NN}}$ is higher for collisions of light ions such as oxygen and maximized in proton-proton collisions. As far as ultraperipheral collisions are concerned, the maximum photon-photon center-of-mass energy $\sqrt{s_{\gamma\gamma}^{max}}$ sets the monopole energy scale. As the photon interaction takes place at a distance on the order of the nuclear radius $R_A$, the photon wavelength cannot be smaller than $R_A$. The uncertainty principle then implies that the maximal photon momentum scales as $\hbar/R_A$. The $1/R_A$ dependence of the photon momentum suppresses $\sqrt{s_{\gamma\gamma}^{max}}$ to be on the order of 200 GeV in xenon-xenon and lead-lead collisions. The LHC program foresees the addition of oxygen-oxygen collisions, which result in higher $\sqrt{s_{\gamma\gamma}^{max}}$.

| | $\sqrt{s_{\mathrm{NN}}}$ [TeV] | $R_A$ [fm] | $Z/A$ | $\sqrt{s_{\gamma\gamma}^{\mathrm{max}}}$ [GeV] |
|---|---|---|---|---|
| p | 14 | 0.8 [4] | 1.0 | $3.6 \times 10^3$ |
| $^{16}_{8}\mathrm{O}$ | 7.0 | 3.0 | 0.50 | 490 |
| $^{129}_{54}\mathrm{Xe}$ | 5.9 | 6.1 | 0.42 | 204 |
| $^{208}_{82}\mathrm{Pb}$ | 5.5 | 7.1 | 0.39 | 164 |

Table 1. Parameters in different ultraperipheral collision systems: nucleon-nucleon center-of-mass energy $\sqrt{s_{NN}}$, nuclear radius $R_A$, charge-to-mass ratio $Z/A$, and maximum photon-photon center-of-mass energy $\sqrt{s_{\gamma\gamma}^{max}}$.

## IMPLEMENTATION AND RESULTS

The monopole production model is built within a Monte Carlo event generator called MadGraph5_aMC@NLO [5]. The photon-fusion model was validated by comparing the monopole production rate predicted by the Monte Carlo generator to a theoretical calculation for a fixed photon momentum. However, the photons in heavy-ion collisions have a nontrivial momentum distribution. We follow the Weizsäcker-Williams approach to implement this distribution, so we can compute the true production rate as a weighted sum of probabilities at different photon momenta.

At the LHC design collision energy, the photons are kinematically bounded by a maximum of 82 GeV in $\sqrt{s_{NN}}$ = 5.5 TeV lead-lead ultraperipheral collisions. Therefore, we examine the production of spin-1/2 $1g_D$ monopoles with masses up to 80 GeV with our model. Although proton-proton collisions are capable of producing monopoles with masses up to 4000 GeV, the lead-lead ultraperipheral production dominates the proton-proton production for the mass range considered in Figure 2. The monopole transverse momentum distribution is shown in Figure 3, indicating a dedicated search is not practical in ATLAS or other general-purpose LHC detectors that are designed to measure particles with high transverse momenta. For example, a few hundred GeV of transverse momentum is required to measure magnetic monopoles in the ATLAS detector.

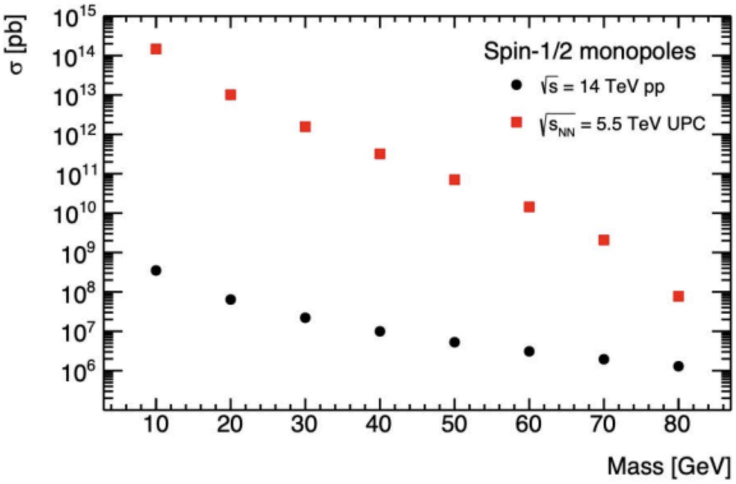

Figure 2. Cross sections for spin-1/2 $1g_D$ monopoles via proton-proton (pp) collisions and via lead-lead ultraperipheral collisions (UPC).

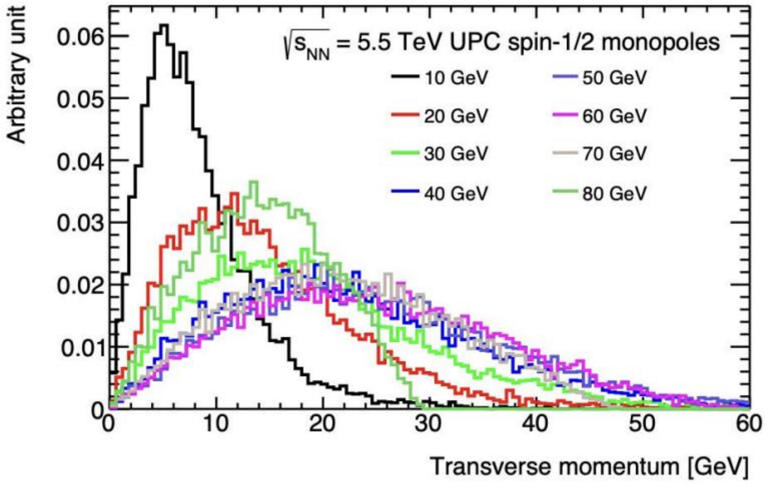

Figure 3. Transverse momentum of spin-1/2 $1g_D$ monopoles in lead-lead ultraperipheral collisions (UPC).

## CONCLUSION

In conclusion, we have studied monopole production in $\sqrt{s_{NN}}$ = 5.5 TeV heavy-ion ultraperipheral collisions and compared it to the proton-proton production system at the equivalent collision energy. The monopole kinematics are significantly constrained in the ultraperipheral collisions, hence, their production in both collision types is examined in a mass range that is accessible in ultraperipheral collisions, where their production is greatly enhanced due to the large nuclear charge. However, the low transverse momenta of these monopoles make it very challenging to measure them in general-purpose LHC detectors.

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# MOVING TOWARD FASTER MEASUREMENTS OF MICRON-SIZED AXON DIAMETERS *IN VIVO*

**SUMMARY**: Methods to determine micron-sized axon radii using oscillating gradients were too time consuming for clinical use. With fewer gradient frequencies, imaging is 4.16 times faster.

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## INTRODUCTION

Autopsy studies indicate that the distribution of axons in brains with schizophrenia could differ from brains without schizophrenia [1]. Magnetic resonance imaging (MRI) has inferred axon diameters and distribution in the brain [2], typically for axons larger than 5 µm in diameter [3]. The goal of this work is to modify these methods to adapt oscillating gradients (OG) to target small axons (1 to 2 µm range) which constitute the majority of cortical connections and shorten the data acquisition time so that the method can be used to measure axon diameters *in vivo*.

Conventional MR inferences of axon diameters use the pulsed gradient spin echo (PGSE) sequence [4,5]. The time over which water diffusion can be studied, or diffusion time, using PGSE cannot be reduced enough to study diffusion over a micron scale because of the presence of the π pulse, and the need for large gradient strengths to measure a sizable effect. Thus, PGSE can be used to study larger axon diameters, but another pulse sequence is needed for smaller axons.

The oscillating gradient spin echo (OGSE) pulse sequences use high frequency sinusoidal gradient pulses in order to target smaller diffusion distances [6]. The signal from diffusion experiments measured using different gradient frequencies and strengths can be fitted to different models which describe the geometry of the sample to find the distance between barriers causing restrictions to the diffusion. Previous measurements required long imaging times which make them unsuitable for clinical and preclinical imaging. The goal of this work was to reduce imaging times so that the methods could be more suitable for clinical and preclinical imaging and to determine more optimal frequency ranges for a more flexible measurement routine depending on the sizes of axons in the sample.

