IEEE Canadian Review

La revue canadienne de l'IEEE

Spring/Printemps 2022 — No. 89

New Frontiers in Space and Physics

James Webb Telescope

Superfluidity

Internet Security

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The 35th IEEE Canadian Conference on Electrical and Computer Engineering ***CCECE2022*** will be held at the ***Westin Nova Scotian Hotel*** in Halifax, Nova Scotia, Canada on ***September 18 to 20, 2022***. CCECE is the flagship conference where researchers, students, and professionals in the area of Electrical and Computer Engineering meet annually in a Canadian city to get up to speed with the latest developments, foray into new fields and emerging topics, network with colleagues to strengthen partnerships and foster new collaborations.

IMPORTANT DATES *(Midnight, Atlantic Time)*

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President's Message/Message du Président

Robert (Rob) Anderson
P.Eng., SMIEEE

2022–2023 IEEE Canada President and Region 7 Director
Président de l'IEEE Canada 2022–2023 et directeur de la région 7

As the new Region Director, I would like to welcome all of you to the new year. It is an honor to be given the opportunity to serve members as the IEEE Canada President. I look forward to interacting and working with many of you.

I would like to recognize the contributions of several senior members within IEEE Canada. First, I thank Dr. Jason Gu for his service over the last two years as Region Director. Jason will be staying on the Board in the position of Past Director. He will continue to contribute, and I will take advantage of his experience to guide me as we move forward in 2022.

Second, I want to recognize the tireless efforts of Dr. Maike Luiken. Not only was Maike the Past Region Director, but she was also the Member Geographic Activities Board Vice President (MGA VP). Her dedication and resolute leadership have served both IEEE Canada and the

(Continued on p. 2)

En tant que nouveau directeur régional, je vous souhaite à tous la bienvenue pour la nouvelle année. C'est un honneur d'avoir l'opportunité de servir les membres en tant que président de l'IEEE Canada. J'ai hâte d'interagir et de travailler avec beaucoup d'entre vous.

J'aimerais reconnaître les contributions de plusieurs membres seniors au sein de l'IEEE Canada. Tout d'abord, je remercie Monsieur Jason Gu, PhD pour ses services au cours des deux dernières années en tant que directeur régional. Jason restera au conseil d'administration au poste d'ancien administrateur. Il continuera à apporter sa contribution et je profiterai de son expérience pour me guider à mesure que nous avancerons en 2022.

Deuxièmement, je tiens à souligner les efforts inlassables de Maike Luiken, PhD. Non seulement Maike était l'ancienne directrice de la région, mais elle était également la vice-présidente du conseil des activités géographiques des membres (MGA VP). Son dévouement et son leadership résolu ont très bien servi l'IEEE Canada et

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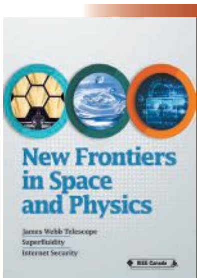

ON THE COVER

New Frontiers in Space and Physics

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(President's Message cont'd from p. 1)

greater IEEE very well. I have had several opportunities to work with Maike over my IEEE volunteer carrier, and it has been an honor and a privilege. I wish her well on whatever comes next.

Finally, I would like to welcome to the IEEE Canada Board Dr. Thamir (Tom) Murad as the President-Elect. I will be working closely with Tom to steer IEEE Canada as we deliver services to members.

Of course, Tom and I cannot do this on our own, so I want to welcome all returning and new volunteers to the IEEE Canada Board. The Board has many enthusiastic, motivated, and dedicated volunteer members. Thank you for volunteering, and I look forward to taking the journey over the next several years with you.

As we start this year, we are still seeing the impacts of COVID-19. The pandemic has been very disruptive to us as individuals (moving from office buildings to home offices, forcing many of us to change careers, and impacting our health) and to IEEE. In the past, IEEE has been methodical and moved very slowly. COVID-19 forced IEEE into revolutionary thinking. IEEE changed business and Member events that were traditionally face to face to online/virtual events. It was done quickly with a great deal of success. COVID-19 turned the IEEE business model upside down, yet IEEE has adapted well and served its members in a timely fashion.

I will provide more details on my objectives and what is going on at IEEE Canada in future articles in *IEEE Canadian Review.*

It is my hope that we can return to face-to-face activities, not only in the local sections, but also at the Region level. If you have been following news outlets, the policies on gatherings and travel change almost daily. At present, IEEE Canada is making plans for our flagship conferences for the upcoming year. The first IEEE Canada Board that was planned as a face-to-face meeting has been postponed by almost two months to improve the chances of meeting everybody in person. Regardless of the meeting style, the organization must move ahead with programs and services.

My three main objectives this year are as follows:

- *Membership*: recruitment, retention, recovery, and recognition
- *Organization and operational efficiency*: including a focus on volunteer leadership training
- *Strategic planning*: determining a strategic direction for IEEE Canada.

When I was running for IEEE Canada President, I heard numerous comments about the state of the IEEE Canada webpage. I want to let you know that I listened. I kicked off a project when I was the President-Elect to review the webpage content. It is important that we have the content correct and up to date before IEEE Canada modernizes the webpage. It

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(Message du Président suite de p. 1)

l'ensemble de l'IEEE. J'ai eu plusieurs occasions de travailler avec Maike au cours de ma carrière de bénévole de l' IEEE, et cela a été un honneur et un privilège. Je lui souhaite bonne chance pour la suite.

Enfin, j'aimerais souhaiter la bienvenue au conseil d'administration de l'IEEE Canada au Monsieur Thamir (Tom) Murad, PhD en tant que président élu. Je travaillerai en étroite collaboration avec Tom pour diriger IEEE Canada alors que nous fournissons des services aux membres.

Bien sûr, Tom et moi ne pouvons pas le faire seuls, alors je souhaite la bienvenue à tous les bénévoles de retour et aux nouveaux bénévoles au sein du conseil d'administration de l'IEEE Canada. Le conseil compte de nombreux membres bénévoles enthousiastes, motivés et dévoués. Merci de vous porter volontaire et j'ai hâte de faire le voyage au cours des prochaines années avec vous.

Je fournirai plus de détails sur mes objectifs et sur ce qui se passe à l'IEEE Canada dans de futurs articles de *la revue Canadienne de l'IEEE.*

Alors que nous commençons cette année, nous constatons toujours les impacts de la COVID-19. La pandémie a été très perturbatrice pour nous en tant qu'individus (passage des immeubles de bureaux aux bureaux à domicile, obligeant beaucoup d'entre nous à changer de carrière et ayant un impact sur notre santé) et à l'IEEE. Dans le passé, l'IEEE a été méthodique et a avancé très lentement. COVID-19 a forcé l'IEEE à une pensée révolutionnaire. L'IEEE a changé les activités commerciales et les événements des membres qui étaient traditionnellement face à face en événements en ligne/virtuels. Cela a été fait rapidement avec beaucoup de succès. COVID-19 a bouleversé le modèle commercial de l'IEEE, mais l'IEEE s'est bien adaptée et a servi ses membres en temps opportun.

J'espère que nous pourrons reprendre les activités en face à face, non seulement dans les sections locales, mais aussi au niveau régional. Si vous avez suivi les médias, les politiques sur les rassemblements et les voyages changent presque quotidiennement. À l'heure actuelle, l' IEEE Canada fait des plans pour nos conférences phares pour l'année à venir. Le premier conseil d'administration de l'IEEE Canada qui était prévu comme une réunion en personne a été reporté de près de deux mois pour améliorer les chances de rencontrer tout le monde en personne. Quel que soit le style de réunion, l'organisation doit aller de l'avant avec les programmes et les services.

Mes trois principaux objectifs cette année sont les suivants:

- *Adhésion*: recrutement, rétention, récupération et reconnaissance
- *Efficacité organisationnelle et opérationnelle*: y compris un accent sur la formation au leadership des bénévoles
- *Planification stratégique*: déterminer une direction stratégique pour IEEE Canada.

Lorsque je me présentais à la présidence de l'IEEE Canada, j'ai entendu de nombreux commentaires sur l'état de la page Web de l'IEEE Canada. Je veux que vous sachiez que j'ai écouté. J'ai lancé un projet lorsque j'étais le président élu pour revoir le contenu de la page Web. Il est important que le contenu soit correct et à jour avant que l'IEEE Canada ne modernise la page Web.

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(President's Message cont'd from p. 2)

may take several years to complete this project, as it depends on skilled volunteer resources being available and the capacity of our budget.

For the strategic plan, I am trying something completely different for IEEE Canada, reaching and engaging with all members by inviting all members with Canada to participate in a Coffee Pot Session (open discussions). The first of these sessions was held in December 2021. The theme of the first session was two questions:

- What has IEEE done for you?
- What do you want or wish IEEE could do for you?

This session was scheduled for 90 minutes, but it ran over by almost 60 minutes. Based on the level of engagement and enthusiastic discussions, additional sessions will be scheduled. Watch out for electronic notices in your email inbox.

I will provide more details on my objectives and what is going on at IEEE Canada in future articles in *IEEE Canadian Review*. If you are interested in participating in the Coffee Pot Sessions or volunteering with IEEE Canada, or if you have a question or comment, please reach out to me at president@iee.ca. ■

Robert (Rob) Anderson, P.Eng., SMIEEE
2022–2023 IEEE Canada President
2022–2023 Region 7 Director

(Message du Président suite de p. 2)

La réalisation de ce projet peut prendre plusieurs années, car cela dépend de la disponibilité de ressources bénévoles qualifiées et de la capacité de notre budget.

Pour le plan stratégique, j'essaie quelque chose de complètement différent pour l'IEEE Canada, atteindre et engager tous les membres en invitant tous les membres avec le Canada à participer à une Coffee Pot Session (discussions ouvertes). La première de ces sessions s'est tenue en décembre 2021. Le thème de la première session portait sur deux questions:

- Qu'est-ce que l'IEEE a fait pour vous?
- Que voulez-vous ou souhaitez-vous que l'IEEE puisse faire pour vous?

Cette session était prévue pour 90 minutes, mais elle a duré près de 60 minutes. En fonction du niveau d'engagement et des discussions enthousiastes, des sessions supplémentaires seront programmées. Méfiez-vous des avis électroniques dans votre boîte de réception.

Je fournirai plus de détails sur mes objectifs et sur ce qui se passe à l'IEEE Canada dans de futurs articles de *la revue Canadienne de l'IEEE*. Si vous êtes intéressé à participer aux Coffee Pot Sessions ou à faire du bénévolat auprès de l'IEEE Canada, ou si vous avez une question ou un commentaire, veuillez me contacter à president@ieee.ca ■

Robert (Rob) Anderson , ing., SMIEEE
Président de l'IEEE Canada 2022–2023
Et Directeur Région 7

IEEE Canadian Review
La revue canadienne de l'IEEE

IEEE Canadian Review is published three times per year: Spring, Summer, and Fall.

Its **principal objectives** are:
To inform Canadian members of IEEE on issues related to the impacts of technology and its role in supporting economic development and societal benefits within Canada. To foster growth in the size and quality of Canada's pool of technology professionals to serve our increasingly knowledge-based economy.

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Jahangir Khan, Ph.D., P.Eng., SMIEEE
mjakhan@ieee.org

As our hopes for a rapid entry into the postpandemic world got dashed by the unwelcomed arrival of the highly transmissible Omicron variant, we are again confined to our homes to a large degree. With high vaccination rates in Canada and reduced virulence of the Omicron variant, we do have good reasons to look forward to a near-normal spring in 2022. It is only practical to assume that our fight against the pandemic will linger much longer than we expected, yet there is a light at the end of the tunnel.

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Alors que nos espoirs d'une entrée rapide dans le monde post- pandémique ont été anéantis par l'arrivée malvenue de la variante hautement transmissible d'Omicron, nous sommes à nouveau confinés chez nous dans une large mesure. Avec des taux de vaccination élevés au Canada et une virulence réduite de la variante Omicron, nous avons de bonnes raisons d'espérer un printemps presque normal en 2022. Il est seulement pratique de supposer que notre lutte contre la pandémie durera beaucoup plus longtemps que prévu. , pourtant il y a une lumière au bout du tunnel.

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(A Few Words From the Editor-in-Chief cont'd from p. 4)

In keeping with the realities around available volunteer resources and funding, in 2022, *IEEE Canadian Review* will aim to address a number of issues, namely, IEEE *Xplore* indexing, website upgrades, author recognition, advertisement placements, and thematic publications. I take this opportunity to thank our outgoing Vice Editors-in-Chief Jonathan Palmer and Adam Detillieux for their services. We will be actively looking to fill these positions shortly, so please watch out for email notifications.

This edition of *IEEE Canadian Review* brings an assortment of topics that are rather unique. We cannot talk about engineering in a Canadian context without mentioning the James Webb Telescope that was launched late last year. Terrance Malkinson, our regular columnist on technology, presents an article on the James Webb Telescope. Daryoush Shiri, in his multipart column, puts a spotlight on the elusive concept of superfluidity. Matthew Wilder presents the concept of resource public key infrastructure (RPKI) in the context of Internet security for the years to come. We also celebrate the 2022 Class of IEEE Fellows from Canada.

I would like to take this opportunity to thank Dr. Jason Gu for his leadership as the Region 7 president during the last few years, especially at the height of the pandemic. Dr. Gu's guidance will be much needed as he continues to serve as past-president. I am excited to work with our new President Robert Anderson and President-Elect Dr. Thamir (Tom) in the coming years.

We stand in solidarity with the people of Ukraine, particularly the innocent civilians. Our thoughts and prayers remain with them.

Enjoy this edition of *IEEE Canadian Review*. Please share your thoughts and suggestions as you read. I can be reached at mjakhan@ieee.org. ■

(Quelques mots du rédacteur en chef suite de p. 4)

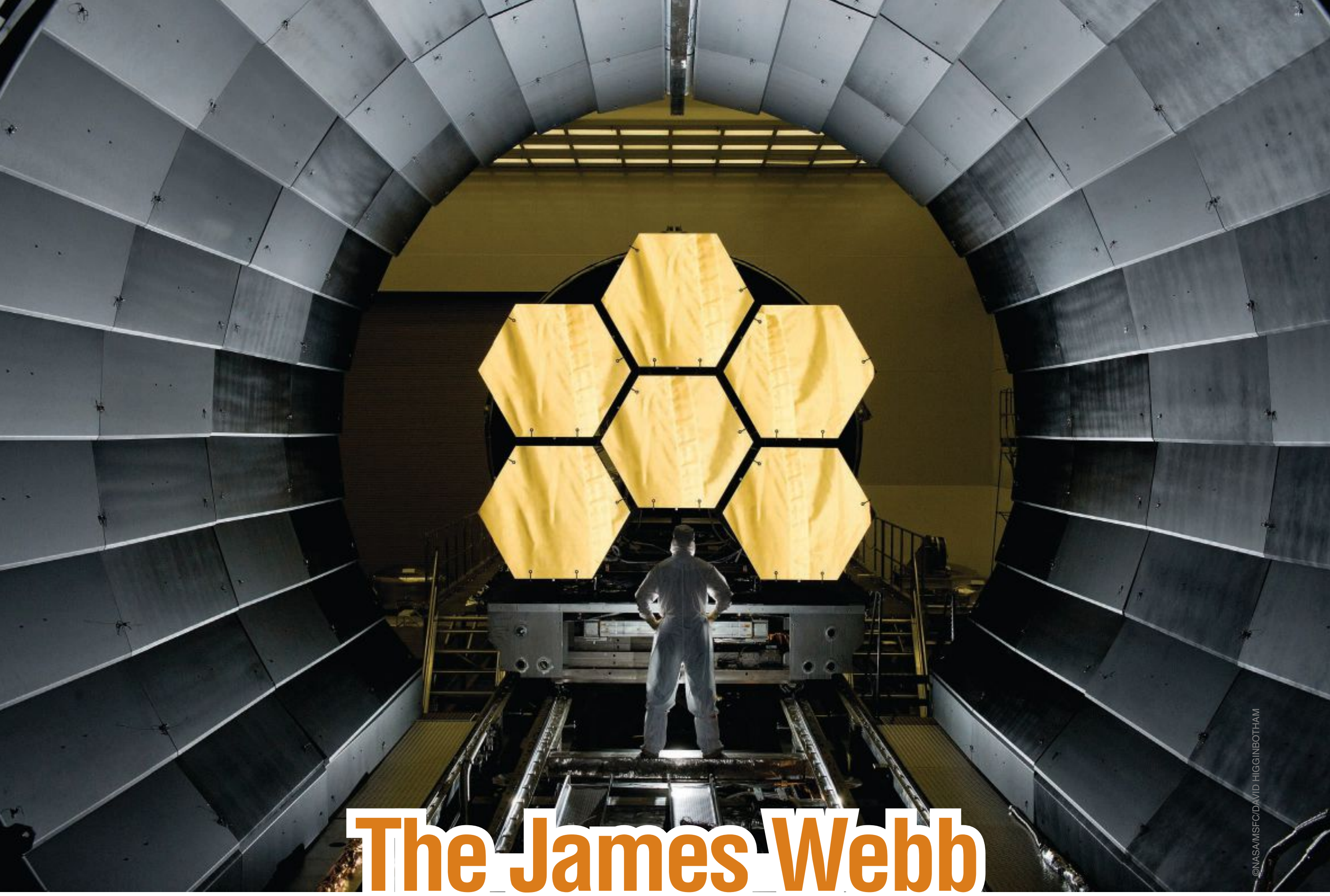
Conformément aux réalités entourant les ressources bénévoles et le financement disponibles, en 2022, *La Revue Canadienne de l'IEEE* visera à résoudre un certain nombre de problèmes, à savoir l'indexation IEEE *Xplore*, les mises à niveau du site Web, la reconnaissance des auteurs, les placements publicitaires et les publications thématiques. J'en profite pour remercier nos vice-rédacteurs en chef sortant Jonathan Palmer et Adam Detillieux pour leurs services. Nous chercherons activement à pourvoir ces postes sous peu, alors faites attention aux notifications par e-mail.

Cette édition de *la Revue Canadienne de l'IEEE* apporte un assortiment de sujets plutôt uniques. On ne peut pas parler d'ingénierie dans un contexte canadien sans mentionner le télescope James Webb qui a été lancé à la fin de l'année dernière. Terrance Malkinson, notre chroniqueur régulier sur la technologie, présente un article sur le télescope James Webb. Daryoush Shiri, dans sa chronique en plusieurs parties, met en lumière le concept insaisissable de superfluidité. Matthew Wilder présente le concept d'infrastructure à clé publique de ressources (RPKI) dans le contexte de la sécurité Internet pour les années à venir. Nous célébrons également la promotion 2022 des boursiers IEEE du Canada.

