UNIVERSITY OF CALGARY

# New Earth-Space Technologies

## A Research Strategy

August 2016

> "Few endeavours capture the imagination or tax the capabilities of humankind like the exploration and exploitation of space. And few have so quickly made themselves so indispensable."
>
> **— Canada's Space Policy Framework**

New Earth-space technologies are capturing, analyzing and visualizing our Earth-space environment through unprecedented advances in sensors, platforms and systems. We are on the cusp of a technological revolution in our ability to sense and monitor our natural environment and built world — with widespread applications for humanity.

From the oldest science (astronomy) to the latest evolution of geomatics, University of Calgary researchers on the New Earth-space Technologies Research Strategy team are providing information that is constantly changing how we make decisions about our world.

# Spatial information helps us make decisions about our world

In the early 1980s, University of Calgary researchers tested a prototype Global Positioning System (GPS) that had so few satellites available they could only navigate for a few hours each day. The idea of continuous positioning and navigation in personal mobile devices was unimaginable back then. Three decades later, we live in a connected world where miniaturized sensor systems are collecting information about everything, everywhere, all the time. This ubiquitous spatial information — often called big data — is driving smarter decisions.

For Canadians, the concept of being connected is of primary strategic importance, given our vast landmass, the world's longest coastline and our sparsely populated northern regions. Evolving technological innovations are letting us sense and monitor remote geophysical, environmental, space, planetary and even astrophysical phenomena. Our ability to collect and synthesize spatial data is transforming everything from environmental monitoring and resource management to personalized medicine, policy and national security.

*We are in a paradigm shift.*

Space research and geospatial information, based in part on satellite imagery and sophisticated spatial positioning systems, are pushing the boundaries of sensor, sensor web, and platform technologies. Such advances are further supported by the development of stream computing and research into big data. Affordable small satellites for space research, drones for Earth-sensing and billions of citizen sensors are enabling unprecedented observation and monitoring of the Earth-space environment.

Geo spatially referenced data is informing us about phenomena and events in the real world — from a remote ice flow in the Arctic to a car turning left on 9th Ave in Calgary — as quickly and easily as we can access the virtual world. There are huge strategic applications for this augmented reality — for safety and security as well as stewardship of the environment and natural resources.

There are also tremendous economic opportunities. In recent years, the global geospatial sector was estimated at USD $200 billion, with annual growth of 30 per cent. The *Internet of Thing*s (a proposed development of the Internet in which everyday objects have network connectivity, allowing them to send and receive data) could connect more than 30 billion spatial devices by 2020, representing a multi-trillion dollar global opportunity. With this huge number of globally distributed devices, interconnection and powering in a remote and dense environment are major challenges. Innovative enabling technologies and infrastructure for communication and sensing are needed.

# New Earth-space Technologies (NEST) Research Strategy

The University of Calgary is a world leader in the development and application of Earth-Space Technologies. This theme cuts across faculties and disciplines, integrating research strengths to create new technologies for improving global communication networks and environmental monitoring. Earth-space research both builds on and underlies technology development for global positioning, telecommunication, and environmental monitoring.

Development of geospatial technologies like GPS, GIS, and LIDAR feed a new industry in support of resource stewardship and agriculture — fields particularly relevant for Alberta and Canada. Environmental monitoring is critical for continued oil sands development. The vast agricultural industry, including livestock operations, will benefit from precision farming technologies that are based, in part, on satellite imagery and sophisticated spatial positioning systems. The overall theme will inform the development of environmental policy and contribute to Canadian arctic sovereignty.

Our NEST researchers are exploring the cosmos looking for answers to fundamental questions about the origin of Earth and the solar system, where and how atomic elements and molecules were created, and how structure and order arise in space. Developing and using technologies including continent-wide sensor webs, satellite-borne instruments and telescopes, our researchers analyze, visualize, mine and simulate observations from space. From the oldest science (astronomy) to the latest evolution of geomatics, our NEST researchers are providing information that is constantly changing how we make decisions about our world.

**We have attracted well over $100 million in funding, led high-profile global projects and been involved in more than 20 space missions.**

The NEST Research Strategy builds on various research strengths at the University of Calgary such as: sensors and sensor webs; global navigation satellite systems including global positioning system; remote sensing; space sciences (planetary, astrophysics, near-Earth-space), and geospatial modeling. It will leverage and strengthen a confederation of scholars, a platform to develop interdisciplinary collaboration to advance research in this rapidly evolving area.

The University of Calgary is home to many national and international leaders in space science, geomatics, communications and satellite systems. A small and respected group, our community of NEST academics punches well above its weight. We have attracted over $100 million of funding, led high profile global projects and been involved in more than 20 space missions. We have trained thousands of scientists, developed transformative technologies and inspired both researchers and everyday Canadians. In advancing this NEST Research Strategy, we are poised to climb even higher in developing and applying new Earth-space technologies.