## METHODS

Data from previous studies using phantoms, vegetables and brain tissue and those from Monte Carlo simulations were used in this study [7-10]. A portion of human corpus callosum tissue was collected from an autopsy specimen, under the protocol approved by the institutional health REB along with the consent obtained from the family members. OGSEs are used to probe diffusion in smaller time regimes (higher frequency) to target smaller axons. Diffusion of water within the brain can be categorized into three regimes: restricted (intra-axonal), hindered (extra-axonal) and free (cerebrospinal fluid) [11]. Free water diffusion signal is usually from ventricles and can possibly be from intracellular and extracellular space with very high frequency gradients and makes insignificant contributions. The main contribution to the MR signal changes measured in our experiments comes from restricted water. Axons are modelled as long cylinders and fibers are modelled as groups of parallel cylinders, possibly of varying diameters.  The signals are then fitted to a model called AxCaliber [12],

$$S = f_{axon} S_r(N_{OG}, G) + (1 - f_{axon}) S_h(N_{OG}, G) \tag{1}$$

where $S$ is the MRI signal, $f_{axon}$ is the volume fraction of axons within the voxel, $S_r$ and $S_h$ are the signals from the water within the restricted and hindered compartments respectively. The AxCaliber model, with data collected using OGSE sequences, requires images collected using $N_{OG}$ different OGSE gradient frequencies and at least two gradient strengths $G$. Previous experiments used as many as $N_{OG}$ = 20 gradient frequencies and as many 6 gradients strengths per gradient frequency [7,8]. Using OGSE and AxCaliber smaller radii have been measured in phantoms, such as celery [7], and human corpus callosum [8]. MR data [7,8] was collected from a 7 T Bruker Avance III NMR system with Paravision 5.0 and BGA6 gradient set with a maximum gradient strength of 1.01 T/m. For experimental and simulated data, the OGSE pulse sequences had two 20 ms sinusoidal gradient pulses separated by 24.52 ms with a maximum range of frequencies from 50 to 1000 Hz along with 5 or 6 gradient strengths depending on the experiment. The geometrical model reflects the average axon widths and axon packing fraction.

With the higher gradient frequencies, the diffusion of water in the extra-axonal space became less hindered and freer, so we studied the effect of abandoning the hindered part of the AxCaliber model when fitting the data due to its negligible contribution in short-time diffusion regime. Rather than 20 different oscillation frequencies, data collected from fewer frequencies were studied to determine if fewer frequencies could be used to reduce imaging time without compromising the precision of the results. With a narrower range of frequencies being recommended for use, the next step was to determine which frequency would be optimal for the center of the range. Theoretically, the expected displacement of water diffusing in a certain effective diffusion time, $\Delta_{eff}$ , can be calculated using Einstein's relation [13]

$$\langle x^2 \rangle = 2N_d D \Delta_{eff(cos)}, \left( \Delta_{eff(cos)} = \frac{T}{4N_{OG}} \right) \tag{2}$$

where $\langle x^2 \rangle$ is the expectation value for displacement squared, $N_d$ is the dimensional freedom of movement, *D* is the diffusion coefficient, *T* is the gradient pulse duration, and $\Delta_{eff(cos)}$ is the effective diffusion time for cosine wave oscillation gradient [14]. We expected that the optimal range of effective diffusion time, or gradient frequency would be sufficient to characterize the expected displacement of water diffusing approximately the distance of an axon radius. This assumption was tested with our data.

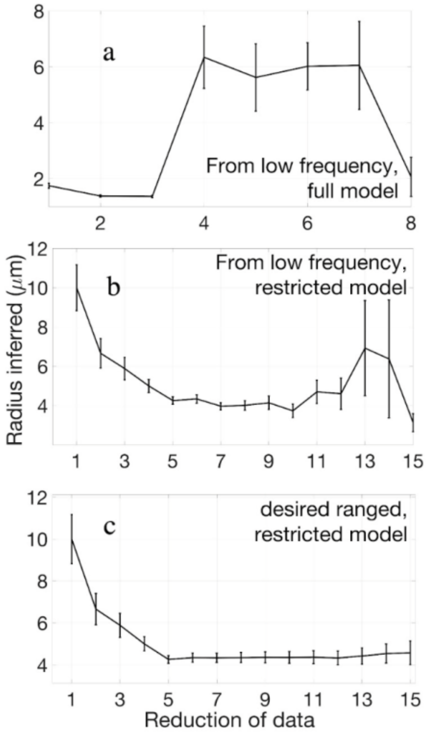

Figure 1. Inferred Radius vs trial number, which is one more than the number of excluded oscillating gradient frequencies from Monte Carlo simulation data. The geometry was hexagonally packed parallel cylinders with radii of 4.5µm and 60% packing fraction, this Figure serves as an example of how different models respond to less data.

a. The full model is used to fit to infer the radius. While data are dropping from $N_{OG}$ = 1 in step of +1. In the first iteration, no data have been dropped. The inferred radius and the error bar both show an inconsistent trend.
b. Restricted compartment purely from the AxCaliber model was used in the fit to infer the radius. Data are dropped similar to A. Visually it can be seen that for these data, a reduction of 5-1 = 4 frequencies resulted in smaller error bars or lower limit of $N_{OG}$ = 5.
c. Continuing with B, starting from $N_{OG}$ = 5, Data are dropping from $N_{OG}$ in step of -1 the inferred parameter(radius) loses its consistency and error bar width at n = 12. Visually it can be seen that for these data, a reduction of (12-1) - 5 = 6 frequencies additionally resulted in consistent error bars and inferred parameter or upper limit is found as $N_{OG}$ = 15.

Overall, it can be seen that the model that excludes the hindered water diffusion contribution appears to provide more consistent and accurate results than the full model with a smaller data set and that approximately 12 frequencies can provide optimal inferences of axon sizes.

## RESULTS

Plotted in Figure 1 is an example comparing different inference models using Monte Carlo simulation data, similar to those published previously, from 4.5 µm hexagonally packed cylinders or axons with an axonal packing density of 60% [15]. All data were initially fitted assuming uniform-sized axons with either the full(a) or only restricted(b,c) AxCaliber model in the first trial. The data set was reduced by removing images from one frequency at a time as described below and the inferred radius was recorded at the end of each trial. The inferences from the fit to the full model always under- or over-estimate the axon size, whereas the inferences from the restricted model converge close to the correct size. The restricted model inferences have the lowest uncertainty when the 4 lowest frequencies were removed from the data, suggesting that using the 16 highest frequencies resulted in the optimal inference of axon radius. Continuing with the reduced data set, that is the one using the 16 highest frequencies, the upper frequency limit was determined to be at the point (i.e., 12th trial, upper limit is found to be $N_{OG} = 15$.) where the uncertainties lose their consistency as shown in Figure 1c. For all the data, it was found that on average, 12 frequencies optimized the uncertainties in the inferences of axon radius. A moderate correlation (R = 0.6487) was found between the expected diffusion displacement based on Equation (2) and the inferred radius based on the reduced data sets as shown in Figure 2. *A priori* knowledge of the expected range of axons desired to be targeted in the tissue, and the expected intra-axonal apparent diffusion coefficient of the water in the sample under the conditions being imaged could be used to calculate the optimal middle frequency choice for the range of diffusion frequencies used in the experiments according to the fit equation shown in Figure 2.