Je voudrais profiter de cette occasion pour remercier le Monsieur Jason Gu, PhD pour son leadership en tant que président de la Région 7 au cours des dernières années, en particulier au plus fort de la pandémie. Les conseils de Monsieur Gu seront très nécessaires alors qu'il continue d'exercer les fonctions de président sortant. Je suis ravi de travailler avec notre nouveau président Robert Anderson et le président élu Monsieur Thamir (Tom) dans les années à venir.

Nous sommes solidaires du peuple ukrainien, en particulier des civils innocents. Nos pensées et nos prières les accompagnent.

Profitez de cette édition de *la Revue Canadienne de l'IEEE*. S'il vous plaît partagez vos pensées et suggestions pendant que vous lisez. Je peux être contacté à mjakhan@ieee.org. ■



The James Webb Space Telescope

by Terrance Malkinson

The James Webb Space Telescope is the largest and most powerful space telescope ever constructed (see Figure 1). The telescope is 100 times more powerful than the Hubble Space Telescope launched in 1990. It is bigger, will capture more distant objects with low luminosity, and will look further back in time—1.3 billion years; within 100 million years of the universe-forming Big Bang. The telescope is named after NASA administrator James E. Webb who managed the space agency from 1961 to 1968. President John F. Kennedy championed his appointment. Both visionaries believed that NASA needed to strike a balance between human space flight and science. This combination would be a catalyst, strengthening universities, opening business opportunities, and expanding knowledge. In 1965, Webb suggested that a space telescope should become a major NASA initiative.

Webb is an international collaboration between NASA, the European Space Agency (ESA), and Canadian Space Agency (CSA). The telescope's large size, deployment in space, mechanoelectrical complexity, and ultracold operating temperature presented extraordinary engineering challenges to its development team, requiring innovative solutions. Thousands of engineers and scientists from universities, professional organizations, and companies from 15 countries have worked for decades to make the telescope a reality. The engineering teams determined that there were 344 single points of failure that could cause the mission to fail; innovative engineering mitigated every identified one of them. Canada has been an important contributor to the James Webb Space Telescope from the start and will be among the first countries to undertake investigations, with many scientists in the Canadian Astronomical Society participating in the project.

The James Webb Space Telescope will observe a part of space and time never before seen. It will look into the epoch when the very first stars and galaxies formed. Ultraviolet and visible light emitted by the very first luminous objects has been stretched and red-shifted into infrared light. It is designed to detect this infrared light with unprecedented resolution and sensitivity. The telescope will use its infrared detectors to see through dust in our universe where stars and planets are formed. It will be able to see the first galaxies.

Webb will also be a powerful tool for studying the nearby universe. Scientists will be able to study planets and other bodies in our solar system to determine their origin and evolution and compare them with exoplanets—planets that orbit other stars. Some of these exoplanets are located in their stars' habitable zones and could contain liquid water and possibly life. Using transmission spectroscopy, the observatory will examine starlight filtered through planetary atmospheres to learn about their chemical compositions.

After decades of conceptualization, design, construction, and testing, the team prepared the telescope for shipment to its launch site on the northeastern coast of South America. Webb was shipped in a custom-built, environmentally controlled container for its journey from Northrop Grumman's Space Park in California. It first traveled 42 km through the streets of Los Angeles to the Naval Weapons Station at Seal Beach. It was then loaded onto the *MN Colibri*, a French-flagged ship designed to safely transport large and valuable cargo. Departing on 26 September, the voyage took the observatory through the Panama Canal to Port de Pariacabo in French Guiana. Arriving on 12 October, it was transported to the launch facility. The Guiana Space Centre is particularly suitable as a location for a spaceport because of its near-equatorial location, open sea to the east, and high percentage of successful launches. France shares this centre with the ESA.

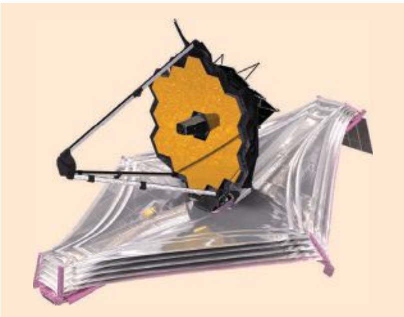


Figure 1: An illustration of the fully deployed James Webb Space Telescope. (Source: NASA.)

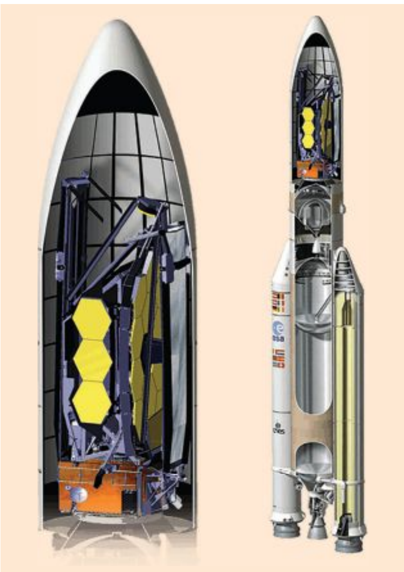


Figure 2: The tightly packed configuration of the telescope encapsulated in the nose fairing of the Ariane 5 rocket. (Source: NASA.)

On 25 December 2021, the ESA's Ariane 5 heavy vehicle rocket with the 6,000-kg folded-up telescope inside its 5.4-m-diameter rocket nose cone was launched (see Figure 2). The US$10 billion observatory will travel to an orbit roughly 1.6 million km away from Earth while unfolding and deploying its sunshield, mirrors, and other components. It will cool down, align, and calibrate before being used for scientific investigations in six-months' time, making it one of the most complex space deployments ever attempted.

Innovative Technology

Numerous innovative and powerful new technologies have been developed for this mission by teams of scientists and engineers. They developed many new technologies, which are described in the following sections.

Lightweight Cryogenic Mirrors

Webb will observe galaxies that are very distant—13 billion light years away. Space telescopes observe by using mirrors to collect and focus light. The bigger the mirror, the more details the telescope can see. Investigators will be looking for stellar objects, some of which are only one nanojansky in brightness. In this case, the primary mirror is 6.5 m across, resulting in 25 m^2 of reflecting area, five times larger than the Hubble Space Telescope's mirror and 62% lighter. A primary mirror this large has never before been launched into space. The team had to develop new ways to build the mirror so that it would be distortion free, light enough, strong enough, and able to fit within the launch capsule. The team designed an 18-hexagonal-segment foldable-mirror array. The foldable-wing arrays of three segments each tessellate snugly when moved into position on deployment. Each of the mirror segments is 1.3 m in diameter. This hexagonal shape provides a high filling factor and sixfold symmetry to focus light onto the 0.74-m-diameter secondary mirror. The base beryllium layer holds its shape across a range of temperatures, is a good conductor of electricity and heat, and is not magnetic. A 100-nm layer of gold, which is an excellent reflector of infrared light, was deposited onto the beryllium, and a thin layer of amorphous silicon dioxide (glass) was deposited on top of the gold to protect it from scratches. The mirrors made 14 stops at 11 different manufacturing and testing facilities (see Figure 3).

Infrared Detectors

The detectors are where photons are absorbed and ultimately converted into electronic voltages (see Figure 4). Engineers have extended the state of the art for infrared detectors by producing arrays that have lower noise, a larger format, and are longer lasting than their predecessors. Two different types of ultrasensitive detectors are used: 1) a mercury cadmium telluride 0.6–5-μm near-infrared four-megapixel detector developed by Teledyne Imaging Sensors and 2) a silicon arsenic 5–29-μm midinfrared one-megapixel detector developed by Raytheon Vision Systems.

Cryocooling

The detectors that convert infrared light signals into electrical signals for processing into images need to be ultracold at 7 °K (–266 °C) to work correctly. Webb's

Figure 3: Engineers inspecting one of the first two flight mirrors at NASA Goddard. (Source: NASA.)

innovative two-cylinder, horizontally opposed pump cools gases and uses pulse tubes, which exchange heat with a regenerator acoustically. This high-efficiency, no-vibration cryocooler (development cost of US$150 million) has advanced the state of the art in spaceflight cryocoolers.

Cryogenic Data-Acquisition Integrated Circuit

Light from astronomical objects is converted into electrical signals by detectors.

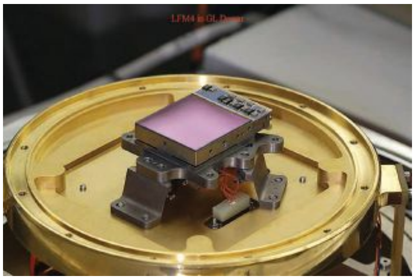


Figure 4: A near-infrared camera detector with its optical baffles removed. (Source: NASA.)

These output signals are susceptible to electrical noise. The engineers developed an application-specific integrated circuit technology to convert the detectors' analog signals to digital near the detectors before sending them to processing and communications electronics. The technology developed for Webb involved a microprocessor with a low-power dissipation 16-bit A-to-D signal conversion at cryogenic temperatures.

Sunshield Membrane Coatings

The sunshield is an important part of the telescope because the infrared cameras and instruments must be kept very cold to function properly. A five-layer, 21 × 14-m sunshield made of separated thin layers of Kapton E (Dupont) with aluminum coating was designed (see Figure 5). The outer two layers are coated with high-emissivity silicon. Each of the five layers is deployed in an angled configuration relative to each other to deflect heat out to space, gradually reducing the temperature. To prevent the possibility of failure from micrometeorites, ripstop seams were bonded onto the layers.

Microshutters

Microshutters are a new technology that was developed for this mission (see Figure 6). They are basically tiny windows with shutters (lids), each of which measures 100 × 200 μm. The arrays of these tiny windows are a key component of the near-infrared spectrograph that will record the spectra of light from distant objects. The programmable, innovative microshutters are opened or closed as desired to view or block a portion of the sky by an on-off magnetic arm. They will be used to select many objects for simultaneous observation, resulting in more and quicker scientific investigation. Microshutters are a remarkable engineering feat that will have applications outside of astronomy in biotechnology, medicine, and communications. They were conceptualized and created at NASA's Goddard Space Flight Center.

The Backplane

The backplane is the large structure that supports not only the primary mirror and telescope optics but also the entire cluster of scientific instruments. The backplane carries more than 2,400 kg of hardware. It is required to be vibration free and have unprecedented thermal stability (see Figure 7). To meet this requirement, the backplane was engineered to be steady down to 32 nm.

Deployment Stages

The telescope is very large and needs to fit within the launching spacecraft's capsule (see Figure 8). The engineers developed an innovative deployment technology to "unfold" it during its journey to orbit. The staged deployment began 30 min after launch, and on 8 January, the most critical deployment stages were all successfully completed. Hundreds of mechanisms needed to work perfectly for success. There are no monitoring cameras on the telescope because of technical complexities and risk. The engineers depended on switches, sensors, and motors to monitor the deployment. The telescope's orbit is too distant to be repaired by spacewalkers during its expected 10 years of operational life, therefore, an error-free deployment was essential. The forecasting suggests that with advances in technologies, the next generation of space telescopes will be

Figure 5: The unfolded sunscreen during testing. (Source: NASA.)

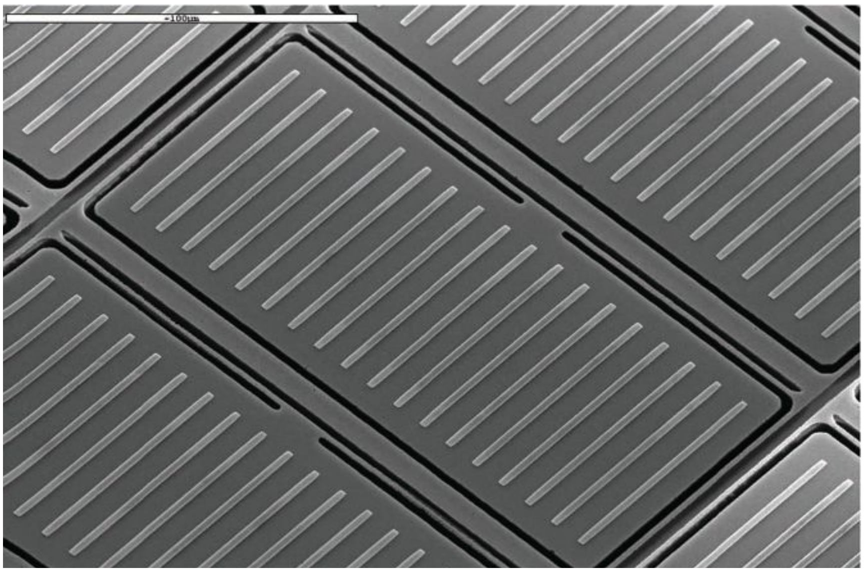


Figure 6: The microshutter device consists of 250,000 individual windows with shutters arrayed in a waffle-like grid. (Source: NASA.)

larger and assembled while in Earth's orbit and then sent to their destination with robotic technologies employed to refuel them in their distant orbits.

Launch

The ESA's Ariane 5 launch vehicle provides thrust for roughly 26 min after liftoff. The first stages fire, consume its fuel, and separate. The upper stage then gives Webb its final push onto a trajectory toward its orbit and separates; the faring drops away, leaving the telescope to continue on its own. The telescope will quickly establish its ability to orient itself and fly in space. Its launch and orbiting trajectory is fine-tuned with small rocket thrusters using an onboard propellant. The depletion of this fuel propellant is the reason for the projected 10 years of operational life. A 29 December NASA press release revealed that the two early midcourse corrections used less propellant than expected, suggesting a "significantly more than 10-year science lifetime."

The Solar Array and Gimbaled Antenna Assembly are Deployed

The first two deployments occur autonomously. The 2,000-W solar panel is deployed, and the telescope will start generating its own power. The gimbaled antenna assembly holding Webb's high-rate antenna is rotated to its permanent position pointed back to Earth, enabling data communication as soon as possible. All subsequent deployments are controlled by commands from the ground.

Tower Assembly and Sunshield Deployment

The tower backplane assembly will then be extended approximately 2 m on a shaft that connects the telescope's two halves. This provides thermal isolation for the mirrors and instrumentation and room for the sunshield membranes to fully unfold. The mirrors need to be cold to suppress any infrared background "noise." To protect the telescope from external sources of light and heat as well as from heat emitted by the observatory itself, the instrument has an innovative, five-layer, diamond-shaped, 21 × 14-m sunshield that provides shade. The forward and aft pallets containing the five sunshield membranes are lowered. The cover that had been protecting the membranes then rolls up. The multistep, two-day sunscreen membrane deployment and tensioning activity successively tensions each of the five layers of the sunshield. The process involves 139 release mechanisms, 70 hinge assemblies, eight motors, 90 cables, and roughly 400 pulleys. The temperatures on the sunny/hot side of the sunshield will reach approximately +110 °C, and on the dark/cold instrumentation side of the sunshield reach –233 °C. This remarkable thermal transition occurs across a distance of only 2 m.

Secondary Mirror Deployment

Ten days following the launch, the secondary mirror is moved into its operational position by swinging its support structure and mirror out and in front of the primary mirror. The secondary mirror is supported by three carbon-fiber struts that extend out from the large primary mirror. This secondary mirror reflects the focused light from the primary mirror onto the detection instrumentation behind the primary mirror through the Cassegrain focus located in the aft optics subsystem in the middle of the primary mirror. This protrusion blocks stray light from entering the aperture and has an additional mirror controlled by the fine guiding system.

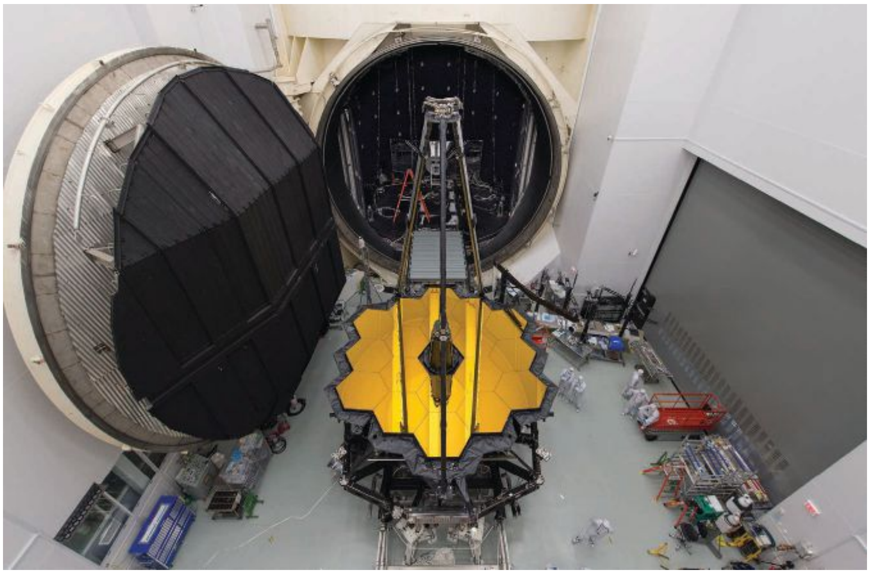


Figure 7: The telescope's combined science instruments and optical element leaving the thermal vacuum testing chamber after cryogenic testing. (Source: NASA.)

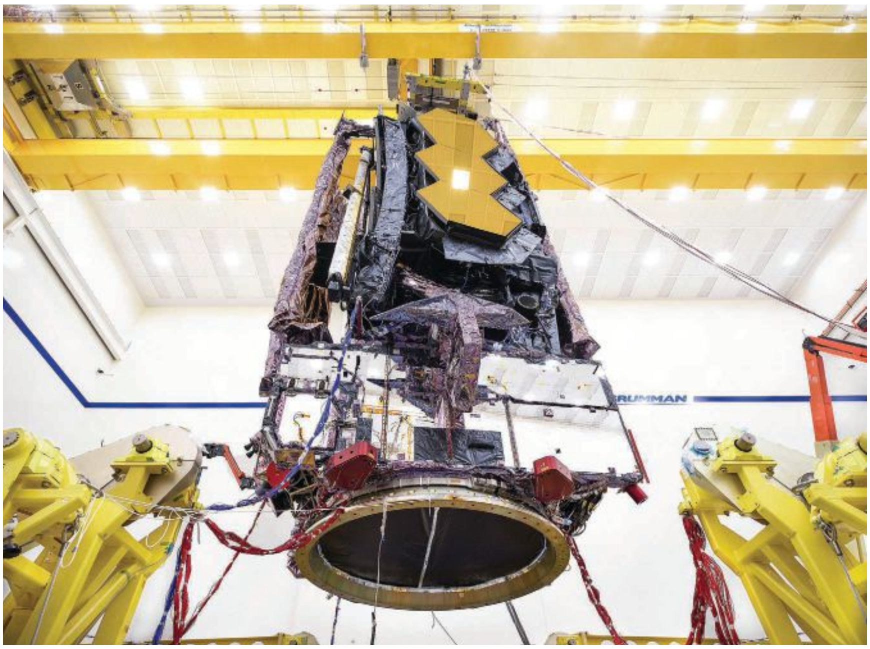


Figure 8: The telescope folded up for launch. (Source: NASA.)