*The ground-based THEMIS All-Sky Imager (ASI) array observes the aurora over the Northern American continent from Canada to Alaska.*

# The need for Earth-space technologies

New Earth-space technologies have an astonishing array of applications for our world. These include exploring how the sun's energetic particles create magnetic disturbances that affect satellites and instruments on Earth to potentially saving the planet from an asteroid in 2182, monitoring grizzly bear conservation efforts in Western Canada, and understanding changing sea-ice dynamics in the Arctic. The information collected by the NEST team is informing human decisions.

Global navigation satellite systems and intelligent sensing enable environmental sensor networks, while geographic information systems provide the storage, retrieval and analytical techniques that exploit data collected into usable information and geointelligence.

A wide range of industries — telecommunications, energy, utilities, defence, automotive, navigation, marine and agriculture — rely on geospatial information to make smarter decisions. New Earth-space technologies are revolutionizing environmental monitoring to better understand and preserve our ecosystems. In the Arctic and other remote regions with little or no cyberinfrastructure, real-time flow of data helps us see scope and scale of environmental change as well as gather information about security.

With Earth-space research we are looking for answers about the universe that can help us here on Earth. Understanding space weather — how the sun's energetic particles interact with the Earth's magnetic field to produce magnetic disturbances — can help us mitigate damage to satellites in space and negative impact on radio waves, directional drilling, power systems and pipelines (e.g. corrosion).

**New Earth-space technologies are revolutionizing environmental monitoring to better understand and preserve our ecosystems.**

New Earth-space technologies also help us satisfy humanity's enduring fascination with the night skies. Powerful telescopes, such as the ones at the university's Rothney Astrophysical Observatory, bring the stars to thousands of school children, post-secondary students and curious citizens. These technologies spur human inspiration and curiosity.

*Researcher Jo-Anne Brown (right) and PhD student Anna Ordog study the structure of the magnetic field in the Milky Way, and how magnetism affects the interstellar medium of our galaxy and other galaxies in our universe.*

*Swarm is a European Space Agency (ESA) mission to study the Earth's magnetic field. UCalgary space physicists led the electric field instruments on these satellites.*

# Research strengths and capacity

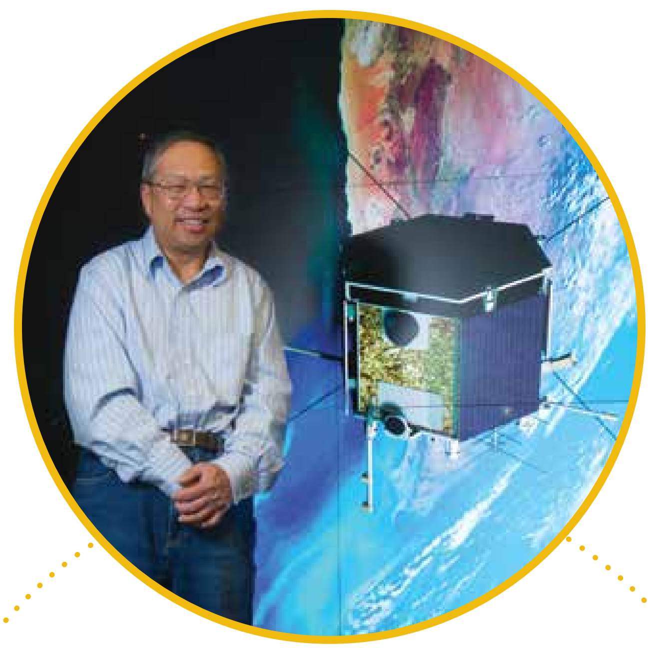
We are creating new collaborations and bringing together expertise and strengths from a number of areas that will foster cross-pollination and deliver success. Think of exponentially growing data volumes, digital imaging, sensor webs, geospatially referenced data, satellite technologies, satellite mission design, space instrumentation — all is relevant across the broad spectrum of NEST.

## Researchers at the University of Calgary dominate the international stage in space physics.

With decades of national leadership and involvement in nearly two dozen space missions — a record unmatched by any other Canadian university — we have a  critical mass of expertise in space physics, a strength that is unique in the world.

Over the past four decades, UCalgary space and planetary scientists have received significant funding from the Canadian Space Agency (CSA), Canada Foundation for Innovation (CFI), the Natural Sciences and Engineering Research Council of Canada (NSERC), the European Space Agency (ESA), and indirectly from NASA and the US National Science Foundation (NSF), allowing our researchers to participate in global efforts to explore space around Earth and other planets. We have put more than 20 instruments in space and led two satellite missions. Our researchers have explored space near and far, leading to scientific discoveries that have transformed our understanding of our world, its history, and the cosmos. We are Canada's most space-active university.

Our researchers are working on more than $5 billion of space science and technology projects involving a worldwide network of industries, universities and government agencies including NASA and the CSA. We have spun off several successful high-technology companies, and generated new technologies and software worth tens of millions of dollars.