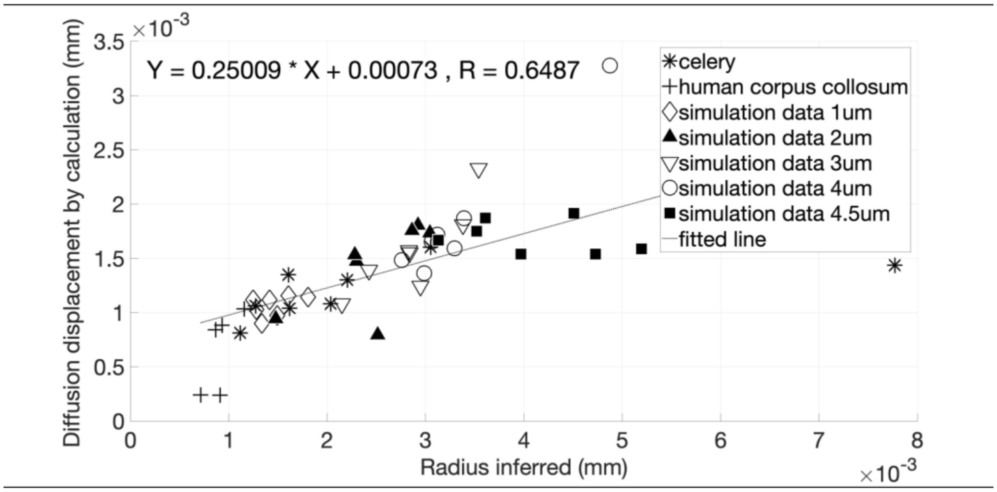

Figure 2. Diffusion displacement calculated using Equation (2) vs inferred radius plotted for all data available during the pandemic. The correlation coefficient is found to be R = 0.6487 (moderate correlation). The least squared fitted line on the plot is $y = 0.25009x + 0.00073$. Knowing the expected size of the axon, *x*, we can calculate the optimal diffusion displacement, *y*, based on this fitted equation. Using the intra-axonal apparent diffusion coefficient and Equation (2) we can then calculated the optimal effective diffusion time $\Delta_{eff}$ and thus optimal central frequency for OGSE measurements.

## DISCUSSION

Using only 12 gradient frequencies rather than 20 gradient frequencies reduced imaging time by a factor of 1.6 without a significant effect on the inferred radius, based on the plots in Figure 1. The hindered part of the model was abandoned because it appeared that water within the extracellular space produced a relatively weak signal for the selected range of oscillation frequencies. Thus, the hindered extracellular water diffusion portion of the model could be neglected in an analogous way to free water diffusion signal being excluded from the full AxCaliber model. In addition to the reduction of the number of gradient frequencies, it has been proposed to reduce the number of gradient strengths used per frequency to two [9] which would cause the imaging time to be 4.16 times faster than using the full AxCaliber model with all gradient frequencies and amplitudes that were used before. Our results found an intermediate correlation between the inferred axon radius and the expected axon radius, based on Equation 2, and suggest that the hindered portion of the AxCaliber model can be dropped for this range of frequencies for OGSE. Our dataset is heavily biased by simulation data thus more brain tissue data are needed to confirm that the central frequency is optimal and the hindered portion can be dropped. Rather than not studying the extra-axonal water diffusion, the discovery of an equation that can fully describe different diffusion regimes in a wide variety of diffusion times or frequency could possibly lead to more accurate inferences. Other modifications to the model can be made, for instance, including a variety of axon radius rather than one, and tested to determine if they help improve the accuracy. Each modification has to be evaluated for the improvement in accuracy versus the increase in imaging time as well as for the bias the modifications could bring to the results. For instance, including a spectrum of radii for fitting could reduce the uncertainty in the inferences but it could also bias the result depending on the chosen spectrum.

## CONCLUSION

In conclusion, reducing the number of gradient frequencies and gradient strengths used to collect images with the OGSE sequence and analyzed with AxCaliber appears to be possible, in theory. It will reduce the imaging time by a factor of 4.16 without a significant change in the precision of the inferred axon radii and consideration of any noise contaminations. The method proposed here requires *a priori* knowledge of the desired cell sizes. Imaging data needs to be collected post-Covid-19-pandemic along with electron microscopy to verify theoretical predictions. More work is needed to obtain a better model of the packing fraction. This work is the first step to reducing the imaging time so that an OGSE sequence can be used with the AxCaliber model to infer 1-2 µm axon sizes in live mouse brains.

## ACKNOWLEDGEMENTS

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# MICROWAVE RESONATORS FOR GLOBAL CONTROL OF ELECTRON SPIN QUBITS

**SUMMARY**: We show preliminary results for a microwave resonator for global control of single-qubit operations on semiconductor spin qubits.

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## INTRODUCTION

Electron spins in semiconductor quantum dots are excellent candidates for qubits for a scalable quantum computer due to their addressability and electrical control. Silicon, in particular, is a promising host material due to the possibility of isotopic purification, leading to decreased nuclear magnetic noise, and integration with classical control by leveraging conventional CMOS electronics. In order to implement single-qubit rotations on such a quantum processor, electron spins must experience a resonant, oscillating magnetic field. The two conventional methods used for creating this oscillating magnetic field are micro-striplines, which produce an oscillating magnetic field directly on-chip [1], and micromagnets, where the magnetic field gradient produced by the micromagnet and an oscillating gate voltage lead to an oscillating magnetic field in the reference frame of the electron [2]. Both methods require on-chip components that are bulky (> 1 µm) compared to the footprint of an individual quantum dot (<100 nm), reducing the possibility for the dense packing of qubits. Furthermore, the oscillating field produced by both methods is local, limiting single-qubit rotations to only a few quantum dots per micro-stripline or micromagnet.

For long-term scalability, there is a clear need for generating a global oscillating field for spin-qubit operations. A macroscopic microwave resonator is an obvious solution, however, there is a key challenge: the electric field component generated by such a resonator can excite the electron to higher orbital states or even out of the dot, which is detrimental to the spin qubit.

Here, we show preliminary results for a 'bowtie' microwave resonator (see Figure 1) that produces a strong magnetic field in a central region while also minimizing the electric field in this region. The resonator will be placed above the quantum device layer, allowing for dense packing of qubits. Individual qubits can be tuned into and out of resonance with this global field electrically by the Stark effect: the electronic g-factor, which controls the spin's resonance frequency, has been shown to vary with an applied electric field [1].

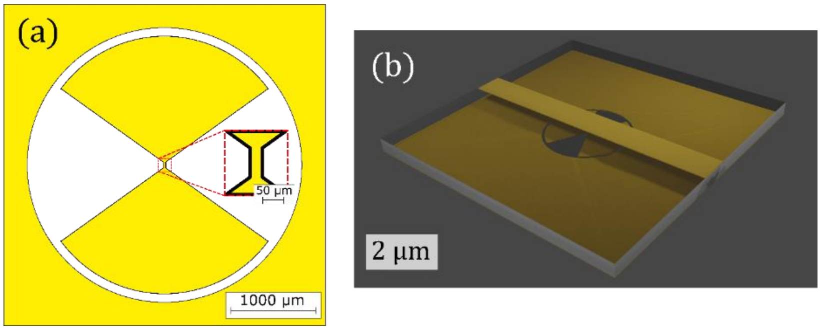

Figure 1. (a) Top-view schematic of the 'bowtie' resonator. Inset: Enlarged view of the device region. (b) 3D rendering of the resonator, showing the stripline used to couple an input microwave signal.

## RESULTS

Simulations of the magnetic and electric field profile of the resonator are shown in Figures 2 (a) and (b), respectively. In an area roughly 40 x 60 µm near the center of the resonator, the magnetic field intensity is within 75% of the peak value of 1.75 mT, which could allow for manipulation of over $2\times10^5$ qubits, assuming a 100 nm device pitch. The electric field is expelled towards the edges of the resonator, away from the central region where the magnetic field is strongest. We also simulated the resonator response as a function of frequency, shown as the blue trace in Figure 3, which indicated that the resonance frequency is near 16 GHz with a quality factor Q≈10. The theoretical Rabi frequency

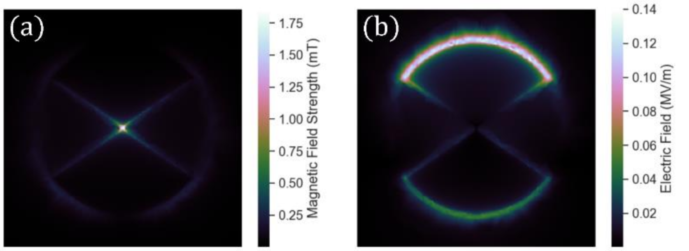

Figure 2. Simulated (a) magnetic field and (b) electric field distribution generated 10 µm below the resonator plane, with a 1 W input power to the stripline.