Primary Mirror-Deployment Phase

After 12 days, the positioning of the two primary mirror wings begins. Each wing holds three of the 18 mirror segments. The cooldown of the telescope and scientific instruments that began with the deployment of the sunshield continues and will be carefully controlled with strategically placed electric heater strips. The remaining five months of commissioning will involve aligning the optics and calibrating the scientific instruments. Aligning the 18 primary mirror segments to form a single large mirror requires precision of 1/10,000th the thickness of a human hair and is enabled by an innovative wavefront sensing and control process. Each of the primary mirror segments and single secondary mirror are adjusted by six actuators (tiny motors) that are attached to the back of each mirror segment. An actuator at the mirrors center adjusts its curvature.

Final Insertion Burn

A final insertion burn corrects any trajectory errors and adjusts the telescope's orbit 30 days following the launch. This telescope will not orbit around Earth like the Hubble Space Telescope. It will orbit the sun at what is called the *second Lagrange point* (*L2*) (see Figure 9). This position keeps the telescope in line with Earth as it moves around the sun, and in a place where the gravitational forces of the sun and Earth will hold a spacecraft in the same position relative to the gravitational bodies with which it is travelling. The six-month orbit keeps the telescope out of the shadows of both Earth and the moon, allowing uninterrupted scientific operations.

Communicating With the Telescope

Webb's position at L2 means it will always be at the same location relative to Earth, allowing continuous communication using three large antennas located in Australia, Spain, and California. The telescope will uplink command sequences and downlink data up to twice per day. Some commands, such as navigation and pointing, occur autonomously. The Space Telescope Science Institute will upload a week's worth of commands at a time and make updates daily as needed.

Canadian Engineering Involvement

The CSA has provided the James Webb Space Telescope with a fine guidance sensor (FGS) and near-infrared imager and slitless spectrograph (NIRISS) scientific instruments, two important components that are described as follows:

- The FGS is used for navigation, enabling the telescope's mirror to point at and focus on objects of interest. It allows the telescope to determine its position, locate its celestial targets, track moving targets, and remain precisely pointed at a specific celestial target. The FGS has a critical role for all scientific observations: ensuring the collection of clear and detailed pictures of celestial bodies. It consists of two cameras and can select one star from a catalogue of nearly one billion guide stars. These cosmic reference points are critical to the telescope when calculating its position in space. This system is active during all observations, essentially locking the telescope's mirror on the guide star and preventing any change in the field of view.

The FGS is used for navigation, enabling the telescope's mirror to point at and focus on objects of interest.

- The NIRISS is an instrument that helps study diverse astronomical objects, from exoplanets to distant galaxies. Using a camera sensitive to infrared wavelengths, the NIRISS will capture infrared light emitted by objects and gather information about the spectra of distant planets. It will examine objects that are very close together. The instrument enables scientists to determine physical properties, such as the chemical composition and temperature of galactic objects.

The Canadian Instrument team designed, developed, built, and tested the integrated FGS/NIRISS unit with Honeywell and with scientists and engineers from the CSA, Université de Montréal, NASA, and the Space Telescope Science Institute. The CSA funded Canada's entire contribution to the space telescope, including the two Canadian scientific instruments, and will support the continued participation of Canadian instrumentation scientists. Canada receives a guaranteed share of the James Webb Space Telescope's observation time, making Canadian scientists some of the first to study data collected by the most advanced space telescope ever built.

Canadian Scientific Involvement

Researchers from a number of universities and institutes are involved with the Canadian science team. Because of the CSA's considerable contribution to the mission, Canadian astronomers will have rapid access to three types of observation programs. The research proposals all went through a competitive process before being selected based on their scientific merit and astronomical benefits.

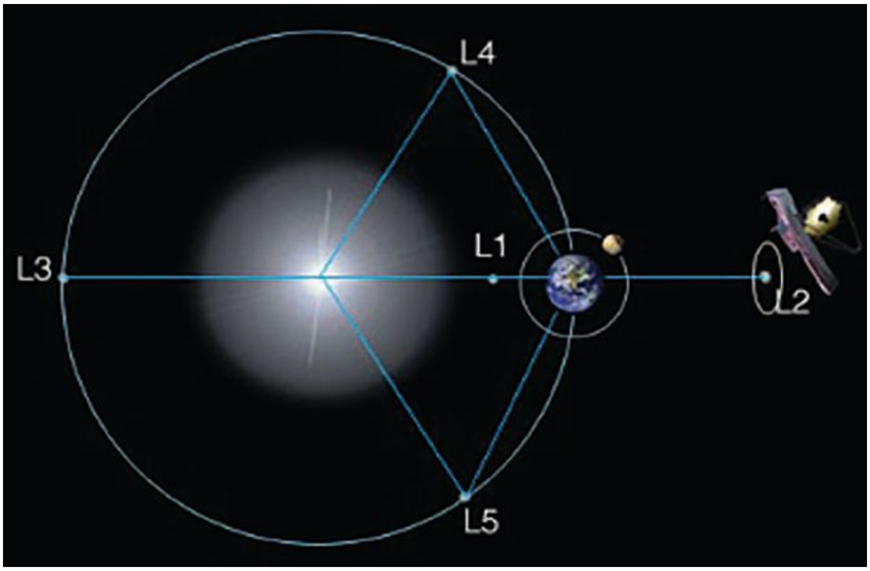


Figure 9: A graphic of the telescope's orbit at L2, an area of balanced gravity between the sun and Earth. (Source: NASA.)

Early-Release Science

Thirteen competitively selected early-release science programs will have exclusive access to the James Webb Space Telescope during its first five months of operation. Canadian astronomer Dr. Els Peeters from Western University will be one of this group's investigative scientists. Dr. Peeters and her team will study the interaction between infrared light produced by very large stars and their surrounding environment and seek to understand how far-ultraviolet light affects the material among stars, called the *interstellar medium.*

Guaranteed Time Observations

During the early years, the Canadian Webb science team will have access to 450 h of guaranteed observation time. Of that time, 403 h will be split between the following two main Canadian programs:

1. Led by Dr. David Lafrenière from Université de Montréal, "The NIRISS Exploration of the Atmospheric Diversity of Transiting Exoplanets" will study the atmospheres of exoplanets, including their composition and temperature. The team's goal is the detection of an atmosphere on rocky planets similar to Earth's, giving us insights into whether or not the planets are habitable.
2. Led by Dr. Chris Willott from the National Research Council and Herzberg Astronomy and Astrophysics Research Centre, "The NIRISS Unbiased Cluster Survey" will study some of the first galaxies ever formed and galaxies found in groups, called *clusters*. They will use the Canadian NIRISS instrument to collect images and spectra from these galaxies at different periods of the universe's history. This will help us to understand how galaxies evolved over time.

The remaining 47 h will be split among the following seven smaller Canadian guaranteed time-observation programs, investigating topics such as rogue planets, brown dwarfs, and exoplanets:

1. "The NIRISS Survey for Young Brown Dwarfs and Rogue Planets," by Dr. Aleks Scholz, the University of St. Andrews.
2. "Planets in Formation Around Young Stars: NIRISS AMI Observations of Transition Disk Systems," by Dr. Doug Johnstone, the National Research Council and Herzberg Astronomy and Astrophysics Research Centre.
3. "Architecture of Directly-Imaged Extrasolar Planetary Systems," by Dr. Julien Rameau, Université Grenoble Alpes.
4. "NGC 1068 as Proving Ground for NIRISS AMI," by Dr. K.E. Saavik, Ford City University of New York.
5. "Probing the Cloud Properties of the Benchmark Variable T Dwarf SIMP0136," by Dr. Étienne Artigau, Université de Montréal.
6. "High-Angular Observations of Ultracool Brown Dwarfs," by Dr. Loïc Albert, Université de Montréal.
7. "Exozodiacal Disks: A Theatre for Planetary Gravitational Shadow Plays," by Dr. Peter Tuthill, the University of Sydney.

General Observations

Canadian astronomers will also have access to 5% of the James Webb Space Telescope's observation time reserved for general observations. The programs are selected by a competitive process on a yearly basis while the telescope is operational. Eleven principal investigator programs have been selected as well as many programs by Canadian coinvestigators.

The Canadian Astronomy Data Centre has archived all of the data from the Hubble Space Telescope since its launch in 1990, and these data are available to researchers from around the world. The Canadian Astronomy Data Centre will be doing the same for the James Webb Space Telescope in support of researchers as they process and analyze their data.

James Webb Space Telescope Spin-Offs

The 25-yr James Webb Space Telescope development program has spun-off new technologies of immediate benefit and will lead to innovative technologies in the future. The following sections describe these novel technologies.

Ophthalmology

Wavefront sensing and control is a term used to describe the subsystem required to sense and correct any errors in the telescope's optics. Engineering innovations on the telescope optics required to align mirror segments resulted in a sensing technology spin-off for diagnosing eye conditions and accurate mapping of the eye. This spin-off supports research in cataracts, keratoconus, and eye movement as well as improvements in the laser-assisted in situ keratomileusis procedure that improves vision by reshaping the cornea. These improvements have enabled eye doctors to obtain much more detailed information about the shape of the eye in seconds rather than hours.

Laser Interferometers

One of the challenges for telescope engineers was to find a way to test mirrors and composite structures at the conditions they will experience in space. To solve that problem, 4D Technology Corporation of Tucson, Arizona, has developed several new types of high-speed test devices that utilize pulsed lasers that remove the effects of vibration. The program has created new technology and jobs well beyond its direct funding, generating more than US$30 million in revenue from a wide range of applications within the astronomy, aerospace, semiconductor, and medical industries.

Restoring Hubble

Integrated circuits used in camera self-repair for the James Webb Space Telescope have led to the development of cryogenic, application-specific integrated circuits now used on the Hubble Space Telescope (see Figures 8 and 9). These small, specialized integrated circuits enable electronics to be condensed into a very small package. Webb's investments in this technology have allowed the circuits to be programmable.

Astronomical Detectors

The infrared sensors based on the technology developed for the James Webb Space Telescope are now the universal choice for astronomical observations, both from space and the ground. This technology is also being used for Earth science and national security missions. The availability of these high-performance detectors developed for the telescope will be critical to life on Earth, both presently and in the future.

Benefits of Space Science and Engineering

Our space capability has grown remarkably since *Sputnik* launched in 1957. This launch awakened the interests of a generation of youth in pursuing careers in science, technology, and engineering. IEEE, through its members, their research, and publications, has played a major role in the space program and developed spin-offs that have benefited life on Earth. Some may question the cost and why we are doing this. In their reader-friendly article in *The Space Review*, Jeff Greenblatt and Al Anzaldua discuss past and current benefits, and future possibilities of space-based capabilities for life on Earth from environmental, social, and economic perspectives. In their conclusion, the authors state the following:

> We believe that the benefits that humanity currently derives from Space, plus the vast anticipated future benefits described in this paper, overwhelmingly support the case for the continued exploration, development and settlement of Space.

Indeed, space science, technology, and engineering have created a plethora of interesting careers and employment opportunities for many women and men. This will continue for those who are motivated and well prepared through education and experience. IEEE has many resources to assist you when selecting your professional career and achieving employment success. Canada has positioned itself well to be a global-leading participant in Space science and engineering. Canada's education system, scientists, and engineers are highly respected throughout the world. ■

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About the Author

Terrance Malkinson, the author of more than 580 peer- and editorial-reviewed earned publications, is now retired. His diverse career path included 26 years in medical research as a founding member of the Faculty of Medicine at the University of Calgary, a three-year appointment as a business manager with the General Electric Company, followed by a one-year applied research appointment with SAIT Polytechnic. He is an alumnus of continuing professional education programs with Outward Bound International, the Banff Centre for Management, the Massachusetts Institute of Technology, and the University of Colorado. During his long career, he has advanced both basic and applied medical, health and wellness, scientific, and engineering knowledge. He has trained and mentored undergraduate, graduate, and postdoctoral students as well as professional staff in the business sector and government. He is a 45-year Life Senior Member of IEEE. He has served in many professional public and private governance and publication roles. He is the recipient of several peer-selected earned awards, including induction into the Order of the University of Calgary, IEEE achievement medals, and APEX awards for publication excellence. In retirement, he vigorously continues basic and applied research, with an extensive portfolio of basic and applied research projects. Other passions include communicating emerging technologies to the public, investigative journalism, philanthropy, and mentorship. His current research interests in emerging technologies and health and wellness extend to being an accomplished multisport triathlete, including, among other events, the completion of 10 full-distance Ironman Triathlons.

Superfluidity for Engineers, Part 1: The Canadian Discoverers

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Like superconductivity, superfluidity is also a macroscopic "quantum" state of matter. When we hear the word *quantum*, we are inclined to think of something unimaginably small or only discernible under a fancy microscope.

Imagine your freshly brewed breakfast coffee could be superfluid, as there is no limit for imagination. Stir it once, and it would whirl around the formed vortex in the center of the cup forever and forever. In a superfluid, the friction between the different layers of liquid or between the liquid and container becomes zero (not very small, just zero). Again, imagine trying to increase the rotational speed of the coffee. The rotation, however, increases in discrete quantum steps, i.e., you would notice the number of vortices increases one by one, and they build a hexagonal array in the cup. If this is not exciting enough, let's look at the following fictional experiments.

Bring two cups of coffee having the same level but different temperatures. Connect both cups at the bottom by a very narrow pipe. Our classical intuition predicts that both cups only exchange heat through the pipe and reach the same equilibrium temperature. However, our quantum fluid (superfluid coffee) flows from the colder cup to the hotter one! The cold cup empties itself to the benefit of the hotter one [1]!

Now we repeat the same experiment with two cups of different levels of coffee but with the same temperature. We expect the taller cup to empty itself continuously through the orifice until we have the same level of coffee in both cups. However, under some conditions (which we will learn later), coffee stops flowing at specific moments and then starts emptying itself, leading to precise, discrete steplike changes in the level. In other words, the pressure or level difference (ΔH) is making itself zero in discrete quantum steps [1], [2].

The good news is that all of the mentioned "quantum" effects happen before our naked eyes [see Figure 1(a)]. However, the bad news is that coffee cannot become superfluid. Instead, we must cool down helium gas (^{4}He) by about 271 °C below zero (2.17 K) and fill our cups with liquid helium. Liquid helium (^{4}He) under 2.17 K was the first material that showed the strange and fully quantum mechanical property called *superfluidity*. (^{4}He has two protons and two neutrons in its nucleus. A rare isotope of helium is ^{3}He, which has one neutron fewer than ^{4}He. The superfluidity in ^{3}He was discovered in 1972. It is of a different origin than the one in ^{4}He.)

On 8 January 1938, *Nature* magazine published a one-page letter submitted by Pyotr L. Kapitza [3], titled "Viscosity of Liquid Helium Below λ-Point." In this letter, Kapitza reports a measurement of the viscosity of liquid helium below $T_\lambda = 2.17$ K (called the *lambda point*). He shows that the viscosity or friction against the fluid flow is immeasurably very small [4]. He

Lighter atoms like nitrogen, oxygen, hydrogen, and helium were resisting the pressure-based liquefication, and other avenues had to be sought.

coins the term *superfluidity* and speculates on its analogy with superconductors wherein the resistivity becomes suddenly zero under a certain critical temperature. In the first few lines of the letter, he writes, "At present, the only viscosity measurements on liquid helium have been made in Toronto." To see what was happening in Toronto, I found myself reading a series of interesting articles and instructive historical recounts, and I would like to share a summary of them here. I postpone the phenomenology and potential applications of superfluid helium, e.g., in cryogenic engineering, to the next part(s) of this article. Let's go back a few decades before 1938.

The Race Toward Absolute Zero in Europe (1800s–1913)

The race to liquefy gases and achieve temperatures as low as absolute zero (–273 °C) started around 1823 when Michael Faraday, then a new apprentice in Sir Humphrey Davy's laboratory in London, United Kingdom, succeeded in liquifying chlorine gas by applying pressure to it in a sealed tube. The boiling temperature of chlorine was –34 °C (239 K). Wintery days in London were not as cold as in Canada; otherwise, he would not need the pressure to liquefy chlorine! After this, he succeeded in producing liquid sulfur dioxide (SO_2); ammonia (NH_3); sulfur dihydride (H_2S); and, finally, carbon dioxide (CO_2). The boiling temperatures of these gases were 263 K, 240 K, 212 K, and 195 K, respectively [5].

However, lighter atoms like nitrogen, oxygen, hydrogen, and helium were resisting the pressure-based liquefication, and other avenues had to be sought. The reason was that the van der Waals force between the molecules of these gases is weak, and applying pressure is not enough to bring the molecules closer together to make them a liquid. This requires lower and lower temperatures beyond the capabilities of previous cooling methods.

Later, in the 1870s, a French mining engineer, Louis Paul Cailletet, was trying to liquify acetylene (C_2H_2) under pressure. The sudden rupture of his apparatus and pressure release led to the formation of a mist of liquid droplets on the inner walls of the pipes. This meant that, to liquefy gases, you don't need pressure but, rather, the sudden release of pressure. This process, which is now called the *Joule–Thomson* or *Joule–Kelvin effect*, was already proposed by James Prescott Joule and William Thomson (who later became Lord Kelvin) around 1852 [5], [6]. This method is now used as a part of modern cryogenic sub-Kelvin fridges [7]. However, it is effective for gases wherein the interatomic force (van der Waals force) is not weak; otherwise, the formation of liquid happens only if the gas has already been precooled to a very low temperature.