*Andrew Yau is mission scientist and project leader for the Enhanced Polar Outflow Probe (ePOP) on CASSIOPE, the first made-in-Canada multi-purpose small satellite mission from the Canadian Space Agency.*

**The following companies all have origins at the University of Calgary:**

## Keo Scientific Inc.

Keo Scientific designs and builds highly sensitive scientific instrumentation capable of wavelength-resolved imaging of sub-visual emissions from the upper atmosphere. Founded in 2003 by a group of science and engineering personnel from the University of Calgary's Institute for Space Imaging Science, this group has hands-on, practical experience with the design and use of specialized scientific optical instrumentation going back to the mid-1970s. Keo's founders have expertise ranging from space and atmospheric research to mechanical, electrical, optical and software engineering, to the deployment and maintenance of distributed imaging arrays in hostile environments.

**keoscientific.com**

## iTRES Research Ltd.

iTRES Research Limited has provided high-quality airborne electro-optical instruments for the scientific and remote-sensing communities since it was founded in 1979 by then University of Calgary physics professor Clifford Anger. The Alberta-owned company conducts research and development in applications using imaging detectors for camera systems that operate in visible light, ultraviolet, near infrared, shortwave infrared, and thermal spectral ranges. iTRES has also developed significant expertise in the successful commercial development of applications and products using these optical imaging technologies, as well as in conducting large-scale domestic and international acquisition programs. Their flagship product is the CASI-1500 (Compact Airborne Spectrographic Imager) — an all-digital, user-programmable, hyperspectral imaging spectrograph, sensitive to visible and near-infrared wavelengths.

**itres.com**

## Trusted Positioning Inc. (TPI)

TPI was founded in 2009 by a group of geomatics engineers from the University of Calgary. It was the first company to develop navigation software for indoors specifically based on microelectromechanical systems (MEMS) sensors. Using inertial sensors such as accelerometers, gyroscopes, magnetometers and pressure sensors in mobile or wearable devices, TPI provided location data in areas where wireless systems such as GPS and Wi-Fi were unavailable or inaccurate. Acquired in 2014 by InvenSense, a top-tier sensor technology company, for US$36 million, TPI essentially became InvenSense's Canadian research and development centre.

**invensense.com**

## Luxmux

Luxmux Technology Corporation, founded by University of Calgary graduate Yonathan Dattner and professor Orly Yadid-Pecht, is a spectroscopy technology company developing unique turnkey solutions and optical components designed for sensing systems for a broad cross-section of industrial and consumer markets. Together with its partners, Luxmux is developing proprietary spectrometers and photonic-based light-source technologies to eliminate moving parts while increasing speed, robustness, sensitivity, stability, repeatability and operating range across instrumentation classes. One company has licensed Luxmux solutions to develop an analyzer that can monitor steam quality at boilers and injection wells in real time. High-quality in-line steam monitoring enables producers to increase output while minimizing greenhouse gases, water consumption and maintenance down-time.

**luxmux.com**

## Our researchers invent sensing systems, devices and platforms.

We are helping lead the global geospatial revolution with excellence in ground, air and space-based platforms (ground networks, drones and satellites), sensors, visualization and analytics. Our work encompasses aspects of remote sensing, monitoring, and spatial informatics that place us at the forefront of *geointelligence.* We build satellite infrastructure that enables new methods of observation and exploration.

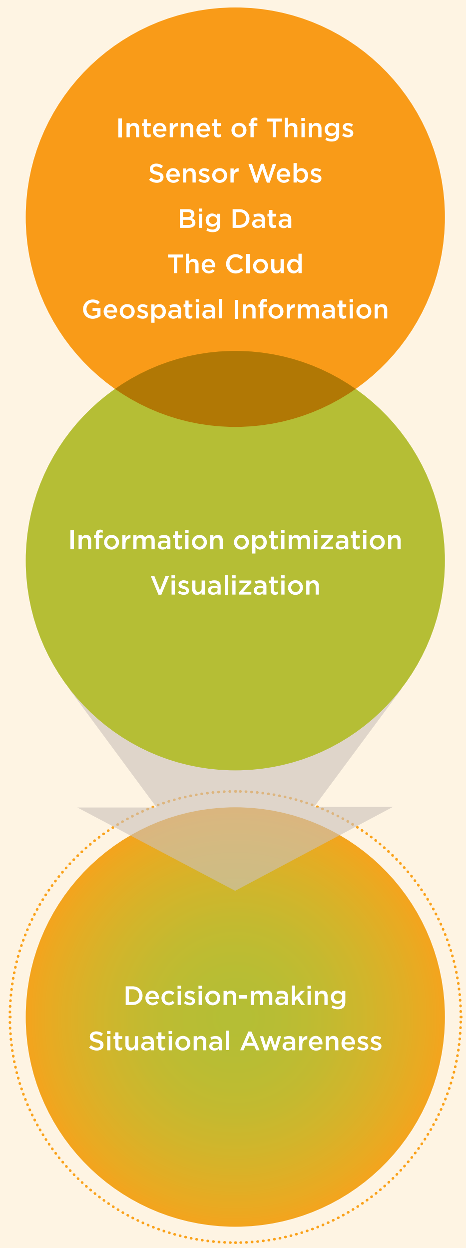
This work has applications in, for example, the energy industry for reservoir visualization, pipelines and drilling. It is transforming environmental monitoring — local and national, ground and space-based. It is also advancing smart cities, integrated resource management, space weather and situational awareness (space, urban and military), Arctic studies and public policy.