(how fast the spins can be rotated) is roughly 775 kHz/(mW)$^{½}$. All simulations were performed using Ansys® HFSS, revision 2020 R2.

## EXPERIMENTS

We fabricated a copper resonator with the same dimensions as the schematic in Figure 1 (a) and measured the transmission response of the nearby stripline as a function of frequency, shown as the orange trace in Figure 3, showing a coupling qualitatively similar to the simulated response with a similar quality factor of Q~10, albeit with a shifted resonance frequency. A possible explanation for this difference in frequency is due to using a plane-wave excitation model in the simulations, which is known to cause overestimation of the resonant frequency in comparison to experiment [3], however, further investigation is required.

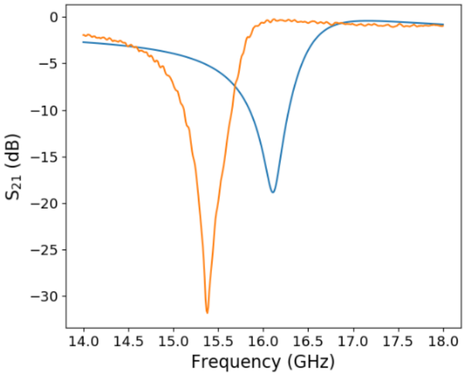

Figure 3. Simulated (blue) and measured (orange) transmission through a coupling stripline, showing strong resonance near 16 GHz.

## CONCLUSION AND FUTURE WORK

The results presented here are promising, but preliminary, and much work remains before we can demonstrate spin qubit control with these resonators. The experiment presented above was performed using a copper resonator at room temperature, but we intend to use a niobium resonator at cryogenic temperatures. Niobium is a type-II superconductor with a critical temperature above 9 K, well above the typical temperatures for experiments on gate-defined quantum dots. Superconducting resonators tend to have higher Q-factors than those with finite conductivity, which would improve the Rabi frequency achievable with the global field. We have already fabricated niobium resonators, and measurements of the magnetic and electric field distribution of these resonators is currently underway.

In parallel, we have been developing single-electron transistors (SETs), both to be integrated as charge sensors for quantum dots, and also as a testbed for the resonators. We can gauge the strength of the electric field produced by the resonator by observing the onset of photon-assisted tunneling through a

SET, as a function of microwave input power.

Finally, we have also been working on strategies to shield the quantum device layer from the remaining stray electric field, to minimize the voltage fluctuations on the metal gates used to define the quantum dots. The ultimate goal of our efforts in this direction is the demonstration of a scalable node-network architecture for spin qubits [4]. With the results presented herein, we are confident that these resonators are promising candidates for global spin control in quantum processors based on lateral semiconductor quantum dots.

## ACKNOWLEDGEMENTS

This research was undertaken thanks in part to funding from the Canada First Research Excellence Fund (Transformative Quantum Technologies), NSERC and the Waterloo-Technion Partnership. S.R.H. acknowledges support from a Waterloo Institute for Nanotechnology (WIN) Nanofellowship and the Ontario government.

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# PHYSICS GRADUATE STUDENT EMPLOYMENT: WHAT WE CAN LEARN FROM PROFESSIONAL SOCIAL MEDIA

**SUMMARY**: Shared data from an online professional network reveals employment trends for recent University of Ottawa MSc and PhD physics graduates.

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## INTRODUCTION

In science, and especially in the physics community, motivation for pursuing post-secondary education can be quite diverse. Whether our inspiration to study physics came from curiosity about the universe around us, a love of applied math, or a desire to pursue a specific career, we are all eager to see how far our education will actually take us when we enter the job market. Will we find work in a physics-related discipline or use our newly acquired skills to contribute to a different sector? The last decade has seen major changes in our daily lives and the job industry, and many students who are about to start their post-secondary education, or to enroll into a graduate program, may wonder how well recent physics graduates have performed in this evolving job market. More specifically, what are recent physics Master's (MSc) and Doctoral (PhD) graduates doing now? Also, considering the increasing influence of social media in our lives, can we assess how the size of a virtual network may have an impact on employment?

In this study, we have addressed these questions by looking at the professional path of recent physics graduate students at the University of Ottawa (uOttawa), our home university. Our database was populated from the public online repository of MSc and PhD theses submitted between the academic years of 2011 to 2019, with employment information subsequently collected from the professional social media platform LinkedIn. Due to the popularity of social media among recent graduates, we could collect detailed professional information from 80% of the 113 graduates considered in this study. In comparison, previous studies on this subject mostly relied on cold calling for data collection and reported a response rate around 50%[1]. We discuss our data collection procedure and analysis in the Methodology section following this article.

## RESULTS AND DISCUSSION

Before analyzing employment details, we first looked at the graduates' academic histories. Our goal was to determine the percentage of MSc students that chose to continue to the PhD level, and among them, how many decided to move to a different university. Figure 1a shows that more than a half of MSc students decided to pursue a PhD. Slightly fewer than half of these students (23%) moved to a different university after completing their MSc degree. This level of student mobility after the MSc is comparable to the one observed in US universities [2]. The fact that many students stay at the same university after their MSc is reflected in our data by the relatively large ratio (41%) of PhD graduates at uOttawa who also completed a MSc degree at uOttawa (Fig. 1b). Note that 37% of the PhD students did not provide MSc information, indicating that many of them may have fast-tracked to their PhD (1-year MSc without a thesis before entering their PhD program) or made a direct entry after their undergraduate degree. Finally, the average time for completing a MSc degree was 2.4 years and 5.0 years for a PhD degree. These results included all graduates, both full-time and part-time students, as well as those who took time off for reasons such as parental leave. We found that 60% of uOttawa MSc students and 70% of the PhD candidates graduate within 2 and 5 years, respectively, which are standard time frames for Canadian universities.

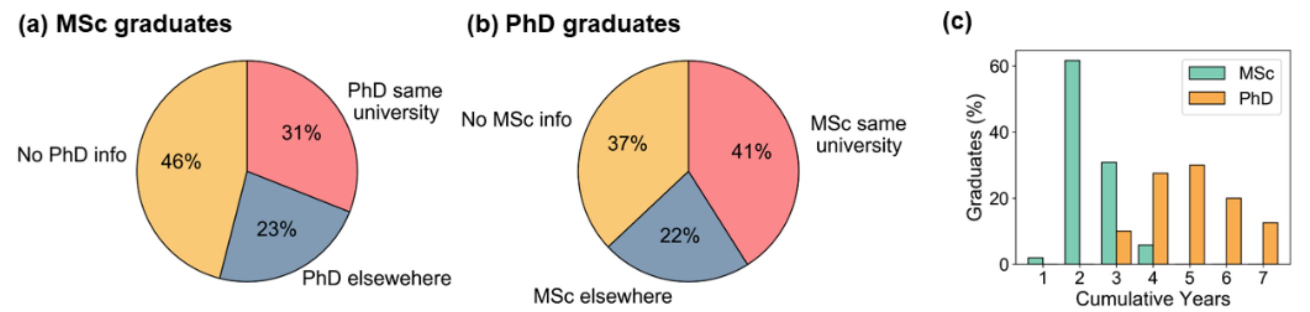

Figure 1. Graduate school history showing (a) the ratio of MSc graduates from uOttawa pursuing a PhD degree at the same university, or elsewhere, and (b) the ratio of PhD graduates at uOttawa who previously obtained a MSc degree from uOttawa (same university), or elsewhere. (c) Length of MSc and PhD degrees at uOttawa indicated by the number of students who graduated within a certain time period.