In 1877, Cailletet and a Swiss physicist named Raoul Pierre Pictet managed to liquefy oxygen. Cailletet used the Joule–Thomson method. He precooled the oxygen by letting it evaporate the liquid SO_2, with a boiling point of –29 °C. Then, the precooled oxygen was put under 300-atm pressure, and the sudden release of the pressure led to the formation of oxygen droplets. Pictet used the cascade method, in which gases of different boiling points are cooled and liquefied one after another. As the name suggests, the gas with the highest boiling point, e.g., CH_3Cl, is used to precool the next one (C_2H_4), and after the next one is liquified under pressure, it is used to precool the third one (e.g., O_2); i.e., the second one is boiled by taking the heat from the third one. Then, applying pressure to the third one converts it to liquid. This can, in turn, be used to

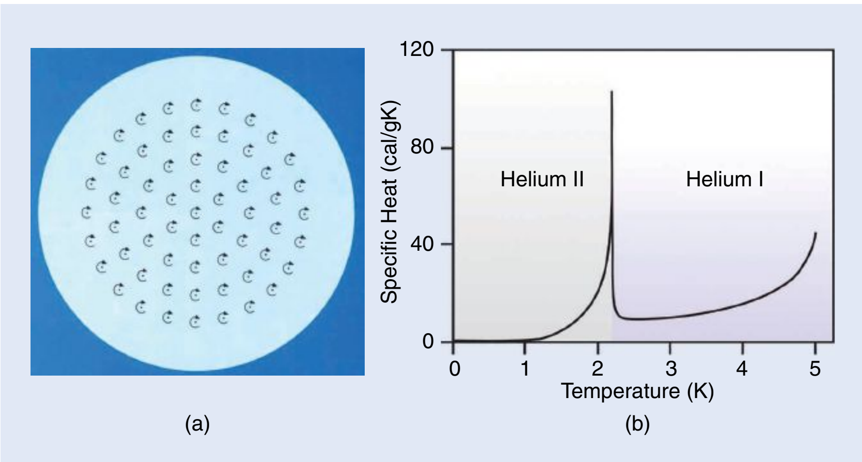

Figure 1: (a) A simulation of superfluid liquid ^{4}He (top view). When a cup of 1.1-cm diameter is rotated with $\omega = 0.05$ rad/s, a hexagonal array of vortices is formed. The vortices are 1 mm apart. (b) Specific heat of liquid helium versus temperature. The sharp discontinuity at $T = 2.17$ K (lambda point) is a sign of a phase transition from a normal fluid to a superfluid. (Permissions granted by Wiley-VCH and American Institute of Physics.)

precool the fourth one (e.g., N_2) [6]. This, however, renders the process very time-consuming and complex.

Now hydrogen and helium remained to be liquefied. As the scientists and engineers approached lower temperatures, more challenges surfaced. One of them was due to the temperature dependency of specific heat. Specific heat (C) is defined by the heat (Q) that is given or taken from a material to change the temperature by ΔT; i.e., it is expressed as $C = Q/\Delta T$ [7]. However, for all materials, the specific heat approaches zero as T approaches zero. This means that, at very low temperatures, even the slightest leak or exchange of heat causes a huge change in the temperature. That means the lower the temperature, the bigger the engineering challenge to isolate and preserve the liquid gas.

Another difficulty arose from the low mass of hydrogen and helium atoms. The lighter the atom, the higher the vibration of the atom around its equilibrium position. Hence, a lower temperature is required to reduce the vibration and ease the liquefaction [8].

In 1898, Sir James Dewar, professor of chemistry at the Royal Institute, obtained a few cubic centimeters of liquid hydrogen (boiling point = 20 K). His secret to success was his invented flask, now known as the *Dewar flask*. The Dewar flask is made of two glass bottles inside each other (something like your coffee Thermos). The outer wall is pumped out and is in a vacuum state. The inner wall is filled with liquid nitrogen (77 K), and, after another layer of vacuum, the innermost bottle is filled with the gas or liquid under investigation [9]. This way, the innermost layer is not in touch with the outside world, and heat cannot leak into it.

The whole flask is made of glass to make the contents visible. Dewar insisted on giving demonstrations and showing experiments while teaching; he wanted the contents of the experiment to be visible for the audience [6]. Previously, using only one or two layers of glass always caused frost formation on the outermost wall, which rendered things invisible, and the liquid would evaporate soon. In parallel with this, Carl von Linde succeeded in commercializing his gas liquefier based on the Joule–Thomson method. Polish chemists in Krakow also succeeded in liquefying oxygen [6].

In 1908, Heike Kamerlingh Onnes, a Dutch scientist, became the head of the low-temperature laboratory at Leiden University (see Figure 2). Luckily, he did his Ph.D. degree under the supervision of Johannes Diderik van der Waals at Amsterdam University. van der Waals provided a detailed theory of how the intermolecular forces work in gases and how they change with temperature, pressure, and volume. They knew that the van der Waals force between helium atoms is very weak, and, even at the lowest temperatures, the atoms in the gas vibrate crazily and refuse to join to form a liquid.

From the beginning of his appointment at Leiden (1881) until 1908, Onnes focused on liquefying air (nitrogen) as the initiator in his updated version of the cascade liquefier, and, through his links with businessmen, he managed to buy tons of monazite sand from the United States. Monazite sand has bubbles of helium trapped in it. He extracted 300 L of helium from the sand. He organized his lab and improved the quality of tools by hiring the best toolmakers, glassblowers, and technicians. By 1907, he had mustered 1,000 L of liquid air (nitrogen) and was ready to begin his next experiment.

On 10 July 1908, he began sending helium down the pipes of his cascade cooler [6] using liquid air, and, after 14 hours, he could see liquid helium sitting at the bottom of the Dewar flask—as much as a cup of tea. He excitedly showed this to van der Waals, as he owed this success to his mentor's theory [5]. That meant that Onnes won the race to liquify helium with Sir James Dewar—but what to do with the liquid helium?

Around that time, understanding the resistance of metals at low temperatures was a hot topic. Lord Kelvin predicted that, at low temperatures, the resistance of a metal goes up as electrons freeze and do not move fast enough to carry the current. Dewar predicted that the resistance goes uniformly and gradually to zero as the temperature approaches 0 K because the atoms in metal cease to vibrate, and they do not scatter electrons around. Hence, electrons move unscathed by any scatterer. Other opinions were something in between—i.e., as the temperature approaches 0 K, the resistance of the metal becomes a nonzero constant value.

Which one was right? Onnes thought it was a ripe time to put this to test, and the best verdict was the experiment. He boiled mercury and distilled it to get rid of impurities, which was an issue in experimenting with gold and copper.

In 1911, his assistant observed a sudden drop in the resistance of a current-biased

Figure 2: Heike Kamerlingh Onnes' low-temperature laboratory with the helium liquefier in the background. From left: Paul Ehrenfest, Hendrik Antoon Lorentz, Niels Bohr, and Onnes. The diagram of the cascade helium liquefier was displayed in the laboratory. (Source: IEEE Council on Superconductivity.)

Dewar insisted on giving demonstrations and showing experiments while teaching; he wanted the contents of the experiment to be visible for the audience.

mercury column as the temperature went below the boiling point of liquid helium (4.2 K). It turned out that this is not an error; indeed, the resistance of mercury drops suddenly to zero as the temperature is brought down below 4.2 K. Onnes called this state in mercury *superconductor*. In 1913, the Nobel Prize in Physics was awarded to him for these contributions [10], [11].

Between 1923 and 1933, Toronto and Leiden were the only places in the world to work on liquid helium.

With this discovery and an abundance of liquid helium at its disposal, Onnes' laboratory in Leiden became the only center of low-temperature physics in the world. It attracted many scientists to visit, work, or give seminars in the laboratory and research superconductivity—people like Albert Einstein, Niels Bohr, et al.

The outbreak of the First World War interrupted the low-temperature physics research in Leiden until it was restarted in the 1920s by a visitor researcher, Leo Dana, from Harvard University [12]. After doing his thesis on the latent heat of liquid oxygen–nitrogen mixtures in 1922, Leo Dana won a scholarship for a one-year stay in Leiden. He obtained Onnes' permission and support to use the liquefier and the assistants' help to measure liquid helium's latent heat and specific heat. He worked from 7 a.m. to 7 p.m. to get results before his one-year scholarship ended [12]. He observed that, when the temperature of liquid helium is brought under 2.17 K by evaporative cooling, there is a discontinuity in the specific heat [later called the *lambda point* since the plot looks like lambda—see Figure 1(b)].

Unfortunately, neither Onnes nor other scientists took these data seriously, and the work appeared in journals three years later. Note that helium starts to become liquid below 4.2 K, but, by pumping out the vapor from the liquid surface, i.e., the evaporative cooling process, it can be cooled down as low as 1 K. This is like blowing on your hot coffee to make it cooler by removing hot (high-energy) molecules from the surface and not letting them go back to the liquid and kick other molecules.

In 1927, Keeson and Wolfke in Leiden [10], [11] published a paper reporting that this lambda point signifies a phase transition in liquid helium. They called liquid helium above T_λ, *He I*, and the helium under T_λ was called the *He II phase*. They observed that, when He I is in the liquid state, it constantly and vigorously boils when the vapor is pumped from its surface. As they kept pumping out the vapor, the remaining liquid became cooler and cooler, and, as the temperature dropped below T_λ, suddenly, the liquid stopped boiling and remained as silent and clear as thin air, with no bubbles. It is so clear that, to see it, you must change your angle of view or use a flashlight or something similar to find the surface of the silent liquid. This is because the heat conductivity of He II becomes enormous, and the whole liquid has the same temperature at all points; hence, no bubbling occurs. Later, we will see that using a flashlight leads to another discovery!

Developments by Toronto Physicists

After the First World War, a Canadian physicist, Sir John Cunningham McLennan (a close friend of Ernest Rutherford), started a research program in low-temperature physics at the University of Toronto. John was born in Ingersoll, Ontario, in 1867. After doing his undergraduate degree in physics at the University of Toronto (1892), he worked as a demonstrator and then, until 1898, in Cavendish Laboratory at Cambridge University, United Kingdom. He then returned to Canada, and he became the first person to obtain a Ph.D. degree in physics in 1900 from the University of Toronto [13]. Later, he became a professor and director of the most advanced physics laboratory in Canada and contributed to different research areas, like magnetism, the physics of auroras, and superconductivity. In 1923, Sir John McLennan built a copy of Onnes' helium liquefier. Thus, Toronto became the second forerunner in the world to liquefy helium and for low-temperature research. Between 1923 and 1933, Toronto and Leiden were the only places in the world to work on liquid helium.

In 1929, a young graduate from the University of Manitoba joined McLennan's group. His name was John Frank (Jack) Allen. Allen was born in 1908 in Winnipeg, Manitoba. He studied at the University of Manitoba, as his father was a physics professor there. In Toronto, Jack Allen devoted his research to liquid helium and the properties of superconductors under McLennan's supervision. In 1932, he designed and built a cryostat to investigate the superconductivity of metals cooled by liquid helium. He also invented a vacuum-sealed O-ring for cryostats, which is a vital component to avoid vacuum leakage.

In the same year, McLennan was invited by the Royal Society in London, United Kingdom, to give a demonstration of persistent current in a superconductor ring. He took Allen's cryostat from Canada to England. To fill it with liquid helium, he asked his close friend, who was a Scottish lord and pilot, to take the cryostat to Leiden and fill it. Keesom, McLennan's Dutch friend in Leiden, was informed and transferred some liquid helium to Schiphol airport near Amsterdam. They filled the cryostat at 3 p.m. After a bumpy flight in a single-engine plane and a taxi ride (which evaporated some of the liquid helium), McLennan managed to start his presentation and demonstration on superconductivity at 8:30 p.m. He showed how a persistent 200-A current could be generated in a superconductive lead ring, and it will stay forever and ever if the lead ring is kept cool with liquid helium [10].

In 1933, Allen graduated with 10 papers on superconductivity [14], [15]. McLennan passed away in 1935, and, after that, Allen was invited by Sir Ernest Rutherford to work in Mond Laboratory at Cambridge University. Pyotr Kapitza founded Mond Laboratory, but he had already left Cambridge for Moscow. John Cockcroft [3], now official director of the laboratory, was in the process of shipping Kapitza's equipment to Moscow. The story goes that Kapitza was detained after a short visit to Moscow. He had no choice except to stay in Moscow and set up his physics laboratory anew, later known as the Institute for Physical Problems.

As a postdoctoral researcher with no supervisor, Allen set out a series of experiments studying the properties of liquid helium using Kapitza's still-available helium liquefier. In 1932, Kapitza had built this liquefier in Cambridge based on the gas expansion method instead of liquid hydrogen as an initiator.

In 1937, Donald Misener, another graduate student from McLennan's group in Toronto, joined Jack Allen in Cambridge to work on his Ph.D. thesis. Donald Misener was the first person who invented a setup to measure the viscosity of liquid helium back in Toronto in 1935. In a personal communication with Roussel J. Donnelly, another Canadian pioneer in superfluidity, he recalled he was looking for an experiment to obtain his M.A. degree in science at the University of Toronto and "It was evident that the physical properties of this liquid had never been measured even though it showed some peculiar patterns" [10].

As an example of those peculiar patterns, if a small glass-made bucket is filled with He II, it empties itself since the liquid creeps up the walls of the bucket and drops from below. Also, if the bucket is shaken a bit, the liquid keeps sloshing with no sign of damping. Misener was right to guess something must be special about the viscosity of this fluid. For this, he made a cylindrical pendulum hanging in liquid helium from a support rod [see Figure 3(a)]. The top part was connected to a torsion fiber to which a mirror was attached. He set the cylinder in rotary oscillation around the hanging fiber. He noticed that, if the temperature is below the lambda point (the He II phase), the oscillation has a very long decay time (as if it rotates in a fluid that has 1,000 times less friction than air), but, once the temperature is raised above the lambda point, it goes back to phase I, and the oscillation dampens immediately. Misener and his colleague, A. R. Clarke, performed this experiment in McLennan's laboratory, and the results were sent to *Nature* magazine [16].

In Cambridge, Allen and Misener carried out another set of experiments to measure the heat conductivity and viscosity of liquid helium during 1937, but, this time, they studied the flow of He II in long capillaries with radii from 0.1 to 100 μm. They noticed that, without applying any pressure difference (Δp = 0), there was a flow of liquid in very narrow capillaries. To see how puzzling this is, imagine if toothpaste or tomato ketchup flowed through a horizontally placed syringe needle by itself and with a very high speed!

At the same time, Kapitza was doing experiments in Moscow but using a different device he made [see Figure 3(b)]. It was a small glass cylinder with two microsized holes at the bottom and immersed in liquid helium. When the liquid was in phase I, it took a few minutes for the cylinder to empty itself through the holes. However, once he lowered the temperature below the lambda point, the cylinder was emptied in a second, proving that it reached a state with no friction (zero viscosity).

In December 1937, another young Canadian researcher named Webster, who was a Toronto graduate, came to Cambridge. He had just arrived from Moscow after working with Kapitza. He mentioned to John Cockcroft that Kapitza had recently submitted a letter to *Nature* reporting

As an example of those peculiar patterns, if a small glass-made bucket is filled with He II, it empties itself since the liquid creeps up the walls of the bucket and drops from below.

the viscosity of He II. Cockcroft, surprised by this news, as he did not expect such secrecy from his close friend, advised Allen and Misener to rush and send their results immediately to *Nature*. After asking Cockcroft to proofread Kapitza's letter, the editor published both letters, one after the other, in the January 1938 issue [4], [17]. Both groups reached the same conclusion that the viscosity of liquid helium in phase II is immeasurably small when the temperature goes as low as 1 K [14].

In February 1938, Allen; Misener; and another physicist from Yorkshire, Harry Jones, discovered the "fountain effect" [18]. To understand the effect of fine tube diameters on thermal conductivity, they built a tube with a small diameter at the top and a large U-shaped feature at the bottom immersed in He II [Figure 3(c)]. They filled the U-shaped part with a powder (because of its random networks of

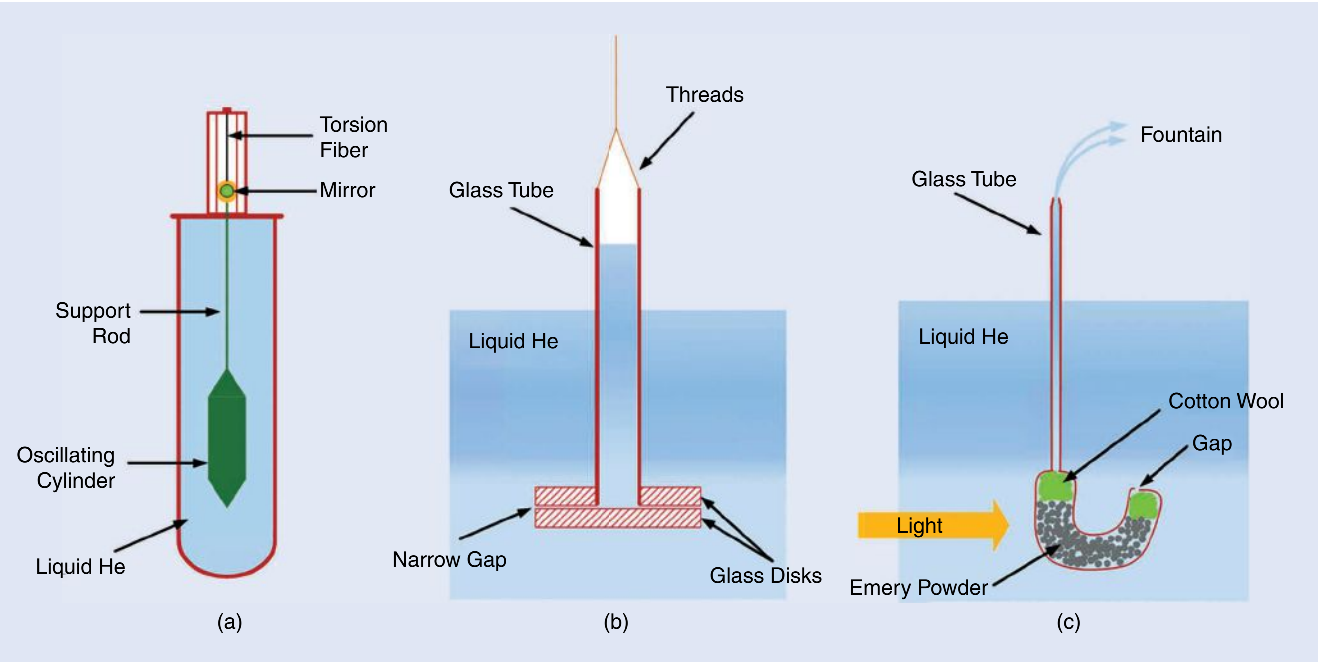

Figure 3: (a) The setup to measure the viscosity of liquid helium was invented by Misener in 1935 at the University of Toronto. From the damping of the oscillating cylinder, he could infer the friction between the liquid and metal. (b) The experiment was devised by Kapitza in 1938 in Moscow to measure the viscosity of superfluid helium. (c) The fountain effect discovered by Jack Allen was proof of the two-fluid model, wherein the superfluid component enters easily through the powder, moves against the temperature gradient, and tries to cool the warm parts. (Drawings adapted from [4] and [10].)

small holes) and blocked it with cotton wool. This time, Allen wanted to examine if the tube was immersed properly in the liquid. He used his flashlight to check the tube, and he noticed that He II spurted from the tip of the glass pipe every time he turned on the flashlight.

They noticed that, at lower temperatures (e.g., around 1 K), the fountain was taller. The next day, instead of heating the powder with a flashlight, they used a 60-W lamp, and they managed to have a fountain as high as 15 cm. Herbert Fröhlich, a German theorist, tried to give a theory for this effect, but it was wrong, contrary to his other amazing theories in other fields [1], [10], [18].