Current methods of monitoring civil infrastructure — highways, railway bridges or transportation networks — is infrequent and prone to errors. Yet failure of any of this infrastructure could be catastrophic. NEST researchers can develop sensors that are mounted on stationary or moving platforms. These low-cost sensors and automated techniques can collect data for intelligent, economical and more frequent infrastructure monitoring.

University of Calgary expertise includes scientists and research chairs exploring micro-electromechanical systems, multi-sensor integration, high-sensitivity receivers, intelligent and green radio systems, wireless location, information visualization, interactive technologies, reservoir simulation/visualization, geospatial sensor web and unmanned aerial systems.

## Geointelligence

*Geospatial intelligence or 'geointelligence' is the exploitation and analysis of imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the earth. Geospatial intelligence consists of imagery, imagery intelligence, and geospatial information.*



Examples of technologies include the following:

- Novel unmanned aerial vehicle (UAV)-based multi-sensor system and processing platform for hydraulic fracturing mapping and monitoring.
- Systems employing radar and laser altimeters, InSAR, LIDAR, gravity, magnetics and other remote-sensing technologies onboard satellites and airplanes to collect observations of the land, ocean and ice surfaces, as well as the Earth's gravity and magnetic fields, hydrosphere, atmosphere and biosphere.
- A new tool that integrates inertial navigation technology for Measurement While Drilling (MWD) surveying.
- Integration of navigation satellite, wireless communication and geospatial systems to support intelligent location-based services with significantly improved precision, availability and robustness.
- Interoperable, intelligent and reusable *Internet of Things* devices.
- Satellite transmitters, transponders, receivers, antennae and imagers for global connectivity.

## We lead in engaging and inspiring the public about space.

Every year, thousands of people — from school children to graduate students to curious citizens — visit the University of Calgary's award-winning Rothney Astrophysical Observatory just south of Calgary. The visitors get a close-up look at the night skies and hear NEST researchers talk about their work, everything from space missions to space storms.

The Rothney Astrophysical Observatory has a computer-controlled telescope with imaging detectors, a solar-filtered telescope and the 1.8 metre A. R. Cross Telescope — one of the biggest telescopes in Canada. At regular open houses and programs, the telescope is operating and astronomers present information and answer questions. The observatory is one way the University of Calgary is engaging, informing and delighting people about new Earth-space technologies.

**The Rothney Astrophysical Observatory** (RAO) is one of the principal research facilities within the University of Calgary's Department of Physics and Astronomy.

As one of Canada's best-equipped astronomical teaching facilities, the RAO provides university students with the opportunity to use research-grade telescopes, an integral part of the undergraduate astronomy curriculum. It also serves the community as a resource to science educators and as a catalyst for science education in Alberta. More than 8,000 members of the general public connect with the universe each year through public events and open houses.

**ucalgary.ca/rao**

## University of Calgary NEST researchers are changing the world.

We have led major space technology developments:

- Developed next-generation transponders for Canada's RADARSAT systems. RADARSAT uses synthetic aperture radar to obtain images of the Earth's surface to manage natural resources and monitor global climate change.
- Developed electric field instruments for each of the European Space Agency's three satellites in the 2013 SWARM mission to investigate Earth's magnetic field.
- In 2013, the CSA-funded CASSIOPE satellite carried two payloads into space. UCalgary built and now operates one of these, called ePOP, which is Canada's first-ever university-designed and integrated scientific satellite payload.
- Designed and built the automated colour imaging systems for AuroraMAX, one of the Canadian Space Agency's most successful public outreach projects, which delivers the northern lights in real-time to the public.
- Established the $25M Resolute Bay Incoherent Scatter Radar (RISR-C; where the C stands for Canada) one of the largest science projects in Canada's Arctic. RISR-C is a multi-disciplinary effort to explore the upper atmosphere in one of Earth's harshest environments.
- Developed the ultra-sensitive antenna arrays for the Square Kilometre Array radio telescope, designed to be the world's largest telescope for studying galaxies and cosmic properties, and supporting the search for extraterrestrial life.