Detailed career information on 89 graduates was obtained from public information on LinkedIn. We focused on the job status within one year following graduation because it provides a strong indication of the degree of employability immediately after receiving the diploma. Note that we are unable to account for graduates who willingly decided to take time off, possibly for traveling, parental leave or other personal reasons. As illustrated in Fig. 2a, most MSc graduates continued to the PhD level, 30% of the MSc graduates were employed and only 3% had no job listed after one year of graduation. A lack of employment information does not necessarily indicate unemployment. Here, we simply refer to graduates falling into this category as having 'no job listed'. This designation also includes anyone pursuing further professional specializations, such as medical school. Figure 2b shows that 49% of the PhD graduates found a post-doctoral research position within a year, 42% occupied another job, while 9% had no job listed after one year of graduation. This information is promising for current physics graduates as it shows that 94% of physics graduates are employed or continuing their post-graduate education after one year of receiving a graduate degree. Of the remaining 6%, approximately a third are actively pursuing a subsequent professional degree, such as medical or law school. This ratio is consistent with a recent study on PhD graduates from the United States [1].

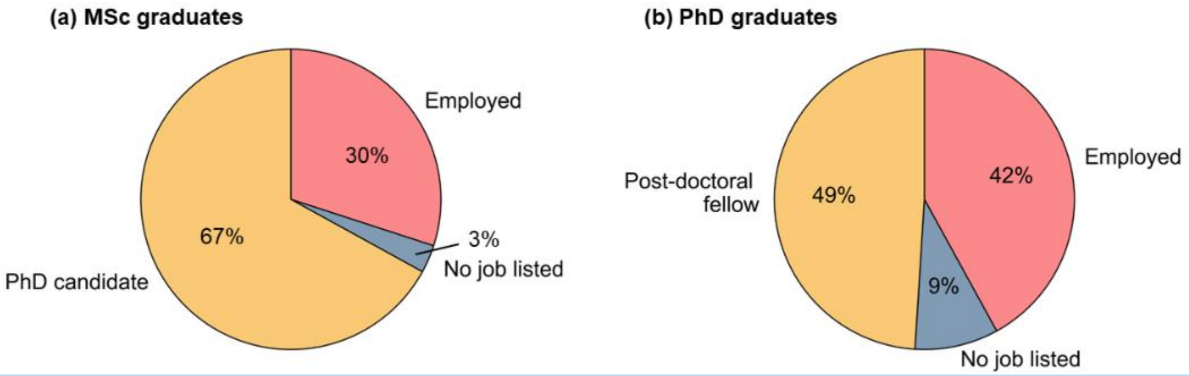

Figure 2. LinkedIn employment status one year following graduation for a) MSc graduates and b) PhD graduates.

One could argue that graduates are more likely to share their success stories on social media, which would imply that our ratio of graduates with “no job listed” is slightly underestimated. However, it is also possible that those without a job are more likely to use social media to establish a network and to find a job, which would indicate that our ratio of graduates with “no job listed” might be, on the contrary, overestimated.

The 2019 employment status of recent MSc and PhD physics graduates was also obtained and categorized into career sectors. We chose six job categories corresponding to academia, industry, and government research, which are traditional science-related fields, as well as information technologies (IT), teaching and ‘other’. The ‘teaching’ category encompasses all those in teaching professions outside of university institutes, such as in high schools or colleges, with university positions considered in the ‘academia’ category. Of those in the academia category, approximately half are in post-doctoral fellowships, while the remainder are employed in research positions at an academic institution. Our results are presented in Fig. 3. Unsurprisingly, academic and industry careers account for most physics-graduate jobs, with ~53% of recent graduates having employment in these two areas. Notably, 40% of graduates end up in an academic or teaching environment, in agreement with a recent report [3]. The third largest career sector is ‘other’; 20% of physics graduates fall into this diversified category that includes jobs in patent agencies, health and medicine, consulting, and business management. Similar to other studies conducted on physics graduates [4], our results show that uOttawa physics graduates are able to diversify their experience and transfer their skills to broader job markets.

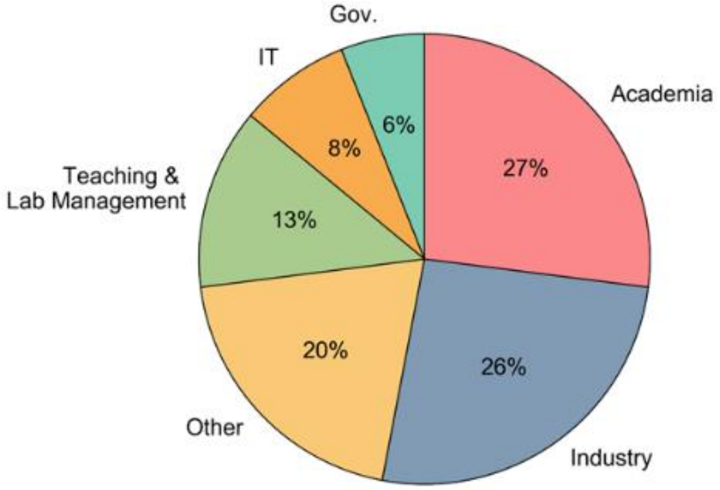

Figure 3. Employment sectors for physics graduates.

In addition to the current employment of recent graduates, we investigated the general online networking strategies adopted by physics graduates to conquer the job market. LinkedIn provides a quantitative measure of this activity through the number of connections. A single LinkedIn 'connection' corresponds to an online contact that has been made between the graduate and another person for the purpose of sharing employment opportunities and skill sets. We analysed these numbers for uOttawa graduates and looked for correlations between connectivity and career choices. Figure 4 shows the number of LinkedIn connections of uOttawa graduates while also indicating their 2019 employment information. Most graduates have fewer than 100 connections, and only 4% of graduates have more than 400 connections.

Though not a perfect predictor, the number of LinkedIn connections can be an indicator of how often one uses the site, either passively (consuming content) or actively (producing/sharing content). It has been shown that use-frequency is a good predictor of how much one will benefit from LinkedIn, with the greatest benefit occurring when all users in a network know the interests and capabilities of one another [5].

Employment information shows that graduates working in academia (red) tend to have fewer online connections in comparison to those in industry (blue) and the 'other' category (yellow). This suggests that, at the time of our study, in-person interactions and networking were potentially more important to finding jobs in academia. In industry, we may assume that a large professional network is more useful to finding a job, or more valued by employers. For graduates with a career in the 'other'

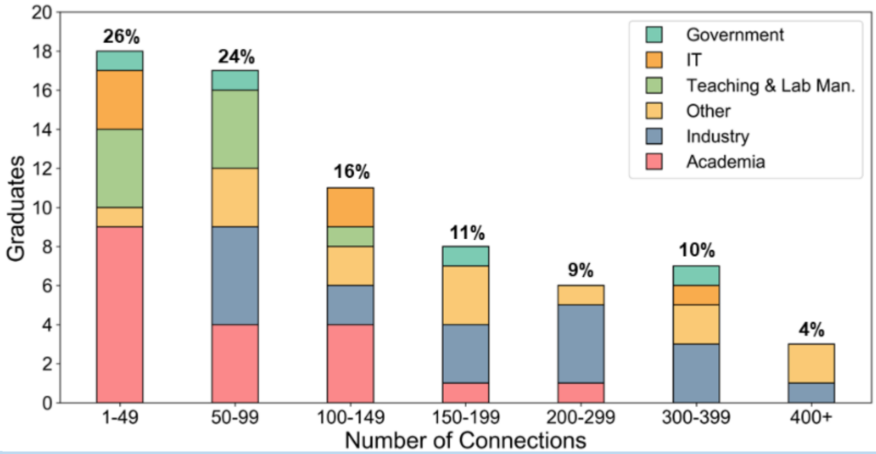

Figure 4. Correlation between LinkedIn connections and current employment career sector.

category, connection numbers reach the highest, potentially indicating a need to diversify their networks beyond science and engineering. As results in Fig. 4 show that workers in 'industry' and 'other' categories have the largest number of connections on LinkedIn, these people may be more likely to have a professional social media profile. Therefore, our findings could be slightly more weighted towards graduates who are employed in these career sectors.