Then, Laszlo Tisza, a physicist in Paris (later to be a professor at the Massachusetts Institute of Technology) proposed his "two-fluid model" theory [19] by hypothesizing that liquid helium is a mixture of two independent, noninteracting fluids: a normal component with nonzero viscosity and a superfluid component with zero viscosity. If the temperature is above the lambda point, the whole liquid is excited to the normal part; once the temperature goes below the lambda point, the superfluid part starts growing until it becomes 100% dominant at temperatures below 1 K.

Later theoretical developments in the 1940s by Lev Davidovich Landau and E. L. Andronikashvili confirmed that, in Allen's fountain experiment, the normal part of the fluid wants to move from the high-temperature part to the low-temperature part, but, due to its viscosity, it is blocked by the powder (which has a random network of small holes as small as 100 nm). On the other hand, the superfluid part with zero entropy moves to the high-temperature part as it tries to keep the density of fluid constant, as $\rho_n(T) + \rho_s(T) = \rho$; as a result, a fountain forms [1], [8]–[10].

Figure 4: Jack Allen demonstrating a physics experiment in the classroom at the University of St. Andrews (dated 1970). (Special thanks to Jane Campbell, Special Collections Division, University of St. Andrews Library, for granting the permission.)

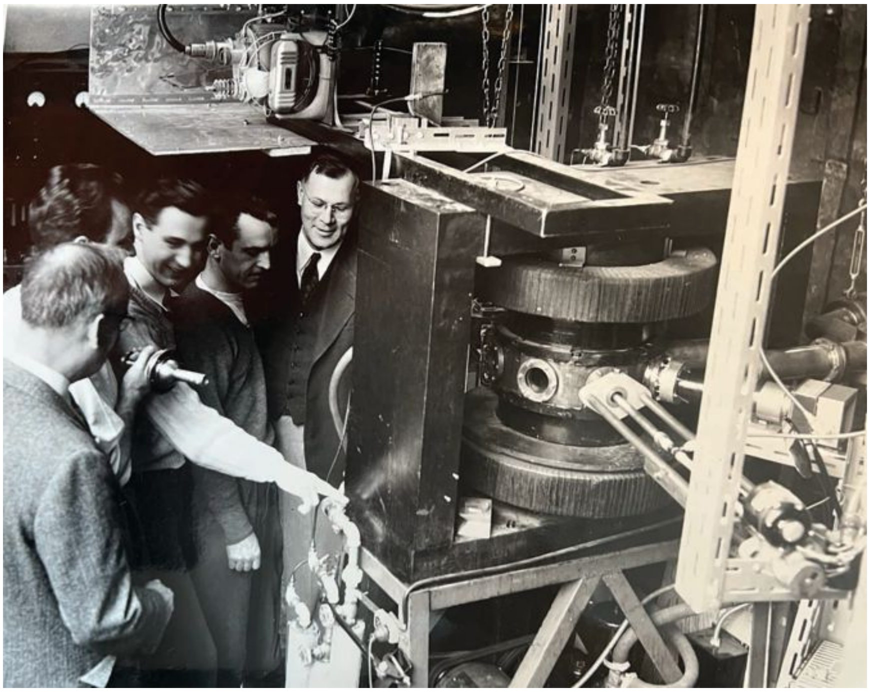

Figure 5: Donald Misener (far right) and colleagues at the Physics Laboratory at the University of Western Ontario. (Special thanks to Emily Adams and Prof. Robert. J. Sica, Western University, London, Ontario for the permission and their kind help in finding and sending this photo to the author.)

Later Developments

The quantum mechanical origin of superfluidity in liquid helium became gradually clear as many theoreticians and experimentalists entered the scene. In the Soviet Union, Landau seriously developed the two-fluid model, and it was approved by Andronikashvili's experiment, followed by works of Khalatnikov et al. In the United States, R. P. Feynman, F. London, L. Onsager, et al. worked actively in understanding this phenomenon. Fritz London suggested that superconductivity and superfluidity might have the same origin.

Today, we know that both effects are based on electrons' and atoms' coherent and in-unison motion as a wave. In analogy with a laser, electrons in superconductors and atoms in superfluids move in phase as a wave instead of randomly moving and elbowing and impeding each other. In superconductors, we can have electric current in zero voltage (i.e., resistance = 0). In superfluidity, we can have a flow of liquid without applying any pressure difference (i.e., viscosity = 0) [8].

Forty years later (1978), the Nobel Prize in Physics was only awarded to Pyotr Kapitza. Sadly, Allen and Misener did not share this award and appreciation, and their contributions remained unnoticed for many years. The reasons for and historical investigations regarding this underappreciation can be found elsewhere [14], [15].

One thing is undeniable and certain. Without the pioneering work of Allen and

Misener in Canada and England, Kapitza would not have been interested in the properties of liquid helium. However, by reading Kapitza's paper [4], we see that he had gumption that this property is of something of significance. He even dared to resemble it with superconductivity and label it with a name. However, the Canadian and Dutch experimenters seemed a bit modest or not so sure if they had stumbled upon something important.

Why? Maybe because Kapitza had a very strong theorist like Landau around. When the KGB arrested Lev Davidovich Landau, Kapitza sent a letter to Stalin and requested his immediate release by saying, "He [Landau] is the only one in the Soviet Union who understands the theory of this new discovery" [10], [14].

Or maybe the previous discovery, superconductivity, and its elusiveness were the focus of experimenters. Why was no one bothered about the aggressive bubbling of liquid helium and its sudden stop when the temperature reached the lambda point?

Because everyone was focused on lowering the temperature of metals in liquid helium to measure their electrical resistance—at least, this was the case for Leiden, since Onnes was dreaming of making superconductivity practical and commercial for zero-loss power transmission cables.

In a personal correspondence with Donnelly, Allen recalls, "In my Ph.D. work in Toronto on superconductivity, I had often seen the sudden cessation of boiling at the lambda temperature but had paid it no particular attention. It never occurred to me that it was of fundamental significance" [10].

Later, Jack Allen made contributions to the education of physics by making movies of superfluid phenomena, which turned out to be a challenging task. He became a professor of physics at St. Andrews University, Scotland, where he stayed until the end of his life in 2001 (see Figure 4). Donald Misener went back to Canada to work at the University of Western Ontario (see Figure 5). He contributed to the advancement of low-temperature physics in Canada. He served as the Head of Physics Department, President of CAP and Director of the Ontario Research Foundation.

In October 1972, D. D. Osheroff, R. C. Richardson, and D. M. Lee (Nobel laureates of physics in 1996) at Cornell University reported the observation of two different kinds of superfluidity (phase A and phase B) in a rare isotope of helium called ^{3}He (a helium atom sans a neutron) when it is cooled below 3 mK [1]. Lee was Russel J. Donnelly's Ph.D. student. Russel J. Donnelly (1930, Hamilton, Ontario, to 2015, Eugene, Oregon) was a Canadian physicist and professor at the University of Oregon. He worked with L. Onsager and S. Chandrasekhar at Yale and the University of Chicago. His research was focused on hydrodynamics, vortex dynamics, and turbulence in liquid helium (^{4}He). His book, *Experimental Superfluidity* [9], is still a great reference for both experimenters and theorists.

^{3}He never stops surprising scientists, and, today, its combination with ^{4}He has useful engineering applications. We will see a few of them in the next part(s). ■

Acknowledgment

I dedicate this humble article to the soul of my departed science teacher, Djafar Bagheri. His small box of colored chalks, nice cross sections of plants and planets on the blackboard, and fervent lecture on Carl von Linné will never be forgotten. Schools of these days can ill spare a teacher like him.

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About the Author

Daryoush Shiri received his Ph.D. degree in electrical and computer engineering in 2013 from the University of Waterloo, Canada. Prior to this, he worked at a few start-up companies as a radio-frequency/analog CMOS design engineer and team leader. His thesis was devoted to the computational study of electron transport in silicon nanowires. As a postdoctoral fellow at the Institute for Quantum Computing, Waterloo (2013–2015), he collaborated in developing a scalable package for quantum-computing circuits. He came to Sweden in 2016 as a postdoctoral fellow at the Department of Physics, Chalmers University of Technology, to work on heat transport in 2D materials. Currently, he is a researcher at the Quantum Technology Laboratory in the same university, working on the simulation of superconducting microwave circuits for quantum computing. He cosupervised several Ph.D. and master's degree students during these years. He loves teaching and always quotes John Archibald Wheeler: "If you would learn, teach."

We Just Couldn't Resist ...

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Mark Edison was an engineering student at Queen's University. He was also a tall and very strong fellow, so he decided to try out for the football squad. The coach simply couldn't decline having such a physically imposing person on the team. He was assigned as a defensive end.

Mark made a name for himself. Being the tallest and strongest guy on the squad, he would often overpower two people on the offensive line of the opposing team. This would frequently allow their star linebacker, Andrew Clarke, to rush in and sack the opposing quarterback. Following this playbook, Andrew was able to amass 32 sacks on the year. Together, they were known as the ACME connection (Andrew Clarke, Mark Edison).

As it turns out, the season came down to the Yates Cup game against Queen's archrival, Western University. Moreover, it meant that Andrew's talented brother, Daniel, would be in town. Daniel was an exceptional running back, registering an impressive 24 touchdowns on the season.

The game was a close and exciting one, with both teams trading leads. It was third down for Western at their own 30 yard line, with three seconds left on the clock. Queen's was up by five points. Time for one more desperation play. Western needed a touchdown to win the game, and all Queen's had to do was stop the play for the win. With the ACME connection on defense, victory seemed all but certain for Queen's!

Western took the snap, and the ball was handed to Daniel Clarke to try to work his magic. Mark easily overpowered the exhausted Western offensive line and found himself with a clear path toward Daniel. He decided to go for the game-ending tackle! Unfortunately, it was usually Andrew who would blow through the line and make the tackle. Andrew couldn't get past his hulking teammate, and ended up colliding with him. Daniel hopped past both hapless defenders on the way to a highlight-reel, improbable 80-yard touchdown for the win.

Mark felt terrible for his misstep. When interviewed after the game, he lamented, "I ended up blocking AC, and I let DC pass right through. I guess I just choked." ■

Grants Energize Student Technical and Professional Growth

Our donor-funded Special Grants program supports new and innovative projects involving students and other groups in IEEE Canada. The grants are of a size that fit the scope, scale, and time frame of typical Student Branch and student team initiatives. The recipients are allowed and encouraged to seek other sources of funding. This can provide opportunities for students to reach out to local industry to build connections and enhance the reputation of IEEE Canada in industry.

More than 320 grants have been provided in support of IEEE interests, all specifically in Canada. Our first grant was made in 1958–1959, well before we took on our present status as a formally established, public benefit corporation and registered charity in Canada. Your gifts enable opportunities for students to collaboratively apply classroom learning in the growth of both technical and soft skills.

University of British Columbia students on the Unmanned Aircraft Systems team.

UBC UAS—IEEE Canadian Foundation Grant Recipient

University of British Columbia (UBC) students in the Unmanned Aircraft Systems (UAS) group applied for and received an IEEE Canadian Foundation Special Grant to support development of the electrical and computer engineering aspects of their UAS. Although the actual competition portion was regretfully cancelled due to the COVID-19 pandemic, students benefited as outlined in their project completion report:

- "UBC UAS's goal is to design and build innovative unmanned aerial systems with real-life applications like disaster response, wildlife analysis, agricultural surveys, law enforcement, and forest fire fighting missions."
- "This project has helped 65 students develop various technical and soft skills. These include learning how to design mechanical and electrical systems, building and testing prototypes, simulating systems, laying out PCBs (printed circuit boards), soldering and assembling components, writing efficient code in different languages, and conducting well-designed and documented quality checks."
- "Members also developed skills in organising the team and subteam, communicating efficiently in an online setting, problem solving, networking, and working in a team. These are crucial skills for aspiring engineers and essential to make them more employable."

IMPORTANT UPDATES

IEEE Canadian Review (*ICR*) is now a "default-digital" publication.

What does this mean?

- All IEEE Canada members will receive *ICR* in digital formats, either through the website or through the IEEE app.
- Members who have explicitly requested not to receive electronic communication will not receive the digital copies. Default mail delivery of print copies will be discontinued to those members in the future. Members are encouraged to opt in for print copies or modify their electronic communication preferences to receive digital copies.
- A print copy will be delivered only to those full-grade members who request it. This will be provided free of additional costs (included in the annual membership fee). Members can opt in for print or digital copies through IEEE membership renewal web page.

Radio Science in Canada

by **David G. Michelson**

The International Union of Radio Science (abbreviated URSI, after its French name, Union Radio-Scientifique Internationale) has a long history of cooperating with IEEE to advance international cooperation in the study of electromagnetic fields and waves. This month's column focuses on URSI conferences in Canada, an initiative to strengthen URSI's presence at the local level in Canada, and a Canadian resolution and U.S. recommendation that were both passed unanimously at the URSI General Assembly and Scientific Symposium in Rome last September.

INTERNATIONAL UNION OF RADIO SCIENCE CONFERENCES IN CANADA

Since its inception in 1952, the Canadian National Committee of the International Union of Radio Science (URSI) has led the effort to host URSI conferences in Canada. These include the following:

- URSI General Assembly and Scientific Symposium (URSI GASS): Ottawa, 1969, and Montreal 2017
- IEEE Antennas and Propagation Society (AP-S)/URSI International Symposium on Antennas and Propagation and North American Radio Science Meeting: Quebec City, 1980; Vancouver, 1985; London, 1991; Montreal, 1997; Columbus, 2003; Toronto, 2010; Vancouver, 2015; and Montreal, 2020
- URSI North American Radio Science Meeting: Ottawa, 2007
- URSI Electromagnetic Theory Symposium (EMTS): Toronto, 1959, and Victoria, 2001.

The first three meetings are large events that draw between 1,500 and 2,000 attendees, while EMTS is a much smaller event that draws a few hundred people. In all cases, Canada has earned an enviable reputation for hosting very successful events that have set records for attendance, financial performance, and attendee experience.

In 2021, Canada was awarded two international URSI conferences:

- URSI EMTS 2025 will bring a few hundred attendees to the University of British Columbia in Vancouver from 11–16 May 2025 to share recent results concerning topics within the fields of interest of Commission B–Electromagnetic Fields and Waves.
- IEEE AP-S/URSI 2025 will bring almost 2,000 attendees to the Shaw Centre in Ottawa from 13–18 July 2025 and involve all 10 URSI commissions.

Planning for these events will begin in earnest in 2022. Those interested in joining the group of volunteers who are organizing the events should contact me at either dmichelson@ieee.org or president@ursi.ca.

TOWARD IEEE AP-S/URSI JOINT CHAPTERS

Given the close cooperation between the IEEE AP-S and URSI at the national and international levels, CNC–URSI has proposed inviting the nine IEEE AP-S Chapter chairs in Canada [Vancouver, Northern Canada (Edmonton), Southern Alberta (Calgary), Winnipeg, Kitchener-Waterloo, Toronto, Kingston, Ottawa, and Montreal] to take on a secondary role as a CNC–URSI liaison or local representative and thereby deliver additional value to our joint communities at the local level. The local representative would ensure awareness of URSI events and opportunities, e.g., scholarships, conferences, publications, awards, and so on. He or she would also work to include more URSI-sourced content at Chapter meetings, e.g., CNC–URSI Distinguished Lecturers.

Over the past year, we have consulted the Canadian IEEE AP-S Chapter chairs, leadership of the U.S. National Committee of URSI, URSI Secretary-General Peter Van Daele, and, of course, IEEE AP-S Chapters Coordinator Ajay Poddar. Because the response has been uniformly positive, we will start to implement the scheme during 2022. We anticipate that this effort will lead to the formation of new IEEE AP-S Chapters in Atlantic Canada in the near future and hope that it will ultimately lead to the formal branding of our AP-S Chapters as AP-S/URSI Joint Chapters.

2021 U02 RESOLUTION ON THE STRENGTHENING OF THE URSI AND INTERNATIONAL TELECOMMUNICATIONS UNION RELATIONSHIP

In our last column, we noted that URSI has a long history of supporting the mission of the International Telecommunications Union (ITU) and that, during URSI GASS 2021 in Rome, the URSI Council would consider a Canadian resolution to establish an URSI–ITU Working Group that would provide a mechanism to enhance cooperation between our two organizations. I'm pleased to report that Resolution U02 was passed unanimously:

The URSI Council, considering

a) that URSI should play a role in the advancement of telecommunications science in general;
b) that the activities of URSI include the study of topics relevant to the advancement of telecommunications, some of which are of direct interest to the International Telecommunications Union (ITU);

resolves that the Board shall form an URSI-ITU Inter-Commission Working Group that will:

1) work within the ITU organisation to identify those areas that may influence the evolution of telecommunications in the long term;
2) keep the URSI community informed on specific questions posed by ITU study groups and WRC Agenda items and particularly those falling under the purview of expertise within the URSI Commissions;
3) stimulate and coordinate studies, collaborations, and symposia that will

(Continued on p. 28)

David John Kemp


David John Kemp

David John Kemp, Senior Member of IEEE, FEIC, passed away on 5 January 2022. Dave graduated with a diploma in electronics engineering technology from the Manitoba Institute of Technology and, later, a certificate in industrial management and administration. He worked for 35 years in the telecom industry. Dave retired as director, information technology, MTS Advanced, a convergent technology service broker. He then engaged as business manager of the Industrial Applications of Microelectronics Centre at the University of Manitoba. Dave went on to consulting activities in Europe and, subsequently, managed the Industrial Hearing Conservation Division of Kemp Hearing Centres.

Dave served as a Board member of both the Electronics Industry Association of Manitoba and the Canadian Institute of Management. He served as the 2018 chair of the Library Board for the City of Winnipeg Public Library system, following several years as a Board member.

Dave began his IEEE involvement by establishing an IEEE Student Branch at Red River College in Manitoba. He subsequently held key officer positions with the IEEE Winnipeg Section. Dave then went on to Region 7 roles, becoming the IEEE Canada Region 7 director and president of IEEE Canada in 1998. Dave served as IEEE secretary in 2000.

Dave's accomplishments include: initiating and chairing the IEEE corporate rebranding initiative of the early 2000s and establishing the IEEE Graduates of the Last Decade (GOLD) program (now Young Professionals). He has served on numerous IEEE boards and committees, including the IEEE Board of Directors, IEEE Awards Board Policy and Portfolio Committee, IEEE Honorary Member Committee, IEEE Service Awards Committee, IEEE Member Benefits and Policy Advisory Committee, IEEE Centre for Leadership Excellence, IEEE History Committee, IEEE Life Member Committee, and IEEE Canadian Foundation.

