Cosmology has made rapid forward strides with the steadily growing flood of observational data and development of precision instrumentation. Despite all that we have learned about the universe thus far, the picture is an enigmatic one with many gaps left to be filled. Hydrogen is the most abundant element in the universe and is an extremely powerful tool for probing the universe's distant past. Neutral hydrogen atoms naturally emit light with a wavelength of 21cm. Because of the expansion of the universe, this wavelength is stretched or “redshifted” in proportion to how far away (or, equivalently, how long ago) the hydrogen emitted its light. Thus, by measuring the sky at radio frequencies, it is possible to access specific epochs of the universe's history by literally tuning into the appropriate observational wavelengths.

One of the greatest mysteries in present day cosmology is dark energy: this bizarre component comprises roughly 70% of the universe's total content and is causing the expansion rate of our universe to *accelerate*. One of the most promising methods for capturing a snapshot of dark energy in the act is using large, highly sensitive radio telescope arrays to survey large areas of sky with broad frequency (redshift) coverage. Here, we present a multi-faceted proposal to build a new, flexible radio signal processor—the McGill “back-end” (MBE)—that will have the unique feature of being self-contained and deployable to remote locations, thus providing a game-changing addition to radio astronomy and cosmology. Research and development efforts for the MBE will be supported by a new lab at McGill to build and test radio instrumentation. This lab will additionally build prototype antennas to search for remote areas in northern Canada with low amounts of human-generated radio interference, which will serve as potential deployment sites for the MBE working in concert with future radio telescope arrays.

The proposed MBE is a portable, custom-built signal processing core that services an array of radio telescopes. The MBE will process 3.25 terabits of information every second, equivalent to the international internet bandwidth of many countries. This back-end leverages technology already developed at McGill for the Canadian Hydrogen Intensity Mapping Experiment (CHIME). The new MBE will be the second-largest system in the world when measured by number of simultaneously processed input radio telescopes, second only to CHIME itself. Upcoming radio telescope arrays will generate an enormous amount of data, thus presenting a daunting data transport challenge. The MBE offers a unique solution to this problem in that the system can be moved physically to the telescopes, thus eliminating the burden transferring the telescope data to a remote processing center. The first deployment of the MBE will be as the heart of the Hydrogen Intensity and Real-time Analysis eXperiment (HIRAX), a southern-hemisphere counterpart to CHIME. HIRAX will be located in the South African Karoo desert, on land owned and protected from interference by the South African Radio Astronomy Observatory (SARAO). Together, CHIME and HIRAX will map almost the entire sky, charting the expansion history of the universe and making significant strides toward shedding new light on dark energy. HIRAX already has significant funding in place, ensuring there will be an array of dishes that will connect to the MBE. With the MBE in place, HIRAX will produce around 50 TB of raw telescope data per day, or 70 PB over HIRAX's 4-year lifetime. Understanding how to search such massive amounts of data, and to compress them while preserving the fidelity of the dark energy signal is a major data challenge aligned with the SQRI key area of "analytique des données massives". Detailed instrument modelling and simulations are key to the success of HIRAX and interpretation of the results; this software development addresses the SQRI goal of "Modélisation, simulation et jeux". The MBE will additionally open new research paths in "Intelligence artificielle", another goal that is specifically highlighted by the SQRI. Artificial intelligence has already been used to make significant progress in the search for transient events, and this initial demonstration represents only the beginning of the full power that artificial intelligence techniques have to offer in the search for additional unexpected signals.

In order to support the development of the MBE, we will build a radio instrumentation lab at McGill to integrate and verify the MBE prior to its deployment to South Africa. This lab will additionally build and test novel low-frequency antenna stations that will be deployed to northern Canada. Northern Quebec, in particular, offers relatively extensive fiber optic connections and road access, while simultaneously being one of the most sparsely populated areas in the world. Each of these factors are critical for supporting radio astronomy, and the rare combination of both gives northern Quebec a truly unique geographic advantage. We will use the antenna stations developed at the McGill radio instrumentation lab to search for areas in northern Quebec with minimal human-made interference yet good infrastructure, which will serve as potential locations for future low-frequency radio telescope arrays. With these sites identified, we will have the literal groundwork in place for proposing next-generation radio telescope arrays in Quebec, which will then be empowered by the MBE. While future deployments are beyond the scope of this proposal, our current work will lay the path forward for cementing Quebec's position as a leader in the international radio astronomy and cosmology community.

In addition to enabling groundbreaking science, our proposed research activities will provide excellent training opportunities for students spanning a wide range of disciplines and levels of study. Students will learn skills that are both broad and versatile: these include hardware design, fabrication methods, electronics, programming, high-performance computing, and systems engineering. Developing these skills will ensure that students who work on our proposed research will be ready to join the next generation of scientific leadership. Proficiency in hardware and software, in combination of problem solving experience, are highly sought after in jobs well beyond academic research, and our students will be well placed to take leading roles in industry and to contribute to positive socioeconomic growth.

The technology that will be developed as part of our proposed research will present many opportunities to engage with local companies within Quebec. Much of the hardware will be custom built, and we will seek out local manufacturing companies to aid in the fabrication. Specialized but non-custom hardware will also be sourced from local Quebec vendors. We will naturally forge industrial ties with commercial organizations in northern Quebec as part of our development efforts for the low-frequency antenna stations; as one example, self-contained and locally tailored solar and wind power solutions are natural areas to explore collaborative work with non-university organizations in the north.