# CONCLUSION

In this study, we investigated the employment status of recent uOttawa physics MSc and PhD graduates, finding that 94% of graduates from 2011-2019 are either employed or pursuing further physics education one year post-graduation. Our results, in agreement with previous studies on physics graduates, highlight that graduates primarily find employment quickly and in their field of study, with most graduates employed in either academia or physics-related industries. We also found that a significant portion of employed graduates, 20%, find employment in non-traditional physics careers, such as business management and healthcare. This may be because, as previous studies have found, physics graduates are well prepared to pursue many careers and are sought for their flexibility, problem solving skills, and exposure to a range of technologies [6-8]. In addition, we explored the role of social media in employment, and argued that online networking via social media platforms is a potential method of creating valuable professional connections. Graduates with careers in academia tend to have lower online connectivity compared to graduates with careers in industry or non-traditional fields, suggesting a greater importance for online networking for students interested in non-academic careers.

We would like to conclude this article on a personal note. The authors of this article are, for the most part, graduate students who grew up being inspired by popular science and the mainstream interpretation of what physicists study: astrophysics, cosmology, string theory, etc. After years of study, many physicists find that their passions lie in less popularized fields. We are researchers studying condensed matter physics, photonics, nuclear physics, and biophysics, and we truly love what we do. Though it is not always obvious to those commencing on their academic journey what careers are available to them when they finish, our study has revealed that there are numerous opportunities in both traditional and non-traditional physics paths. While our initial goal was to inform current and future uOttawa graduates about recent graduate employment, we think these results are of interest to the entire physics community. We suggest that this exercise is routinely performed in every department and university to maintain a record of graduate employment and provide relevant and up-to-date information on career prospects for future students.

## METHODOLOGY

We primarily collected data for this study from LinkedIn, a professional online networking platform that fosters connections between people for the purpose of sharing employment opportunities, as well as individuals' employment statuses and skills. When two people 'connect' on LinkedIn, they can view each other's resumes and skill sets, and pass along employment opportunities. Note that information on LinkedIn is likely to accurately reflect the curriculum vitae presented to potential employers, therefore we believe that our results are highly reliable and arguably more trustworthy than those that can be obtained from online surveys or phone surveys. Data was supplemented with information from ResearchGate, a similar platform for research-oriented networking. We limit our assessment of available career information to employment status and career-sector categorization, rather than attempt to assess more subjective career information like job quality. Out of the 136 uOttawa physics theses submitted by 113 individuals between January 2011 and February 2019, 78 were MSc and 59 were PhD theses.

We were able to obtain LinkedIn education information on 103 graduates and employment information on 89 graduates. Note that all percentiles presented in this article have been rounded to whole numbers. Finally, the total number of graduates considered in this study contains 27% women and 73% men as estimated from Gendre-API.com, an internet platform that predicts gender from the full name. This method cannot account for non-binary students, transgender students enrolled under their birth name or students with names that can apply to both men and women. As such, it provides only an incomplete overview on the gender ratio. A study relying on self-identification would be necessary to obtain more reliable data.

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# 2021 CAP MEDAL RECIPIENTS / *LAURÉATS DES MÉDAILLES DE L'ACP DE 2021*

The CAP is very pleased to recognize its 2021 medal recipients. Please visit the website below for the list of medal recipients with a link to the detailed citations and any remarks submitted by the recipient following the receipt of the award.

https://www.cap.ca/programs/medals-and-awards/

*L'ACP est très heureuse de reconnaître ses récipiendaires de médailles 2021. Veuillez consulter le site web ci-dessous pour obtenir la liste des récipiendaires de médailles, ainsi qu'un lien vers les citations détaillées et les remarques à la suite de la réception de la récompense.*

*https://www.cap.ca/fr/activites/medailles-bourses*

### CAP-COMP Peter Kirkby Memorial Medal for Outstanding Service to Canadian Physics / *La Médaille commémorative Peter Kirkby de l'ACP-OCPM pour services exceptionnels à la physique au Canada*

**HENRY VAN DRIEL**, University of Toronto

to recognize his outstanding service to the Canadian physics community over a period of more than forty-five years, which has included international efforts, great service to the CAP, work with NSERC on behalf of Canadian physics, and editorial service to distinguished journals in North America.

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

**ROBERT RAUSSENDORF**, University of British Columbia

to recognize his eminent contributions to the theory of quantum computing, including groundbreaking work on measurement-based or "one way" quantum computing, fault-tolerant quantum computing, and computationally universal quantum phases of matter.

## CAP-TRIUMF Vogt Medal for Contributions to Subatomic Physics /*Médaille Vogt de l'ACP-TRIUMF pour contributions en physique subatomique*

**SANGYONG JEON**, McGill University

to recognize his contributions to the theory of relativistic heavy-ion collisions and of the resulting quark-gluon plasma.

## CAP-DCMMP Brockhouse Medal / *Médaille de l'ACP-DPMCM Brockhouse*

**ROGER MELKO,** University of Waterloo / Perimeter Institute

to recognize his work on the theoretical understanding of many-body quantum systems through large-scale computer simulations. The theoretical tools developed by Dr. Melko's group provide a new perspective on understanding of quantum condensed matter and have proven highly influential in areas such as quantum information, field theory, cold atomic matter, and artificial intelligence.

## CAP Medal for Excellence in Teaching Undergraduate Physics / *Médaille de l'ACP pour l'excellence en enseignement de la physique au premier cycle*

**RICHARD JAMES EPP,** University of Waterloo

to recognize his accomplishments in teaching and commitment to physics outreach. He consistently receives high teaching evaluations from majors and non-majors alike, and students commended his "Thinking Like a Physicist" series that replaced informal interactions during the pandemic lockdown.

## CAP Medal for Outstanding Achievement in Industrial and Applied Physics / La Médaille de l'ACP pour des réalisations exceptionnelles en physique industrielle et appliquée

**VINCENT TABARD-COSSA,** University of Ottawa

to recognize his innovative contribution to Physics by developing a new nanopore fabrication technique. Nanopores can electrically detect individual molecules like DNA and proteins and are finding applications in next generation diagnostics, sequencing, and data storage devices. Dr. Tabard-Cossa's ground-breaking controlled breakdown method of nanopore fabrication simplifies and replaces a previously cumbersome and expensive process, enabling scalable, low-cost fabrication of solid-state nanopores at sub-nanometer scale.

## CAP Herzberg Medal / *Médaille de l'ACP Herzberg*

**SIMON CARON-HUOT**, McGill University

to recognize his creation and development of nonperturbative techniques in conformal field theory, thereby opening the way to broad-ranging applications from particle physics to condensed matter physics

## CAP Medal for Lifetime Achievement in Physics /*Médaille de l'ACP pour contributions exceptionnelles à la physique*

**ROBERT BRANDENBERGER**, McGill University

to recognize his coupling of ground-breaking developments in theoretical cosmology with recent dramatic advances in observational astronomy of the early universe.

# 2021 HIGH SCHOOL–CÉGEP PHYSICS TEACHING AWARDS / PRIX DE L'ACP EN ENSEIGNEMENT DE LA PHYSIQUE AU SECONDAIRE ET AU COLLÉGIAL

## British Columbia and Yukon / *Colombie-Britannique et Yukon*

**KELVIN DUECK**, Pitt Meadows Secondary School

Awarded for his passion and dedication to teaching physics and making physics accessible to all through his physics YouTube videos.

Mr. Kelvin Dueck is a science and mathematics teacher who has taught at Pitt Meadows Secondary School for the past 24 years. He is passionate about empowering his students to learn on their own time and has been uploading his materials online (at www.pittmath.com) and his lessons online (on YouTube at https://www.youtube.com/user/pmssmathteacher) for the past decade.