The Dave Kemp Memorial Fund has been established in association with IEEE Canada in support of aspiring students and professionals.

Dave received several awards, including the following:

- IEEE Outstanding Leadership and Service to Student Branch, 1965 (Winnipeg Section)
- IEEE Centennial Medal, 1984
- Region 7 Western Canada Silver Medal Merit Award, 1990
- IEEE Professional Communication Society Emily K. Schlesinger Award, 1995
- IEEE RAB (MGA) Leadership Award, 1998
- Fellow, The Engineering Institute of Canada, 1998
- IEEE Millennium Medal, 2000
- IEEE Canada W.S. Read Outstanding Service Award, 2009.

David John Kemp

David John Kemp, membre senior de l'IEEE, FEIC, est décédé le 5 janvier 2022. Dave a obtenu un diplôme en technologie du génie électronique de l'Institut manitobain du commerce et de la technologie et, plus tard, un certificat en gestion et administration industrielles. Il a travaillé pendant 35 ans dans l'industrie des télécommunications. Dave a pris sa retraite en tant que directeur de la technologie de l'information, MTS Advanced, un courtier de services de technologie convergente. Il s'est ensuite engagé comme directeur commercial du Centre des applications industrielles de la microélectronique à l'Université du Manitoba. Dave a poursuivi des activités de conseil en Europe et, par la suite, a dirigé la division de conservation de l'ouïe industrielle de Kemp Hearing Centres.

Dave a été membre du conseil d'administration de l'Association de l'industrie électronique du Manitoba et de l'Institut canadien de gestion. En 2018, il a été président du conseil d'administration de la bibliothèque du réseau des bibliothèques publiques de la ville de Winnipeg, après plusieurs années en tant que membre du conseil.

Dave a commencé son implication dans l'IEEE en établissant une branche étudiante de l'IEEE au Red River College au Manitoba. Il a ensuite occupé des postes clés d'officier au sein de la section IEEE de Winnipeg. Dave a ensuite occupé des postes dans la région 7, devenant directeur de la région 7 de l'IEEE Canada et président de l'IEEE Canada en 1998. Dave a occupé le poste de secrétaire de l'IEEE en 2000.

Les réalisations de Dave comprennent: le lancement et la présidence de l'initiative de changement de marque de l'IEEE au début des années 2000 et la création du programme IEEE Graduates of the Last Decade (GOLD) (maintenant Young Professionals). Il a siégé à de nombreux conseils et comités de l'IEEE, notamment le conseil d'administration de l'IEEE, le comité des politiques et du portefeuille du conseil des récompenses de l'IEEE, le comité des membres honoraires de l'IEEE, le comité des récompenses de service de l'IEEE, le comité consultatif sur les avantages et les politiques des membres de l'IEEE, le centre IEEE pour l'excellence en leadership, IEEE Comité d'histoire, Comité des membres à vie de l'IEEE et Fondation canadienne de l'IEEE.

Dave a reçu plusieurs prix, dont les suivants:

- Direction et service exceptionnels de l'IEEE à la branche étudiante, 1965 (section de Winnipeg)
- Médaille du centenaire de l'IEEE, 1984
- Médaille d'argent du mérite de la région 7 de l'Ouest canadien, 1990
- Prix Emily K. Schlesinger de la Société de communication professionnelle de l'IEEE, 1995
- Prix du leadership IEEE RAB (MGA), 1998
- Boursier de L'Institut canadien des ingénieurs, 1998
- Médaille du millénaire IEEE, 2000
- Le Prix WS Read du Service Exceptionnel de l'IEEE Canada

Dave a été le mari de Lynn pendant 55 ans, le père de Jason (Krystal) et de Janine (Al) et le grand-père de Tianna (Marissa), Dave was a husband to Lynn for 55 years, father to Jason (Krystal) and Janine (Al), and grandfather to Tianna (Marissa), Hayley (Christian), Benjamin, Jackson, and Calvin. Dave had a wonderful supportive family near and far and many long-time friends.

The Dave Kemp Memorial Fund has been established in association with IEEE Canada in support of aspiring students and professionals. Donations in honour of Dave may be made at https://www.ieeecanadianfoundation.org/EN/davekempmemorial. ■

Hayley (Christian), Benjamin, Jackson et Calvin. Dave avait une merveilleuse famille de soutien proche et lointaine et de nombreux amis de longue date.

Le fonds commémoratif Dave Kemp a été créé en association avec l'IEEE Canada pour soutenir les étudiants et les professionnels en herbe. Les dons en l'honneur de Dave peuvent être faits à https://www.ieeecanadianfoundation.org/EN/davekempmemorial. ■

Dr. Madan M. Gupta

Dr. Madan M. Gupta, Life Fellow of IEEE, Fellow of the International Society for Optical Engineering (SPIE), and Fellow of the International Fuzzy Systems Association (IFSA), passed away on 8 November 2021 in Saskatoon, Saskatchewan, Canada. At the University of Saskatchewan, he was a distinguished research chair, engineering professor, and founder and director of the Intelligent Systems Research Laboratory.

Dr. Gupta was born in Lansdowne, India, on 10 April 1936. He received his B.E. (Hons.) and M.E. degrees in electronics–communications engineering from the Birla Engineering College, Pilani, India, in 1961 and 1962, respectively. As a commonwealth scholar, he received his Ph.D. degree from the University of Warwick in 1967. Dr. Gupta joined the University of Saskatchewan in November 1967, where he served for more than 54 years.

Dr. Gupta authored or coauthored more than 1,000 reviewed and published research papers. Among other publications, he coauthored the seminal book *Static and Dynamic Neural Networks: From Fundamentals to Advanced Theory*. His research interests spanned topics such as adaptive control systems, fuzzy computing, neurocomputing, neuro-vision systems, and neurocontrol systems.

He was elected Fellow of IEEE for his contributions to the theory of fuzzy sets and adaptive control systems and for the advancement of the diagnosis of cardiovascular disease. He was elected fellow of the SPIE for his contributions to the field of neuro-control and neuro–fuzzy systems. He was also elected fellow of the International Fuzzy Systems Association for his contributions to fuzzy–neural computing systems. In addition to numerous honors and awards, in 1998, Dr. Gupta received the prestigious Kaufman Prize Gold Medal for research in the field of fuzzy logic. In the fall of 1998, for his extensive contributions in neuro-control, neuro-vision, and fuzzy–neural systems, Dr. Gupta earned a D.Sc. degree by the University of Saskatchewan.

In addition to an accomplished career, Dr. Gupta was a founding member of the Hindu Society of Saskatchewan. While serving as the president of the society from 1983 to 1985, he worked with the Saskatoon community to have the Shri Lakshmi Narayan Temple built. Dr. Gupta was an avid nonfiction reader, puzzle solver, and gardener. He enjoyed traveling with his family and exploring destinations around the world. ■

Dr. Madan M. Gupta

Dr. Madan M. Gupta

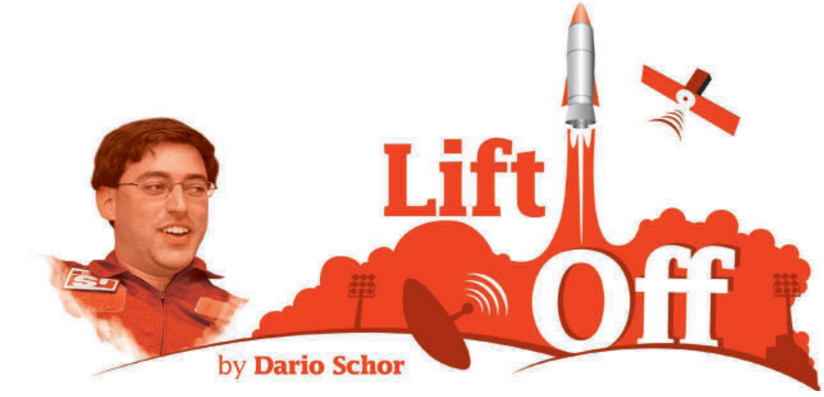
Dr. Madan M. Gupta est membre à vie de l'IEEE, membre de la Société internationale d'ingénierie optique (SPIE), et Fellow de l'International Fuzzy Systems Association, est décédé le 8 novembre 2021 à Saskatoon, Saskatchewan, Canada. À l'Université de la Saskatchewan, il a été titulaire d'une chaire de recherche distinguée, professeur d'ingénierie, fondateur et directeur du Laboratoire de recherche sur les systèmes intelligents.

Dr. Gupta est né à Lansdowne, en Inde, le 10 avril 1936. Il a obtenu ses diplômes BE (Hons.) and ME en génie électronique et des communications du Birla Engineering College, Pilani en Inde, en 1961 et 1962, respectivement. En tant que chercheur du Commonwealth, il a obtenu son doctorat. Diplômé de l'Université de Warwick en 1967. Dr. Gupta s'est joint à l'Université de la Saskatchewan en novembre 1967, où il a servi pendant plus de 54 ans.

Dr. Gupta est l'auteur ou le coauteur de plus de 1 000 articles de recherche révisés et publiés. Entre autres publications, il est coauteur du livre fondateur *Static and Dynamic Neural Networks: From Fundamentals to Advanced Theory*. Ses intérêts de recherche couvraient des sujets tels que les systèmes de contrôle adaptatifs, l'informatique floue, la neuroinformatique, les systèmes de neuro-vision et les systèmes de neuro-contrôle.

Il a été élu Compagnon de l'IEEE pour ses contributions à la théorie des ensembles flous et des systèmes de contrôle adaptatifs et pour l'avancement du diagnostic des maladies cardiovasculaires. Il a été élu membre du SPIE pour ses contributions dans le domaine du neuro-contrôle et des systèmes neuro-flous. Il a également été élu membre de l'International Fuzzy Systems Association pour ses contributions aux systèmes informatiques neuronaux flous. En plus de nombreux honneurs et récompenses, en 1998, Dr. Gupta a reçu la prestigieuse médaille d'or du prix Kaufman pour ses recherches dans le domaine de la logique floue. À l'automne 1998, pour ses importantes contributions aux systèmes de neuro-contrôle, de neurovision et de neurones flous, Dr. Gupta a obtenu un D.Sc. diplôme de l'Université de la Saskatchewan.

En plus d'une carrière accomplie, Dr. Gupta a été membre fondateur de la Hindu Society of Saskatchewan. Alors qu'il était président de la société de 1983 à 1985, il a travaillé avec la communauté de Saskatoon pour faire construire le temple Shri Lakshmi Narayan. Dr. Gupta était un lecteur passionné de non-fiction, un résolveur d'énigmes et un jardinier. Il aimait voyager avec sa famille et explorer des destinations à travers le monde. ■



After decades of unfulfilled promises, more space tourists flew in 2021 than in the previous 60 years combined. While still too expensive for most people, the idea that an individual can purchase a seat on a rocket to experience microgravity and observe the pale blue dot from space is mind boggling. This article provides a brief history of space tourism and current challenges facing the industry.

Ad astra,
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What Is Space Tourism?

In the words of Tom Rogers, space tourism "is concerned only with people who live on Earth who will take trips to/from space, and not beings from elsewhere in the universe who might take trips to visit the Earth" [1]. It is a kind of adventure vacation offering stunning sights of Earth and the heavens while also providing unique microgravity experiences.

According to Rogers [1] and Chang [2], there are four fundamental reasons why space tourism is important:

- *as an end in itself*: promoting a growing space market
- *as a means to achieving other space ends*: increasing revenue streams for the space industry
- *as a facilitator of other space activities*: a precursor for new space activities and technologies
- *as an expression of our society's character*: bringing the transformative space experiences to the masses.

There are many categories of space tourism [2]–[4]. Though not technically in space, some choose to market near-Earth activities as space tourism because they provide a space-like sensation for a fraction of the cost. These include parabolic flights, where participants experience a few seconds of microgravity in high-altitude aircraft, giving a glimpse of Earth's atmosphere against the deep darkness of space. However, for many people, space tourism starts with suborbital flights, where participants get a few minutes in space and promptly return to Earth. Continuing along this spectrum, a more powerful rocket would allow participants to enter low-Earth orbit and stay in space for hours or days. Depending on the trip, the spacecraft may or may not dock with an orbiting all-inclusive space hotel. Finally, one can conceive of trips landing on other celestial bodies.

A Short History of Space Tourism

Space tourism is not a new concept. Aside from ancient myths and science fiction references, space and travel entrepreneurs have been promoting the idea that humans would soon be able to travel to outer space and visit celestial bodies [3], [5]. Trying to stay ahead of the curve, Thomas Cook, a British travel agency, began a "Moon Register," attracting more than a thousand people to register in 1954 for a future lunar adventure—years before the launch of *Sputnik* [3]. Later, in 1968, Pan Am Airlines initiated a similar campaign known as the *First Moon Flights Club*, where the 93,000 members signed up and received a certificate with a serial number along with a letter reading, "Starting date of service is not yet known. . . . Fares are not fully resolved and may be out of this world" [3].

The first attempt at privately funded space tourism was initiated by Robert Truax in 1981 [2], [3]. After pioneering the work on hypergolic propellants and building the steam-powered rocket (or motorcycle, as it was legally registered) used by Evel Knievel to jump over the Snake River Canyon, Truax began working on a low-cost suborbital passenger spacecraft known as the *Skycycle X-3* [3], [6]. Although a brilliant engineer, his pitch appearing in the *Wall Street Journal* for "risky capital for risky project" failed to secure the necessary funds [6]. Moreover, even after appearing on *The Tonight Show* with Johnny Carson, none of Truax's interested customers could afford the $100,000 ticket price to become the first private space explorer [6]. Thus, after a decade-long effort, Truax abandoned the *Skycycle X-3* project.

Early in the Shuttle days, NASA identified the challenges in teaching astronauts to operate complex payloads in space. Consequently, McDonnell Douglas proposed flying its own engineer, Charles Walker, to operate a protein crystal payload aboard the Shuttle while becoming the first nongovernment-affiliated astronaut. Around the same time, the agency initiated journalists-, politicians-, and teachers-in-space programs to help promote the agency and its educational goals [5]. To be clear, these individuals were not spaceflight participants but, rather, civilians selected and trained to serve as payload specialists. Having said that, they did ignite the imagination of space entrepreneurs [5].

NASA's programs led to spin-offs for passenger modules that could fit within a spacecraft's cargo bay [7]–[9]. For instance, in 1985, the Space Expeditions travel agency out of Seattle suggested a detailed schedule for a "3-day cruise to nowhere in space" aboard a 24-passenger cabin with room to float around and a bar for refreshments [9]. Unfortunately, things didn't turn out as planned. Putting aside Utah Senator Jake Garn's legacy setting the scale to measure of space motion sickness, both the NASA programs to fly civilians on the Shuttle and the excursion packages came to a devastating end in 1986, when the beloved social studies teacher Christa McAuliffe perished in the *Challenger* disaster [2], [5]. However, the harsh realities of human spaceflight did not deter NASA from adapting the idea of a pressurized middeck module into Spacehab to carry additional supplies to the International Space Station (ISS) [5].

Discouraged by the NASA experience and before Britain joined the European Space Agency, a group of British companies initiated a private campaign to launch the first Briton into space. After sorting through 13,000 applicants, Helen Sharman was selected on live television like a present-day reality TV show. (Nowadays, this would be a reality TV show). Though privately funded, she went through a two-year training cosmonaut program with Roscosmos before visiting the *Mir* space station in 1991.

In the mid-1990s, the X Prize Foundation announced the X Prize competition for the first private organization to fly a reusable crewed spacecraft to the Kalman line twice within a two-week period [2], [3]. The $10 million prize attracted global attention, revived discussions for civilian flights, and led to the first international symposium on space tourism in Bremen, Germany, in 1997 [2].

The space tourism momentum was picking up. In 1998, Eric Anderson founded Space Adventures in Virginia for the sole purpose of creating spaceflight opportunities for his clients [2]. By 1999, a British businessman by the name of Peter Llewellyn began training with Russian cosmonauts to become the first spaceflight participant for a hefty $100 million to help support the *Mir* space station and help build a new hospital [10]. As many predicted, he was unable to raise the necessary funds and never flew to space. However, this set the precedent that Roscosmos was open for business.

Two years later, in 2001, Dennis Tito became MirCorp's first spaceflight participant [2]. Despite criticism from some NASA officials, Tito became the first space tourist, flying on the Soyuz TM-32 mission and spending eight days on the ISS for a mere $20 million. Over the next decade, there would be seven more trips to the ISS coordinated by Space Adventures, including Canadian Guy Laliberté in 2009.

In 2004, the first private suborbital crewed vehicle, *SpaceShipOne*, reached the edge of space [3]. Designed by the California-based company Scaled Composites, the spacecraft was attached in a parasite configuration to a jet-powered aircraft. Later that year, the company won the X Prize competition, achieving two suborbital flights, reaching altitudes of 103 and 112 km with the same spacecraft only six days apart [3].

Following on the success from *SpaceShipOne*, a joint venture between Virgin Galactic and Scaled Composites designed and built *SpaceShipTwo* to carry up to six passengers. The first prototype broke up during a test flight in 2014, killing one pilot and injuring the other [3]. After a crash investigation, the company continued to work and qualify its vehicle for spaceflight participants.

In 2010, expecting growth within the space tourism industry, Title 51 of the U.S. Code was updated with new sections regulating commercial spaceflight activities. Amongst the changes, the Americans introduced terms to differentiate between government astronauts, crew, and spaceflight participants (i.e., tourists) based on their training, rights, and responsibilities (USC § 50902 Definitions for Commercial Space Launch Activities). In layperson's terms, this was like the different roles on a ship. More importantly, these laws would later feed into how the Federal Aviation Administration (FAA) licensing process for any nongovernment human spaceflight activity. Finally, it is worth noting that legal scholars have yet to agree on how these terms fit within the language used in international agreements like the 1967 Outer Space Treaty.

Figure 1: The crew from Inspiration4 aboard the SpaceX Crew Dragon. [Credit: SpaceX. Source: https://www.flickr.com/photos/spacex/51492841387/. License: attribution-noncommercial 2.0 generic (CC BY-NC 2.0).]

When the Space Shuttle was decommissioned, NASA purchased additional seats on the Soyuz to fly crews to and from the ISS. Ergo, Roscosmos's manifest was booked, and there were no vacation seat sales for space tourists from 2009 to 2021.

However, during that time, there were many new space companies designing and testing prototypes to fly civilians. Building on the success of their Stratollite and Z-Class experimental cargo platforms, World View Enterprises began working on a stratospheric balloon capable of carrying passengers to 100,000 ft. Being only a third of the way to space means the flights are significantly cheaper than those of competitors while still offering breathtaking views of the planet.