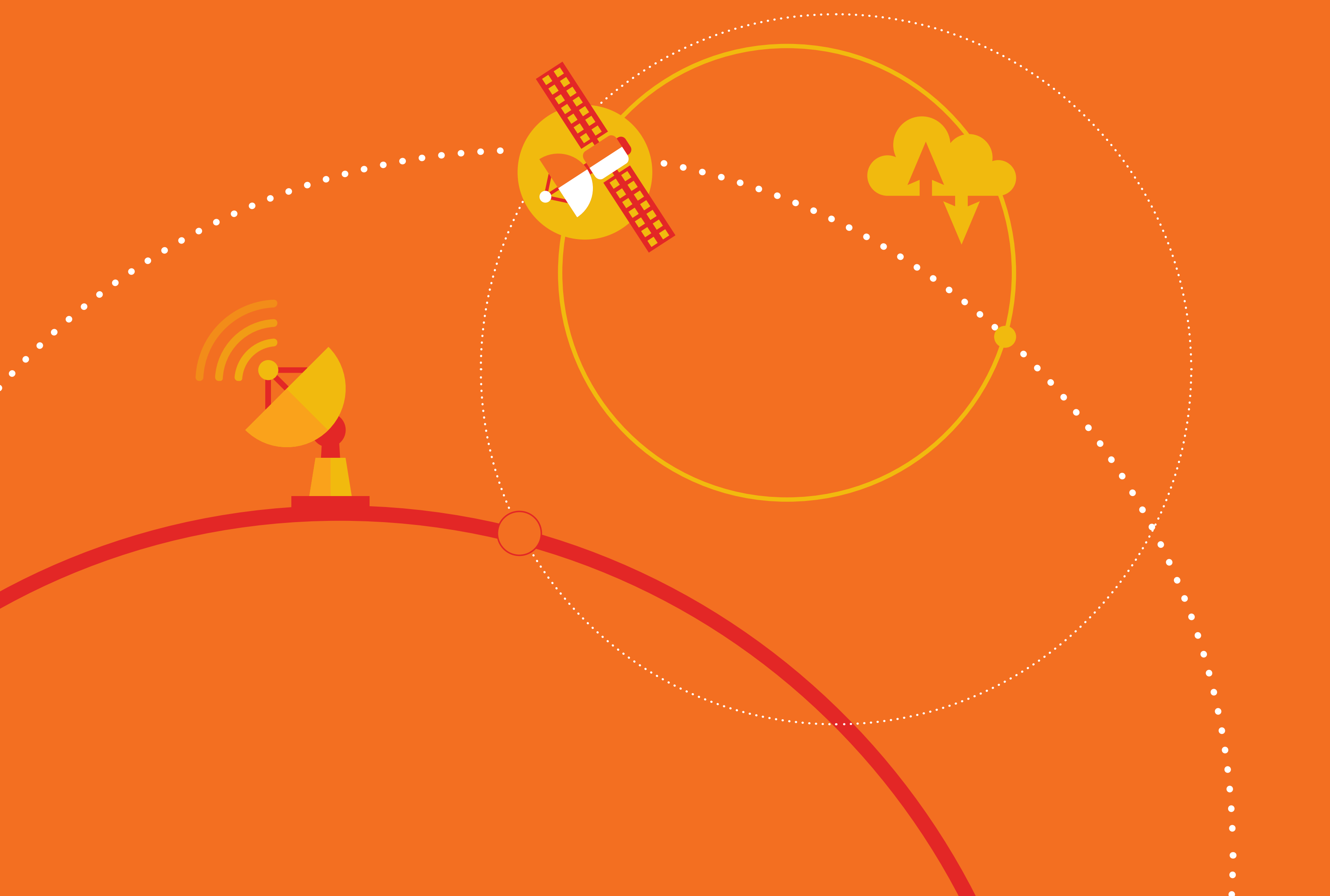
***Opposite:*** *Earth from LANDSAT satellite*

***Below:*** *Researcher Leo Belostotski holds an ultra-sensitive miniaturized radio amplifier developed at UCalgary for the C$3-billion international Square Kilometre Array (SKA) project. When completed in the late 2020s, SKA will be the largest radio telescope ever built.*

# NEST Grand Challenges

The Grand Challenges represent significant targets or themes that our NEST community will advance collectively. They are bold and inspirational and offer significant opportunities in space science, remote sensing/earth observation/digital imaging, positioning and navigation and Arctic research.

We have world-leading strength within and across the Confederation of Scholars and are positioned to pursue major opportunities. The Grand Challenges presented here are highly relevant to society and our work at the University of Calgary can deliver significant benefits.



# 1

## Environmental Monitoring

Environmental monitoring — the systematic observations of land, air, water, and biodiversity — is a crucial component of societal efforts to understand ecosystem processes and the effects of human activities on ecosystem health.

However, delivering high-quality information across vast and diverse landscapes is tremendously challenging. New Earth-space technologies are revolutionizing how environmental monitoring is conducted. State-of-the-art sensor systems measuring light, gravity, and magnetics can be mounted on satellite, airborne, and ground-based platforms to observe an array of environmental phenomena.

Environmental sensor networks can operate and sample broadly and effectively across multiple scales — coupling local through global ecosystem processes. Enabling technologies such as geographic information systems provide the storage, retrieval, and analytical techniques that derive new knowledge from big data collections. Products include a powerful supply of multi-layered information with visualization and analytics capabilities to support responsible environmental stewardship.

We have strength in both the technology and application domains that are necessary to research the development of new Earth-space technologies for environmental monitoring in a variety of applications.