His YouTube channel has nearly 3000 subscribers and over 680,000 views. He strives to create a classroom where students feel comfortable taking risks, making spectacular mistakes, and learning from those mistakes. Kelvin has also shared his resources electronically with other teachers in BC and around the world. His innovative and enthusiastic teaching style, his ability to inspire students about physics, and his creative use of technology in the classroom resulted in being recognized with a Prime Minister's Teaching Excellence in STEM Award in 2019.

## Prairies and Northwest Territories / Prairies et Territoires du Nord-Ouest

**MURRAY GUEST**, Walter Murray Collegiate

Awarded for his passion and dedication to teaching physics and his work with the Knowledge and Education Exchange Network and Math 9+ program.

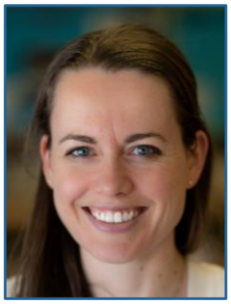
Murray is recognized for his work in teaching physics to students as a human endeavour while engaging them to communicate physics to themselves and others. He has done this by removing impediments to learning, talking about physical world situations which are as close to student experience as possible. He engages students to independently explore the physics dynamics through the eyes of a physicist. He continues to inspire students to become future physicists, engineers and professionals in diverse pursuits with a better understanding of the physical world around them as well as an appreciation of logical rigour of mathematics and physics.

He has a leading role in mentoring educators for their teaching practices. A positive impact on a teacher will in turn provide an ambassador for more than two decades with a positive influence on a few thousand youngsters, the future leaders and professionals of the country. Murray continues to influence the educators in positive ways.

Furthermore, engagement in the Provincial accreditation committee and his leading role in emphasizing the need and value of regular self-analysis of the student performance assessment across the curriculum. In our system, education does not end with teaching. Student performance assessment plays a prominent role. Murray recognized this on his own and continues to strive to make it a central theme of discussions in teaching not only in his classes but across the provincial school system.

For his outreach activities with the Knowledge and Education Exchange Network (KEEN) for the workshops between the university community and high school educators in a multi-disciplinary setting. He provided further engagement to connect students with the professional researchers and educators through a KEEN hallmark activity of Annual Nobel symposia and access to university resources.

## Ontario



**ASHLEY McCARL-PALMER**, Waterloo Collegiate Institute

Awarded for her passion and dedication to teaching physics, her innovative teaching methods, and her commitment to collaboration and sharing with other teachers.

Ashley is driven to improve her practice continuously. She is a risk-taker who pushes her students to leap out of their comfort zones and feel more successful and accomplished as a result. Her students speak highly of her effort, her energy and her passion, all of which create a dynamic and positive learning environment.

Inquiry-based learning, or active learning, is well-established in Ontario physics classrooms after years of leadership and research from post-secondary institutions. Ashley has adopted these practices, which focus on conceptual learning and student-constructed knowledge. She spirals content to give students multiple opportunities to experience and consolidate important concepts, witnessing deeper understanding and retention in her students.

Never one to turn down a learning opportunity or an opportunity to inspire others with her learning, Ashley participates in, and has lead, multiple professional learning opportunities. She has consulted with the Perimeter Institute Advisory Team on materials designed for grade 11 Physics courses, and she has shared her learning about sequencing content and a gradeless classroom with science and non-science educators around the province at various conferences, including Bring It Together, CONNECT and Science Teachers' Association of Ontario.

She is a valuable, active and contributing member of the physics educator community.

## Quebec and Nunavut / Québec et Nunavut

**NADIA RENZO**, Collège Saint-Louis

Awarded for her passion and dedication to teaching physics and her commitment to real-world physics demonstrations and extra-curricular activities.

Nadia Renzo has been teaching grade 5 physics at Collège Saint-Louis since 2008. Known for her boundless energy, boundless creativity and warm humour, she paints epic frescoes for her students as they discover Newton, Galileo and many others. A lover of the history of science, she fills her classes with anecdotes that do justice to the place of women in science, but also touch on the more human aspect of the great physicists. Far from limiting herself to theoretical speeches, this action-oriented teacher conceives ever more extravagant demonstrations, from the demonstration of Newton's three laws with Mario Kart - with competition to back it up - to her famous bowling ball on the ceiling that has become the most convincing (and feared) of clocks. By the way, don't be surprised to see her standing on her desk playing bass guitar in front of the students' astonished eyes: she is explaining acoustics.

Ms. Renzo believes that physics is part of everyday life and encourages her students to see it that way. During the final lab evaluations, they are free to do any mechanical physics experiment they can imagine. It inspires them so much that no one at Collège Saint-Louis questions it anymore when they see one of them launching a parachute from the 3rd floor catwalk with a stopwatch in hand.

And let's not forget all the extracurricular activities she leads, from the science fair to robotics to the annual rock show! Mrs. Renzo is the colorful whirlwind of the school that leads her students and colleagues on a thousand and one adventures. One thing is certain: she leaves indelible traces of her physics class in the hearts of her students, who still remember them years later.

## Atlantic / Atlantique

**SHANE MACLEOD**, Dartmouth High School

Awarded for his passion and dedication to teaching physics and his development of physics teaching and learning resources.

Shane MacLeod has been an inspiring teacher for almost two decades. Every day he brings his enthusiasm for thinking and his compassion for students into his high school physics classes at Dartmouth High School. He provided glimpses into how education was affected by the pandemic through interviews with CBC. His devotion to making modern physics accessible has led him to making videos of classroom-ready resources developed by Perimeter Institute for Theoretical Physics to help teachers throughout Atlantic Canada. He has also supported teachers in Nova Scotia by presenting at the NS Science Teachers’ Conference.

# MEET YOUR 2021-22 EXECUTIVE / RENCONTREZ VOTRE EXÉCUTIF 2021-22

## PRESIDENT / PRÉSIDENT

Manu Paranjape was born in Liverpool, UK, he did not live there too long, and grew up in Edmonton, Alberta. As a high school student, he won the Alberta wide high school exam in mathematics. He received his BSc (Honours) and MSc from the University of Alberta. His MSc supervisor was Yasushi Takahashi, of the Ward-Takahashi identities. His thesis was on the field theory of hydrodynamics. He then went to MIT, in Cambridge, Massachusetts to pursue his PhD, which he did under the supervision of Jeffrey Goldstone, well known of course for the discovery of the Goldstone boson. After his PhD, he spent 9 months at UBC as a postdoc under the guidance of Gordon Semenoff followed by two years as a postdoc at the ETH (Eidgenössiche Technische Hochschule) in Zürich, under the guidance of Christoph Schmid. After this, in October of 1986, he came to the Université de Montréal, as a chercheur adjoint (a position equivalent to assistant professor), officially an Attaché de Recherche du CRSNG. He obtained tenure and eventually promotion to full professor by 2002. He is currently a Professor with the Department of Physics at the Université of Montréal.

He has been active in many CAP related activities, serving as co-chair and then chair of the Division of Theoretical Physics for four years. During this time, he founded of the series of meetings, Theory CANADA, which are now in their 14th session. Since then, he was co-chair of the local organizing committee of the Annual Congress of the Canadian Association of Physicists that was held in Montreal in 2013, and he has been a member of the IUPAP committee for mathematical physics, and a member of the CNILC (Canadian National IUPAP Liaison Committee) for the past two years. Most recently, he has been involved with the accession of Canada into the Asia Pacific Center for Theoretical Physics, and he is the council member for Canada.