In addition to Virgin Galactic's *SpaceShipTwo*, two other companies set to develop suborbital passenger vehicles [2], [4]. XCOR Aerospace built prototypes of the Lynx single passenger rocket–plane, but after years of development, the company filed for bankruptcy before testing its spacecraft [2]. In contrast, Jeff Bezos's Blue Origin developed the New Shepard vertical-takeoff, vertical-landing rocket carrying a crew capsule for six passengers [2], [4].

On the orbital front, there are three front-runners who were all initially supported by NASA's Commercial Crew Program. Sierra Nevada Corporation's Dream Chaser is a seven-passenger space plane mounted on top of a rocket capable of docking with the ISS before returning to Earth and landing on a runway like the Space Shuttle [2]. In contrast, Boeing's Starliner and SpaceX's Crew Dragon are both capsule designs that fly on top of a rocket and parachute down to the ocean [2], [4]. Both vehicles went through various tests over the course of the last decade in preparation for their maiden crewed flights. Not to be outdone, Bigelow Aerospace began testing its inflatable structures on the ISS in the hopes of establishing the first orbital all-inclusive hotel.

Amid a global pandemic, 2021 was filled with space tourism milestones [11]:

- *July 11*: *SpaceShipTwo*'s first operational suborbital flight took off from Spaceport America in New Mexico carrying four passengers, including Virgin Galactic's founder Richard Branson. The crew spent four minutes in microgravity and reached apogee at an altitude of 86 km.
- *July 20*: After numerous unmanned test flights, Jeff Bezos, Wally Funk, and two others experienced the 10-min flight of their lifetimes, reaching an

altitude of 107 km in Blue Origin's New Shepard spacecraft.

- *September 15*: Billionaire Jared Isaacman chartered a three-day SpaceX Crew Dragon orbital flight, known as Inspiration4 (Figure 1), as part of a fundraising campaign for St. Jude Children's Research Hospital. The event marked the first time a four-person crew orbited the planet without a professionally trained astronaut on board.
- *October 5*: Russian actress Yulia Peresild and producer/videographer Klim Shipenko boarded the Soyuz MS-19 spacecraft to film *The Challenge*. This fictional movie tells the story of a Russian cosmonaut requiring emergency surgery to return to Earth. The film crew spent 12 days on the ISS, beating Tom Cruise to become the first film shot in outer space.
- *October 13*: *Star Trek*'s William Shatner became the oldest person to reach space as a four-person crew flew aboard New Shepard (Figure 2) and passed the Kalman line.
- *December 8*: Space Adventures was back in action, flying two Japanese spaceflight participants on the Soyuz MS-20 for a 12-day ISS experience.
- *December 11*: The third Blue Origin flight of 2021 took a six-person crew to the edge of space.

Interestingly, with so many spaceflight participants flying in 2021, the FAA announced that it would terminate the "Commercial Space Astronaut Wing" program that awarded astronaut-like commemorative pins to spaceflight participants [11]. For now, it is expected that most launch providers will offer their own version. But, as trips become more frequent, it is conceivable that in the future passengers will step off a space capsule and walk into a gift shop to purchase a souvenir from their experience.

The aforementioned companies are already filling up flight manifests for 2022 and beyond. In parallel, Axiom Space is also planning its first mission of carrying four passengers to the ISS aboard the SpaceX Crew Dragon for early 2022 [11]. The flight is not technically a vacation, as the four businesspeople will be assessing opportunities for commercial ventures in space. Axiom sees this as a first step toward establishing its own space station for lodging, research, and manufacturing purposes. Not to be outdone, Blue Origin and Sierra Nevada Corporation are investing in their own Orbital Reef space hotel. Needless to say, the future looks very exciting.

Future Challenges

After many failed predictions, space tourism is finally becoming a reality. However, in addition to technological, financial, and legal challenges, the industry has also met with some criticism. Unlike the previous generations mesmerized with the Apollo launches, a large portion of today's audience is concerned with how recurring recreational rocket launches will affect climate change [11]. This goes beyond the effects of a single suborbital or orbital launch and how that compares to transatlantic flights. The real concern is growing a relatively new industry without a sustainable foundation. What would the greenhouse emissions be like if one of these space entrepreneurs delivers on his or her promise for the number of flights per year?

In an ideal scenario, passengers flying will experience their own "overview effect" that invigorates them to address issues relating to climate change [11]. The effect could be even more significant if any of the billionaires currently flying use their influence and resources to help our planet. Traditionally, astronauts spend part of their training learning about our planet to use while admiring the pale blue dot from the ISS cupola over the course of their missions. In contrast, spaceflight participants will only get a short amount of time in space, so they may be busy adjusting to microgravity, looking out the window, and taking pictures to share on social media. Therefore, as space historian Jordan Bimm warns us, these tourists may claim they had a transformative experience and use that as a get-out-of-jail-free card to do anything they want to advance their business goals [11]—a gloomy perspective indeed.

While it may seem morbid, the industry must also be prepared for its first accident costing the lives of spaceflight participants. NASA used a probabilistic risk analysis to estimate that roughly 1 in 100 Space Shuttle flights would fail—which wasn't too far off from the actual 2 in 134 failures [12]. The bottom line is that space is hard. It doesn't matter how these new space ventures are insured and what kind of liability waivers they ask participants to sign. Participants are human, and it will be interesting to see how the industry bounces back from these unfortunate and inevitable events.

Another major issue is the public disengagement. These are expensive private ventures currently unattainable for most people. The missions are not emphasizing national goals, but rather company objectives that may be perceived as a "space race for billionaires" [11]. In other words, it makes it hard for people to relate to the news and therefore falls short of inspiring a generation the way some of the previous missions did. In that regard, this is not too different from how the aviation industry started [4]. Therefore, it may just be a matter of time before the perspective changes, prices drop, and more people are able to experience spaceflight.

The space industry is literally taking off. It will be interesting to see how space tourism develops and its impact on society. We can only hope that spaceflight participants use their newfound knowledge and experiences in ways that, like our IEEE tagline, "advance technology for humanity." ■

Figure 2: The crew from NS-18 aboard Blue Origin's New Shepard. (Credit: Blue Origin. Source: https://www.blueorigin.com/news/gallery.)

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About the Author

Dario Schor is a software engineer at Magellan Aerospace, Winnipeg and a Ph.D. candidate in aerospace sciences at the University of North Dakota. He obtained his B.Sc. and M.Sc. degrees in computer engineering from the University of Manitoba in 2008 and 2013, respectively, before attending the 2013 Space Studies Program from the International Space University in Strasbourg, France. He is an active IEEE volunteer currently serving as the Editor-in-Chief for *IEEE Potentials*. He can be reached by email at schor@ieee.org.

Radio Science in Canada

(Continued from p. 22)

address these ITU questions and prepare URSI statements on such topics in an appropriate form;
4) establish task groups or other mechanisms as appropriate to undertake the above tasks.

CNC–URSI is currently working with both the URSI Board and the ITU to develop Terms of Reference for the proposed URSI–ITU Inter-Commission Working Group. By mid-2022, the working group should be active, and a new era of enhanced URSI–ITU cooperation will begin.

2021 R04 RECOMMENDATION FOR THE ESTABLISHMENT OF WOMEN IN RADIO SCIENCE COMMITTEES

At URSI GASS 2022, the URSI Council also considered a recommendation by the U.S. National Committee (USNC) for URSI concerning the establishment of women in radio science committees, which passed unanimously:

The URSI Council, considering

a) that women have played and continue to play an important role in radio science, but have generally been underrepresented in proportion to men in the field;
b) that it is in the best interest of URSI to encourage and support more women in pursuing careers in radio science;
c) that the US National Committee for URSI has formed a Women in Radio Science (WIRS) Committee with the stated vision "To promote inclusivity, gender diversity, and technical excellence in the radio-science community;"
d) that the formation of similar committees to mentor and support women in areas of science and engineering has been successful in such endeavours in other learned organizations;

recommends that the URSI Board and Council strongly encourage and support the establishment of Women in Radio Science committees under all URSI Member Committees, with a similar URSI Women in Radio Science Committee to coordinate such activities across the Member Committees.

CNC–URSI has supported prior efforts to support Women in Radio Science, e.g., through organized activities at IEEE AP-S/URSI 2020, which was held virtually from Montreal, and it will follow the lead of the USNC by establishing a Canadian Women in Radio Science Committee within our own group during the coming year. ■

The National Research Council of Canada is the adhering body for Canadian membership in URSI and appoints the members of the Canadian National Committee of URSI.

For more information about URSI International, please visit http://www.ursi.org/.

For more information about URSI Canada, please visit http://www.ursi.ca/.

About the Author

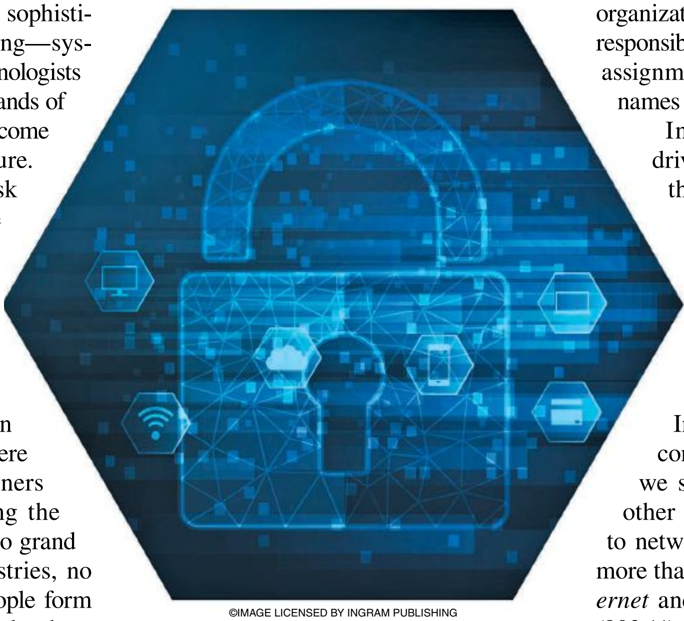
David G. Michelson is president of the Canadian National Committee of the International Union of Radio Science (2018–2024). He has led the Radio Science Lab at the University of British Columbia, Department of Electrical and Computer Engineering, since 2003. His current research focuses on short-range/low-power wireless networks for industrial vertical and transportation applications, millimetre-wave channels and systems, and satellite networks for communications and remote sensing. Prof. Michelson serves as a member of the Board of Governors of the IEEE Vehicular Technology Society, as a member of the Steering Committee of the National Institute of Standards and Technology-sponsored NextG Channel Model Alliance, as director of the AURORA Smart Transportation Testbed, and as principal investigator of the Campus as a Wireless Living Lab project at UBC.

Securing Internet Routing

by Matthew Wilder

The Internet is a wildly sophisticated—and ever-evolving—system. Engineers and technologists have created hundreds and thousands of solutions to help the Internet become more reliable, scalable, and secure. The Internet Engineering Task Force (IETF) has published more than 9,000 requests for comments (RFCs). These are the documents that define the protocols that make the Internet work.

When the Internet Protocol (RFC 791) and Transmission Control Protocol (RFC 793) were published in 1981, their designers had no intention of connecting the world's population. There was no grand plan to disrupt countless industries, no desire to transform the way people form and share opinions. Unfortunately, there was no idea that the Internet would provide new and seemingly countless opportunities for bad actors to exploit the trust of others.



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A Village Becomes a City

The Internet began as a network to connect research institutions. Originally, the institutions connecting with the Internet were also socially connected. It was only in the late 1980s and early 1990s that the number and diversity of organizations connecting to the Internet began scaling beyond the familiar.

What had begun as a village was, most certainly, becoming a sophisticated global city—and, with the transition from village to city, there comes a raft of challenges. Organization, structure, and processes are the first tools to be employed to tackle these challenges.

Organizing the Decentralized

One of the unique and famously fundamental features of the Internet is that it is decentralized. There is no person or entity at the helm of the Internet. Instead, there are countless organizations and engineers running independent networks that are interconnected to one another. To support the rapid scaling of the Internet, organizations were established to assume responsibility for standards as well as the assignment and registration of Internet names and numbers.

Internet standards are mainly driven by the IETF, which defines the functional protocols responsible for the connectivity of network equipment, hosts, and servers. Additionally, the World Wide Web Consortium shapes the standards for one of the Internet's killer apps, the web. Whereas the Internet defined the nature of the connection, the web defined how we surf on that connection. Many other organizations have contributed to networking standards, perhaps none more than IEEE, which has defined *Ethernet* and *wireless local area networks* (802.11), to name but two of the everyday network standards brought about from IEEE.

IEEE also provides the standards and registration authority for the assignment of media access control (MAC) addresses, a familiar identifier for network-connected devices. The need for unique identifiers for network devices is actually a much broader requirement that drove the creation of some of the Internet's most important supporting organizations. The Internet Corporation for Assigned Names and Numbers (ICANN) plays a central role in the coordination of the unique IP addresses and domain names across the world. With respect to Internet names, ICANN coordinates the Domain Name System (DNS), which acts as the Internet's phone directory, allowing names (domains) to be translated to numbers (IP addresses). The IP addresses

Unfortunately, there was no idea that the Internet would provide new and seemingly countless opportunities for bad actors to exploit the trust of others.

allocated by ICANN are then managed by five regional Internet registries (RIRs). The RIR responsible for Internet numbers in North America is the American Registry for Internet Numbers (ARIN).

Enter the Border Gateway Protocol

To enable the interconnection of an exponentially increasing number of networks to the Internet, the Border Gateway Protocol (BGP) was first defined in 1989 by RFC 1105. Several revisions were introduced in subsequent versions of the protocol, ultimately culminating in BGP version 4, defined in RFC 1771. The

The most significant change BGP brought about from previous routing protocols was to change the topology of the Internet from a tree-like structure to a mesh structure.

most significant change BGP brought about from previous routing protocols was to change the topology of the Internet from a tree-like structure to a mesh structure. This mesh structure was able to facilitate the growth of the Internet because it is less hierarchical, thus allowing more connections to form with less coordination.

The essence of BGP is that interconnected networks are able to share information with one another to discover and learn the optimal path for routing traffic between networks. Each network will advertise to its peers what IP addresses are used within its network. Those neighbouring networks then update their routing table to point traffic destined for those IP addresses to their peers advertising them. Subsequently, they will also share that with their own neighbours and, possibly, become a transit network to pass along traffic originating from other networks. Implicit to all of these steps is trust. Networks implicitly trust the routing information shared, from the advertisement of a route to the sharing of routing table information from peers.

BGP Route Hijacking

Trust is the foundation of all social systems, including the Internet. In the absence of trust, systems cannot take the actions necessary to drive progress. In the case of Internet routing, trust is what allows autonomous networks to learn from each other and decide how to route traffic. The vast majority of the time, networks can and should trust one another when it comes to BGP advertisement. However, two categories of exceptions do exist. First, human error does occur. A typographical error in an IP address may result in a bad advertisement, possibly making the Internet—or certain websites—unreachable for some users. Second, hackers (with a variety of motives) may intentionally create or propagate bad route advertisements.

Famous cases exist among both categories of route hijacking. The variety of motives for intentional hijacking is somewhat surprising. Hackers have collected user data by hijacking the traffic destined to well-known websites. Nations have intentionally blocked access to YouTube and other websites by deflecting traffic through BGP route hijacking. Hackers have stolen cryptocurrency by route hijacking Internet service provider (ISP) network IP addresses.

Securing BGP With Resource Public Key Infrastructure

Resource Public Key Infrastructure (RPKI) was created as a means to secure BGP and, especially, to offer protection against BGP route hijacking. The system works using two main system components. The first component is the ability for resource holders to authorize route advertisements. The second is the validation and enforcement of those authorizations.

RIRs, such as ARIN, have implemented systems to allow those who hold IP addresses to specify route origin authorizations (ROAs). An ROA is a cryptographically signed declaration of acceptable BGP route advertisements. This includes the IP address block and the ASN of the network, which may advertise this block.

The validation and enforcement of ROAs is voluntarily performed by each autonomous network. The ROA records may be learned from publicly available data published by each RIR. RPKI validators may be configured to learn of those ROAs, and network administrators may implement routing policies that will put those ROAs to use. For example, if an address holder has defined an ROA for its IP addresses, any network running RPKI validation can drop advertisements from rogue networks as "RPKI invalid." Whether an advertisement was made by mistake or with malicious intent, address holders are able to protect their routes by defining ROAs for their resources.

RPKI in Canada

Several ISPs in Canada have implemented RPKI or, at least, secured their BGP advertisements by defining ROAs for the routing of their IP Addresses. Marc Kneppers, chief security architect of TELUS, has this to say of RPKI:

> Too few people realize that the Internet, and all of the services relying on it that we deem as essential, depend on the integrity of BGP. RPKI is one of the few concrete measures that can be taken to secure BGP and strengthen Canada's critical infrastructure, and I'm proud that TELUS was able to implement it and contribute to the global initiative to secure routing.

It is time for more networks in Canada to secure Internet routing by implementing RPKI and by defining ROAs for their IP addresses. These measures will help guard the great volume and variety of traffic on our networks. After all, isn't it in all of our best interests to build an Internet we can trust? ■

About the Author

Matthew Wilder is an engineer whose passion is to see Internet technology improve lives. He works at TELUS as a network engineer, having held responsibilities including network standards, planning, architecture, security, and systems architecture. He received his M.B.A. degree from the University of Victoria and his B.A.Sc. degree in electrical engineering from the University of British Columbia. He currently serves as the chair of the IEEE Vancouver Section.

History and IEEE Canada

by David G. Michelson

Our sense of who we are, our values and beliefs, and our ambitions for the future are guided, in large part, by the stories and anecdotes concerning the past that we share with each other. In this light, history may be viewed as a formal process by which we preserve, organize, and interpret the stories that both matter to us and define us.

Although historical fact is immutable, historical evidence is inherently fragile and often irreplaceable. Accordingly, efforts to preserve and interpret the past are among the most valuable of legacies. In this column, we review recent successes among Section-led history activities and the IEEE Canadian Foundation's effort to reprint John Swettenham's three-volume biography of Gen. Andrew G.L. McNaughton.

Since its inception in 1983, the IEEE Milestones program has become one of IEEE's most effective outreach activities and has been cited as the Institute's most valuable intangible asset. Once a milestone proposal is approved by the IEEE Board of Directors, one or more bronze plaques containing the milestone citation are cast, installed at specified location(s), and dedicated at a formal ceremony. As of late 2021, nearly 250 Milestones have been approved worldwide, including 17 in Canada.

The Trans-Canada Microwave System (1958)

On 17 January 2022, the Board of Directors approved recognition of the completion of the Trans-Canada Microwave System in 1958, as Canada's 18th IEEE Milestone, with the following citation:

On 1 July 1958, the Trans-Canada Microwave System introduced both live network television and direct-dialled long distance telephone service to Canadians from coast to coast. Comprising 139 microwave relay towers spanning more than 6275 kilometres, it was, at time of completion, the longest such network in the world. Later extended and upgraded, the system had an immense impact on Canada's society and economy.