### Key areas of investigation

- Understanding the effect of resource extraction activities on Canada's ecosystems
- Earth observation technologies for environment and resource monitoring in Canada's North
- Environmental monitoring of disasters, hazards, and natural disturbances
- Monitoring cryospheric environmental change to understand the effects of climate change
- Development of multi-sensor systems for geospatial data acquisition
- Technology, applications, and analytics for unmanned aerial vehicles

# 2

## Geospatial Connections – Enabling Better Knowledge for Better Decisions

We are on the cusp of a generational transformation in geospatial sensing.

In our connected world, location devices are becoming so pervasive that soon everything and everyone will be locatable everywhere. The world increasingly relies on such comprehensive spatial data to drive smarter decisions. The telecommunications, energy, utilities, defense, automotive, navigation, marine and agriculture industries are just some of the sectors that rely heavily on geospatial products and services.

There is an increasing need for data that is more accurate, has higher density and higher resolution, is produced more rapidly, and is acquired less expensively. New technological developments are required to realize the digital Earth and smart cities of the future. Platforms, sensors and systems are fundamental to spatial representation.

Current geospatial data acquisition systems include multi-sensor approaches that integrate various positioning (e.g. global navigation satellite systems), navigation (e.g. micro-electromechanical systems and inertial navigation systems), remote sensing (e.g. imaging and laser scanners), and wireless (e.g. wireless sensors networks) technologies.

Geospatial analysis and modeling support applications in situational awareness, environmental monitoring and resource development, emergency response and urban planning. The integration of positioning information, wireless communication and geospatial processing supports intelligent location-based services for mobile information devices. Next-generation systems will acquire geospatial data on demand and across all scales to better understand spatial connections of events and processes everywhere. The University of Calgary is well positioned to lead future advances in geospatial technologies.

### Key areas of investigation

- Global data structuring and geovisualization across all scales
- Managing exponential growth in data volumes
- Acquisition of continuous indoor/outdoor positioning information
- Seamless linked data integration from diverse sources
- Development of dynamic geospatial systems to provide context relevant information
- Low-cost and high-efficiency data collection
- Rapid acquisition and distribution of data
- Provision of 3D and even 4D geospatial information

*Researcher Steve Liang is working in the Internet of Things.*

3

## Understanding the Influence of Arctic Change at Local, Regional, and Global Scales

The Arctic is a dynamic and compelling place, where change is constant and life is both challenging and rewarding. Yet today, Arctic change is unprecedented. It's accelerating across the physical, biological and human components of the system, transitions so great in scale and scope that it is difficult to comprehend what they mean for the future, and how they will ultimately influence life at local, regional and global scales.

The challenges of Arctic change are complex and addressing them requires global action and local innovation. The use of technologies to improve our understanding of change and to ensure the long-term viability and sustainability of northern communities is complicated by local and regional conditions that include poor communications infrastructure, significant gaps in observational infrastructure and technologies, lack of access to technologies, and lack of appropriate technologies.

There is scale mismatch that hampers downscaling of remotely sensed data for local problem-solving, and up-scaling of local information to address regional and global issues. The University of Calgary can take the lead in exploring ways to provide robust, open and transparent solutions that include technology that can inform on environmental issues and support social and political initiatives to mitigate and manage change.

The Arctic serves as a research target that spans a broad spectrum of scientific and social science disciplines. Integrated Arctic science studies the system from the lithosphere to the upper atmosphere and beyond, exploring the interplay between Earth, ocean, atmosphere, space and even the biosphere. But it is important to remember that it is a unique environment, presenting a strategic opportunity for Canada, with its large Arctic territory. We refer to using the Arctic as a laboratory for studies enabled by its uniqueness. UCalgary deployed the Resolute Bay Incoherent Scatter Radar in the High Arctic for just this reason. We imagine the Arctic as a platform for other fundamental research, including particle physics and astrophysics.

### Key areas of investigation

- Developing real-time and near-real-time data flow that is useful for understanding the scope and scale of change in remote regions
- Determining what the necessary measurements are, and the appropriate spatial and temporal resolution(s) for environmental monitoring in the Arctic
- Development of high-resolution imaging and monitoring with year-round coverage
- Development of technologies that are both state of the art and culturally appropriate for local use, and addressing scale mismatch for local, regional and global understanding and adaptation to change
- Remote sensing, or downscale deployment of sensors for use in community-based monitoring and citizen science
- Development of cyberinfrastructure for the Arctic (arctic webmap, arctic sensor web, arctic BioMap)

*UCalgary researchers at the Resolute Bay Incoherent Scatter Radar (RISR) in the Canadian high Arctic.*

# 4

## Space Applications — Bringing the Benefits of Space to Society

The ever-growing international fleet of Earth-orbiting satellites provides security, communications, navigation, and remote sensing for weather, resource management, scientific research, and serves many other purposes that are increasingly critical for the world economy. This sector is worth hundreds of billions of dollars globally, and touches virtually every aspect of life for large and growing populations of people around the world.

Space and satellite technologies are particularly important for Canada. We have vast and varied geography, including the changing Arctic, and we have high geomagnetic latitude, which means understanding space weather is crucial.