## VICE PRESIDENT / VICE-PRÉSIDENTE

Barbara Frisken is a Professor of Physics at Simon Fraser University. She completed her Ph.D. in physics at the University of British Columbia in 1989 and was a postdoctoral fellow at the University of California, Santa Barbara, before joining the faculty at SFU in 1992. Her research interests include structural studies of soft matter systems aimed at understanding relationships between microstructure and bulk properties; current projects focus on anion-conducting polymer membranes for fuel cells. She served as Chair of her department from 2006-2011, during which time she led a team of 30 faculty members and also chaired search committees for staff and faculty and the department's salary and tenure review committee. She currently serves as Chair of her department's Undergraduate Curriculum Committee. She has chaired two university-wide committees: The University Curriculum Implementation Task Force (2004-2006) and the Teaching Assessment Working Group (2017-2019). Barbara's involvement in the CAP includes a term as Chair of the Division of Condensed Matter and Materials Physics (1997-1998), Chair of the Publications Committee (1999-2001), Chair of the Committee to Encourage Women in Physics (2002-2005), Director of Academic Affairs (2012-2015), and Co-Chair of the 2019 CAP Congress Local Organizing Committee.

## VICE-PRESIDENT ELECT / VICE-PRÉSIDENT ÉLU

William (Bill) Whelan is a Professor of Physics at the University of Prince Edward Island. He completed a PhD in Medical Physics at McMaster University in 1996 and joined the faculty at the Toronto Metropolitan University that same year. After 12 years on faculty at TMU, he joined the University of Prince Edward Island in 2008 as a Tier 2 Canada Research Chair in Biomedical Optics. His research is focused on the design and development of biomedical sensors, based on Raman, optoacoustic, and near-infrared spectroscopy. He was Chair of the Department of Physics (2015-2021) and Chair of the Faculty of Science Research Committee. Bill has served on grant review panels for NSERC (Physics EG1505), the Canadian Cancer Society Research Institute (Innovation/I2I Programs) and CIHR (Medical Physics and Imaging). Bill's participation in the CAP includes serving as Chair of the Division of Medical and Biological Physics (2001-03), Director of Communications (2006-09) and Chair of the CAP- NSERC Physics Liaison Committee (2014-17). He was also a member of the National Board of Directors of the Canadian Cancer Society (2010-12). Bill is actively involved in science outreach, including chairing the PEI Science Fair for 10 years and co-chairing the Canada-Wide Science Fair in 2012.

## PAST PRESIDENT / PRÉSIDENT SORTANT

Rob Thompson is a Professor in the Department of Physics and Astronomy (PHAS) in Calgary. He completed his BSc (Physics) at UBC, PhD (Laser Physics) at UToronto, and post-doctoral positions at theMax -Planck-Institut fur Quantenoptik and Rice University. He leads Calgary's Trapping of Atoms, Molecules, and Exotic Species research group and has membership in the ALPHA and TITAN Collaborations. He has been PI or Co-PI on a sequence of NSERC Discovery, SAP-Project, and RTI Grants, and is PI for the ALPHA-g CFI Grant. He was co-recipient of the 2013 NSERC John Polanyi Award for studies of antihydrogen. He is an award-winning teacher, having received the 2007 CAP Medal for Excellence in Undergraduate Teaching and multiple institutional cognitions. He has worked in pedagogical development, leading the group that developed labatorials at UCalgary. As an academic leader, he served as Head, Undergraduate Program Director, and Graduate Program Director of PHAS in Calgary, on the Board of Governors for UCalgary, and currently on the Boards of TRIUMF and ACURA. He has extensive experience working with CAP as Director of Student Affairs, Chair of DPE, Secretary-Treasurer of DAMP/DAMPHi/ DAMOPC, PiC Editorial Board member, and member of the Award for Excellence in Teaching High-school/CEGEP Physics Committees.

## SECRETARY-TREASURER / SECRÉTAIRE-TRÉSORIER

Christine Kraus is a professor in the Department of Physics at Laurentian University. Her research field is particle astrophysics, where she takes advantage of the having SNOLAB around the corner. In 2004 she received her Ph.D. from the Johannes Gutenberg University in Mainz, Germany for the final analysis of the Mainz Neutrino Mass experiment. From there she moved to Canada to pursue a postdoctoral fellowship on the famous SNO experiment at Queen's University. Since 2010, when she moved to Sudbury as a Canada Research Chair, her main focus is the SNO+ experiment, which is now taking data. Prof. Kraus is a past advisory council member as well as a past PPD chair.

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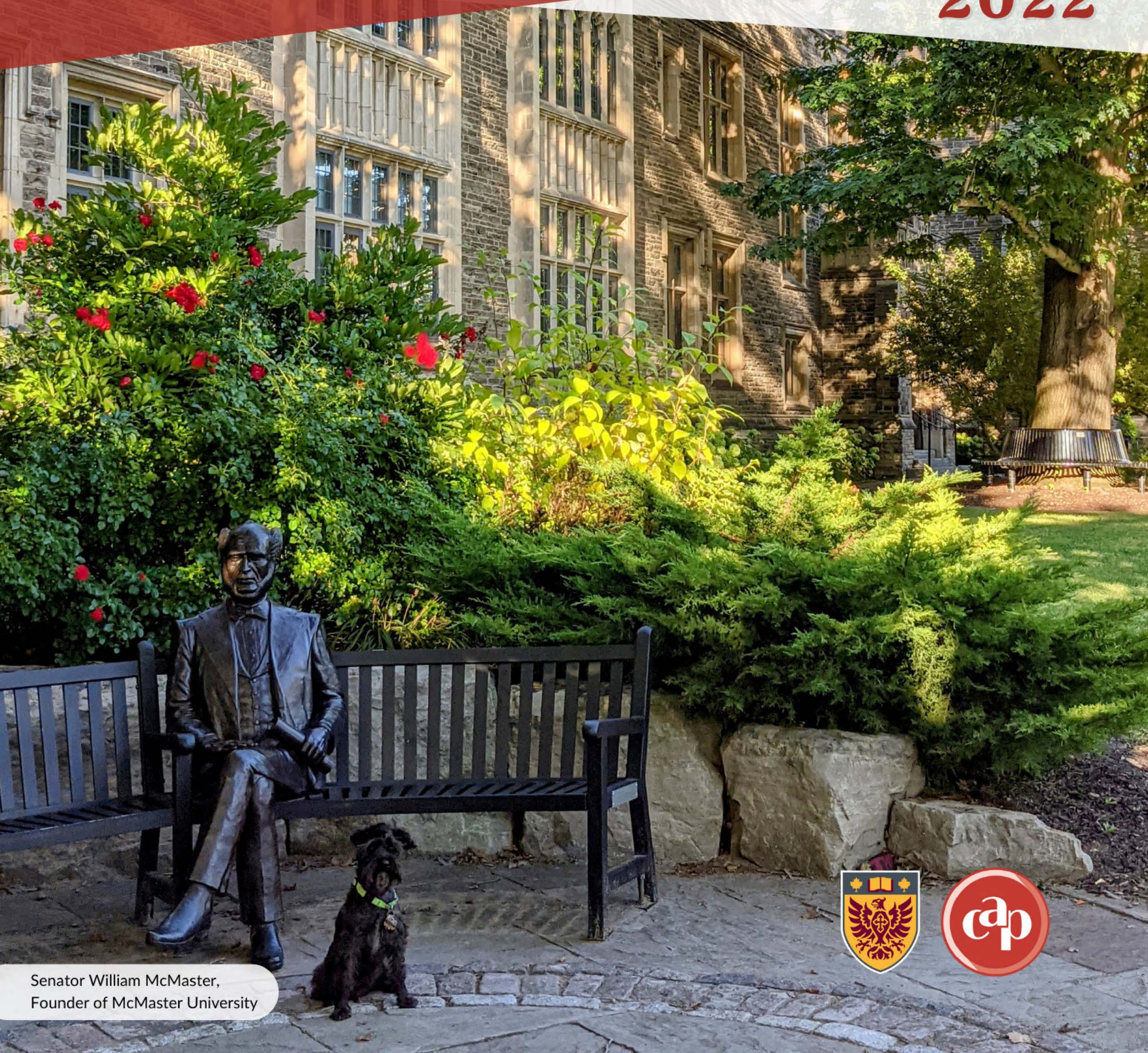

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