A Coast-to-Coast Telephone and Television Network

During the early 1950s, the operational feasibility of intercity microwave relays for telephone and television transmission was proven, first in Atlantic Canada, and later in Central Canada. The effort soon shifted to overcoming the various financial and regulatory hurdles that made the deployment of a coast-to-coast telephone and television network a truly daunting task. In the end, the task of building the first transcontinental microwave network in Canada fell to Bell Canada and other member companies of the Trans-Canada Telephone System and the Canadian Broadcasting Corporation.

On 8 March 1955, construction of the national system began. The essential elements of the overall system are described in three papers published between July 1956 and May 1958 [1]–[3]. Just over three years later, on 18 June 1958, operation of the entire network was successfully demonstrated. The system officially opened on 1 July 1958, via a live coast-to-coast television broadcast called *A Memo to Champlain*. The efforts

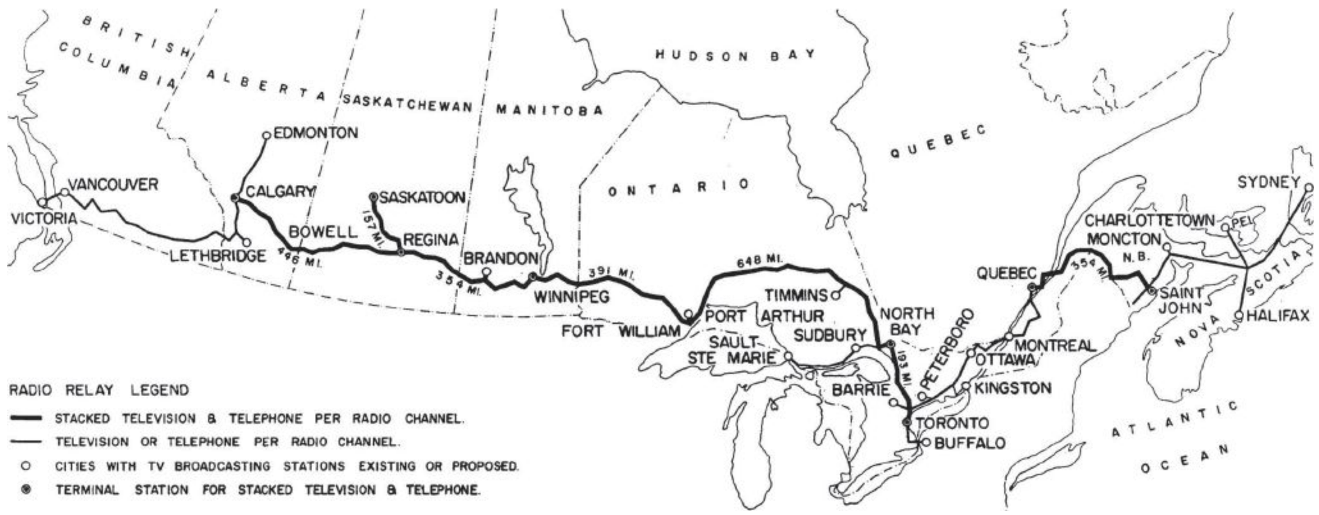
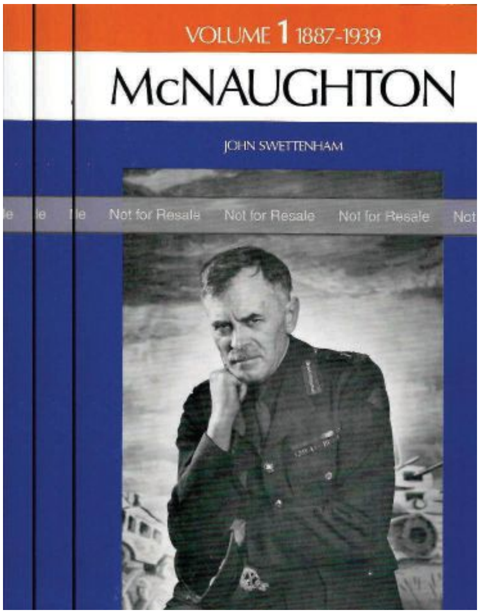


Figure 1: The Trans-Canada TD-2 radio system television and telephone network routes. (Source: [1].)

of the team over the previous three years were recalled in a commemorative booklet [4].

At the time of its completion, the Trans-Canada Microwave System was the longest microwave relay network in the world. The number of microwave relay towers required to span the great distances involved meant that the deployment cost was at an order of magnitude higher than that of a regional network. Installing microwave towers in wilderness and mountainous areas far removed from roads and other infrastructure added to the difficulty and, ultimately, the cost.



Impact

In 1987, the Engineering Institute of Canada selected the Trans Canada Microwave System from a pool of 110 projects as one of the 10 most exceptional and representative feats of Canadian Engineering's First Century (1887–1987). Few engineering achievements of the past century have had a greater impact on Canada, its society, economy, and indeed, individual Canadians.

By introducing live network television from coast to coast, the Trans Canada Microwave System provided the Canadian Broadcasting Corporation with an opportunity to realize the full potential of television as a national medium and thus shaped how Canadians saw themselves as people and as a nation. By introducing direct-dialed, long-distance telephone service to Canadians from coast to coast, the system immediately transformed the way that Canadians communicated with each other for both business and pleasure.

The Trans-Canada Microwave System also served as an important training ground for the generation of telecommunications engineers who would later export Canadian telecommunications expertise across the globe, establish the first domestic geostationary telecommunications satellite network just 14 years later in 1972, and deploy Canada's first cellular telephone networks just 13 years after that in 1985.

The route, followed by the system, is shown in Figure 1, which is reprinted from [1]. The Milestone dedication is scheduled to be held at multiple locations across Canada on 1 July 2022, exactly 64 years after the system's original opening ceremony. A joint IEEE/industry team has taken on the task of ensuring that the event will be a memorable one.

McNaughton—A Three-Volume Biography

IEEE Canada has honoured the legacy of General Andrew G.L. McNaughton (1887–1966)—Canadian electrical engineer, scientist, army officer, cabinet minister, and diplomat—through the McNaughton Gold Medal, the region's highest award, and the McNaughton Learning Centres, which can be found in electrical and computer engineering departments across the country.

The definitive story of McNaughton's many accomplishments is a three-volume biography by John Swettenham that was first published in 1968 and has long been out of print. The McNaughton Biography Project, cosponsored by the IEEE Canadian Foundation and the IEEE Canada History Committee, has been a multiyear effort to produce a high-quality reprint volume that can be given to recipients of McNaughton awards and funding, and made available to those interested in learning more about the life and career of an extraordinary Canadian.

During the past year, a team led by David Whyte and involving Amir Aghdam, Branislav Djokic, Dave Kemp, and David Whyte (IEEE Canada), Robert Colburn and Mike Geselowitz (IEEE History Center), John Swettenham (the author's son), Sarah Van Sickle (a book and literary advisor), and the Toronto Public Library, Digital Innovation Hub and Preservation and Digitization Department completed the arduous task of scanning, typesetting, proofreading, and finalizing a reprint version of the book.

The result of the team's efforts is simply stunning. Following the lead of the IEEE History Center, the team proposes to publish the book on demand through Amazon with all the proceeds supporting the IEEE Canadian Foundation, a registered public foundation in Canada and the philanthropic partner of IEEE Canada. Details of the book launch will be shared with IEEE Canada members via both an e-notice and an announcement on the IEEE Canada website. ■

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About the Author

David G. Michelson is the IEEE Canada historian and chair of the IEEE Canada History Committee. An active contributor to the history of technology for two decades, he has been a member or associate member of the IEEE History Committee since 2012 and is responsible for one quarter of the 18 IEEE Milestones that recognize Canadian achievements. He is also a member of the Society for the History of Technology (and its Special Interest Group on Telecommunications History) and a member of the History and Archives Committee of the Engineering Institute of Canada. His research interests in this area include the historiography of contemporary science and technology, the development and impact of Canadian science and technology since the Second World War, and the development and impact of both wireless technology and space technology since the Second World War. He can be contacted at dmichelson@ieee.org or historian@ieee.org.

Congratulations to the Newly Elevated IEEE Fellows as of January 2022

IEEE Canada congratulates all the newly elevated IEEE Fellows for the class of 2022. The grade of Fellow is a highly significant achievement, recognizing the impact of our esteemed colleagues in the advancement or application of engineering, science, and technology, bringing significant value to our Society. The grade of Fellow is available to only the top engineers, scientists, and technologists. The newly elevated IEEE Fellows from Region 7 are

Babak Nahid-mobarakeh, Hamilton Section,
for contributions to service continuity of electric motor drive systems
Steve Hranilovic, Hamilton Section,
for contributions to optical wireless communication systems
Ihab Ilyas, Kitchener-Waterloo Section,
for contributions to data integration, data cleaning, and rank-aware query processing
Roland Malhame, Montreal Section,
for contributions to mean-field games and stochastic hybrid systems
Ibrahim Gedeon, Northern Canada Section,
for leadership in consumer-oriented applications of broadband communications
Liang Zhang, Ottawa Section,
for contributions to nonorthogonal multiplexing technology in terrestrial broadcast and broadband systems
Anthony Chan Carusone, Toronto Section,
for contributions to integrated circuits for digital communication
Joyce Poon, Toronto Section,
for contributions to integrated photonics on silicon and resonant microphotonic devices
Mladen Sasic, Toronto Section,
for contributions to development of diagnostics testing of motor and generator windings
Ping Wang, Toronto Section,
for contributions to radio resource allocation and performance modeling of heterogeneous wireless networks
Mukesh Nagpal, Vancouver Section,
for contributions to economic and safe integration of distributed renewables in electric utility networks
Trevor Maguire, Winnipeg Section,
for leadership in the development of large scale real-time power systems simulators

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Biz Tech Report

by Terrance Malkinson

Insulin was codiscovered as a treatment for type 1 diabetes 100 years ago (14 November 1921) by London, Ontario, researcher Frederick Banting and Charles Best from Maine. The first dose was administered to a Toronto youth on 23 January 1922. Banting won the Nobel Prize in Medicine in 1923 for this discovery, placing Canada on the world stage as a leader in scientific discovery. London, Ontario's Banting House (https://www.bantinghousenhs.ca) was where Banting resided when he came up with the idea that led to the insulin discovery. It is now a museum and national historic site celebrating the achievement.

University of Toronto Professor and Canada Research Chair in Optical Sciences Sajeev John is the 2021 winner of Canada's top science prize, the $1 million Gerhard Herzberg Canada Gold Medal (https://www.nserc-crsng.gc.ca/Prizes-Prix/Index_eng.asp). The medal is awarded to recognize the sustained excellence of research conducted in Canada. John developed a way to confine and control light. The discovery has many applications. It may be possible to process information optically rather than electronically, enabling a supercomputing technology more stable and scalable than quantum computers. Another application is in the laser surgery used for procedures such as destroying tumours. His team is investigating the concept of capturing light from the sun. His goal is to create thin, lightweight, flexible, high-efficiency solar cells by using photonic crystals.

A Canadian virtual reality (VR) technology program developed in Canada will mitigate the effects of isolation. This VR tool is being developed at the iSpace Lab at Simon Fraser University (ispace.iat.sfu.ca/in) in collaboration with the Centre for Space Medicine and Extreme Environments in Berlin. An international team of volunteers has recently begun an eight-month isolation experiment in Russia to simulate a long-duration space flight. The psychological challenges of isolation can be formidable, not just for space explorers but also for people isolated during COVID lockdowns.

Evolutionary biologist Toby Kiers is leading a team of scientists known as the *Society for the Protection of Underground Networks* (https://spun.earth) to study networks of fungi throughout the world. These fungal networks are disappearing at an alarming rate, accelerating climate change, the loss of biodiversity, and the interruption of global nutrient cycles. These networks are threatened by agricultural expansion, deforestation, and urbanization. This underground and mostly invisible organism sustains much of life on Earth by isolating carbon from plants. Kiers plans to create a global map of fungi.

Insulin was codiscovered as a treatment for type 1 diabetes 100 years ago (14 November 1921) by London, Ontario, researcher Frederick Banting and Charles Best from Maine.

Ottawa stroke researchers are advancing our understanding of treatment for patients globally. Dr. Dar Dowlatshahi discussed his clinical trial for stroke during the University of Ottawa's Brain Health Awareness Week (www.brainhealth.uottawa.ca). This clinical trial will enrol 860 patients in five countries. The event's goal is to showcase innovative Canadian science. Canada has achieved considerable international recognition for its medical research, but, often, this is not known within the country.

Universities in Canada are experiencing many challenges. Some students are questioning if a university degree is still worth the time and money. They expect their university education to give them the knowledge, skills, and credentials needed to prepare them for future careers. Public spending on higher education has been stagnant or decreasing for many years. Part-time or adjunct instructors are the norm. Tuition has been rising. In his book *Nothing Less Than Great: Reforming Canada's Universities* (University of Toronto Press, 2021; https://utorontopress.com), Dr. Harvey Weingarten provides his observations and analysis of the Canadian university environment. The author is the principal of the School of Applied Health Sciences at the Michener Institute of Education at UHN and formerly president of the University of Calgary. He presents a very detailed and factual analysis of postsecondary education from the point of view of the student who is investing his or her time and money. Weingarten believes that Canada has a good public higher education system; however, success in today's world and the future requires a top-quality educational experience. In the concluding chapter, he offers a number of recommendations on how we might move our postsecondary education system from "good" to "great."

The large conglomerate General Electric (GE) announced in November that it will divide itself into three public companies focused on aviation, health care, and energy. GE's aviation unit will keep *General Electric* in the name. GE will spin off its health-care business in early 2023 and its energy segment, including renewable energy, power, and digital operations, in early 2024. The strategic rationale is clear: three well-capitalized, industry-leading public companies, each with a deeper operational focus and accountability, greater strategic flexibility, and tailored capital allocation decisions. The conglomerate model faces challenges in a marketplace in which only the quick and agile survive.

Fifty years ago, the world was introduced to the Intel 4004 microprocessor, the world's first single-chip, general-purpose CPU, which heralded the start of a new era of integrated electronics. Twenty-five years ago, the DVD was first introduced in Japan in November 1996. Many have transitioned to other technologies; however, similar to vinyl records, many value their DVD collections. Seventy years ago, in December 1952, an experimental nuclear reactor in Chalk River, Ontario, experienced mechanical problems and operator error that led to overheating fuel rods and significant damage to the reactor core. This was the world's first nuclear reactor meltdown. The Canadian government turned to its neighbour to the south for assistance. A 28-year-old U.S. naval lieutenant by the name of Jimmy Carter (future U.S. President Jimmy Carter) was called upon to head north. Carter was one of the few in the world at that time with expertise in this new technology. He led a team of men on the mission that required the reactor to be shut down, taken apart, and replaced. This was accomplished at considerable personal risk, as Carter and his men absorbed a year's worth of radiation in each of the 90-s shifts of rushing in, cleaning, and repairing the reactor (https://www.cbc.ca/news/canada/ottawa/chalk-river-nuclear-accident-1.6293574).

These fungal networks are disappearing at an alarming rate, accelerating climate change, the loss of biodiversity, and the interruption of global nutrient cycles.

The Rothney Astrophysical Observatory (https://www.science.ucalgary.ca/rothney-observatory), located near Priddis, Alberta, about 30 km southwest of Calgary, recently celebrated its 50th anniversary. The observatory opened on 7 January 1972, beginning a journey of research, science education, and dark skies advocacy in southern Alberta. The observatory serves the community as a resource for school children, teachers, and community groups, catalyzing an interest in science education. The observatory is also one of Canada's best-equipped teaching facilities. University students are provided with the opportunity to learn and use premium telescopes. In 2008, Rob Cardinal discovered a new comet, and a second comet was discovered in 2010. The video *Some Background to the Rothney Astrophysical Observatory* (https://www.youtube.com/watch?v=-a4eknKMV9M) provides an excellent overview of the history and contributions of the observatory.

The year 2021 was outstanding for space exploration and astronomical events. Three of these included the following:

- For the first time in history, a spacecraft has flown through the sun's atmosphere, the corona. The *Parker Solar Probe* (https://www.nasa.gov/content/goddard/parker-solar-probe) flew through sun's corona in April 2021. *Parker* was 13 million km from the centre of the sun when it first crossed the uneven boundary between the solar atmosphere and solar wind. The spacecraft will continue moving deeper into the corona until its final orbit in 2025. Exploring this magnetically intense region up close can help scientists better understand solar outbursts that can interfere with many aspects of life on Earth.
- The ExoMars *Trace Gas Orbiter* (https://exploration.esa.int/web/mars/-/46475-trace-gas-orbiter), launched in 2016 as a joint mission between the European Space Agency and the Russian Roscosmos, detected water in Valles Marineris on Mars. The water located beneath the surface of the canyon system was detected by the orbiter's fine-resolution epithermal neutron detector, which is able to map hydrogen in the top metre of Martian soil.
- The *Perseverance* rover (https://mars.nasa.gov/mars2020) that landed on the planet 10 months ago has discovered that the bedrock it has been driving over since landing was once formed by volcanic lava flows. Analysis of the rocks that have been sampled revealed that they interacted with water multiple times, and rover instrumentation suggests that some of them include organic molecules. *Perseverance* has collected four rock samples with plans to collect more that will be returned to Earth by future missions for detailed analysis. ■

About the Author

Terrance Malkinson, the author of more than 580 peer- and editorial-reviewed earned publications, is now retired. His diverse career path included 26 years in medical research as a founding member of the Faculty of Medicine at the University of Calgary, a three-year appointment as a business manager with the General Electric Company, followed by a one-year applied research appointment with SAIT Polytechnic. He is an alumnus of continuing professional education programs with Outward Bound International, the Banff Centre for Management, the Massachusetts Institute of Technology, and the University of Colorado. During his long career, he has advanced both basic and applied medical, health and wellness, scientific, and engineering knowledge. He has trained and mentored undergraduate, graduate, and postdoctoral students as well as professional staff in the business sector and government. He is a 45-year Life Senior Member of IEEE. He has served in many professional public and private governance and publication roles. He is the recipient of several peer-selected earned awards, including induction into the Order of the University of Calgary, IEEE achievement medals, and APEX awards for publication excellence. In retirement, he vigorously continues basic and applied research, with an extensive portfolio of basic and applied research projects. Other passions include communicating emerging technologies to the public, investigative journalism, philanthropy, and mentorship. His current research interests in emerging technologies and health and wellness extend to being an accomplished multisport triathlete, including, among other events, the completion of 10 full-distance Ironman Triathlons.


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