In 2013-14, the Canadian Space Agency led the development of the Canadian Space Policy Framework to provide the policy rubric for making decisions about Canadian investment in space and identifying our country's needs. Given our heritage and significant capacity, we are well positioned to contribute in this endeavour. The University of Calgary has a tremendous record of high-impact space-related activities spanning our entire 50-year history. We aspire to be Canada's leader in using space for the benefit of society.

*NeuroArm, the world's first robot capable of performing surgery inside magnetic resonance machines, was born of the Canadarm.*

### Key areas of investigation

- Mitigating the hazards of space weather
- Identifying all significant near-Earth objects
- Low cost and rapid access to space and mission planning
- Satellite technologies
- Sensor webs and SCADA (supervisory control and data acquisition)
- Space medicine and tele-medicine
- Space mining and space robotics

The near-Earth-space environment is dynamic and at times treacherous. Space storms can cause radiation and magnetic fields to swirl around the planet in complex patterns with beautiful and sometimes dangerous effects.

Scientists at the University of Calgary are building our understanding of extreme space weather and how it affects technology and our daily lives.

- There are more than 1,100 satellites currently operating in near-Earth-space; operators use space weather forecasts to monitor damaging radiation.
- Space weather affects technologies that depend on radio wave propagation; including Global Positioning Systems (GPS), and communications with aircraft, for example.
- During severe space storms, the aurora borealis can be seen as far south as Texas and planes flying in the Arctic are diverted due to risk of radiation.

# 5

## Understanding the Universe Near and Far

Space inspires people. In the words of Plato, it "compels the soul to look upward." University of Calgary scientists develop and use exciting new technologies to explore space, from the upper reaches of our atmosphere to the outer limits of the cosmos and from the beginning to the end of time. In highly focused areas, our research addresses fundamental questions in space physics, planetary science, and astrophysics. Through cutting-edge science conducted with advanced technology, we lead on the national and world stage. Our research asks questions such as:

- What are the nature and origin of the Earth and solar system?
- Where and how in the universe were the atomic elements and molecules created?
- What is the origin of cosmic magnetism?
- How does structure and order arise in space?
- How are particles in space accelerated to enormous energies?

We bring technologies to these questions, including continent-wide sensor webs, satellite-borne instruments, telescopes and other powerful radio facilities and instruments. Our research incorporates advanced computational techniques to analyze, visualize, mine, and simulate our big data.

### Key areas of investigation

- Planetary science
- Astrophysics
- Space physics
- Plasma physics
- Complexity science
- Atmospheric chemistry and evolution
- Numerical simulation and high-performance computing
- Data mining and machine vision

*Johnathan Burchill (right) and intern Carl Wei are designing a prototype of a plasma/space instrument that measures winds and temperatures of charged particles in the Earth's space environment.*

# Building on and expanding our confederation of scholars

A key element of the NEST strategy is the ongoing development and growth of our group of scholars engaged in new Earth-space technologies. Through our scholars' research strengths in sensors and sensor webs, global navigation satellite systems, remote sensing, space sciences and geospatial modeling, the University of Calgary has built a long and successful history of national and international collaborations and industry partnerships.

Our scholars have long been engaged in major projects, conferences and strategic discussions worldwide. Researchers advance their individual research programs and build their networks in their particular areas of expertise. Based on the successes in these key areas, teams will be created to implement interdisciplinary and collaborative research activities. This growth in the confederation of scholars will strengthen Earth-space research while identifying new opportunities for our scholars to continue ranking highly in capacity and excellence.

*Researcher Emma Spanswick is working with the Canadian Space Agency to look at how space weather interferes with GPS signals.*

# Key partners and infrastructure

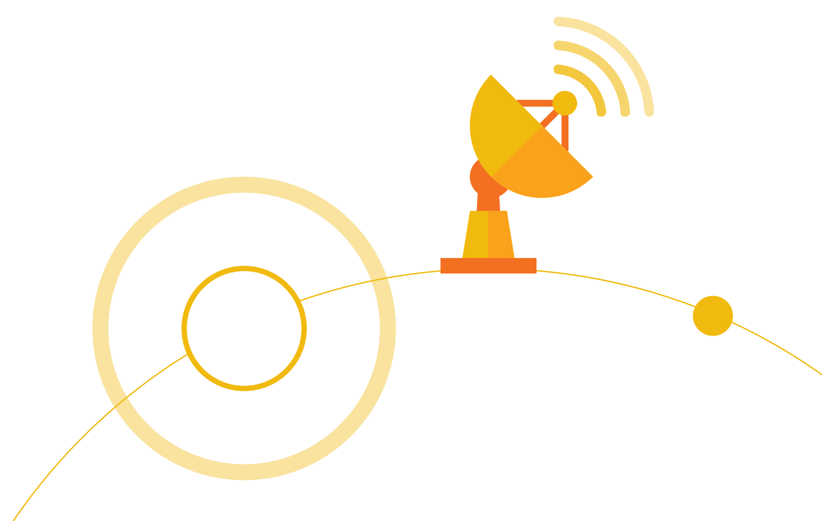
Building on the strengths of our scholars, the strategy will support the development of long-term relations and build new partnerships with key partners, both nationally and internationally, to support leading infrastructure. The Canadian Space Agency has long supported ground and space-based experimental work by University of Calgary scientists and engineers. This CSA-funded research has positioned our researchers to lead multiple successful infrastructure proposals such as the Canadian face of the Resolute Bay Incoherent Scatter Radar (RISR-C), the Transition Region Explorer (TREx), the Array for Broadband Observations of VLF/ELF Emissions (ABOVE), and and the NOrthern Solar Terrestrial ARray (NORSTAR). Additionally, our researchers have access to international state-of-the-art instruments such as the Atacama Large Millimeter/submillimeter Array (ALMA) in the Chilean Andes, the Arecibo Observatory with the world's largest and most sensitive radiotelescope located in Puerto Rico, the x-ray observatory CHANDRA, NASA's flagship mission for x-ray astronomy, and several others.

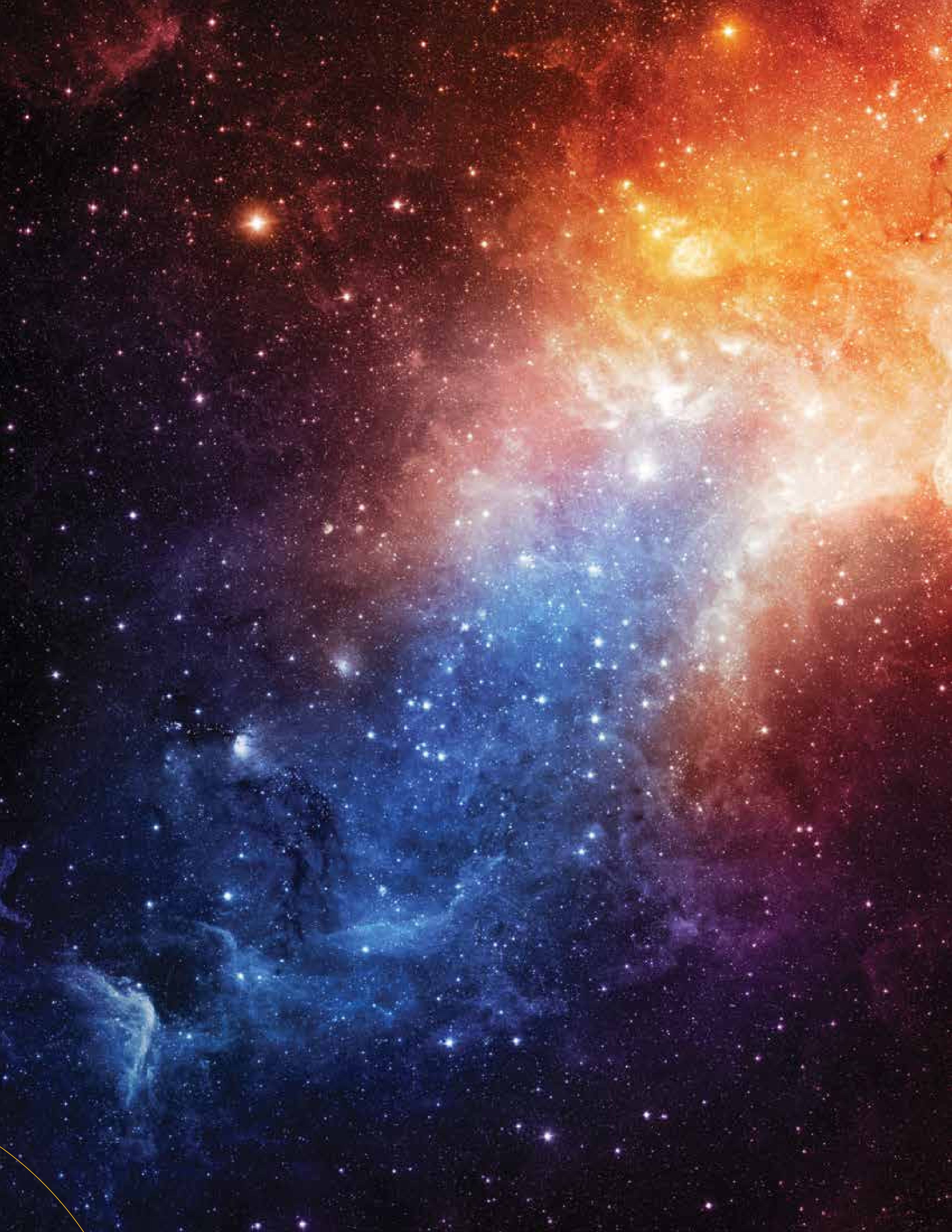
The university's researchers design, build, and utilize instruments that remotely sense space phenomena from the ground and space, and measure the properties of the space environment around balloons, rockets, and satellites. Because our scholars are leaders in instrument development, they are well positioned to join international proposals.

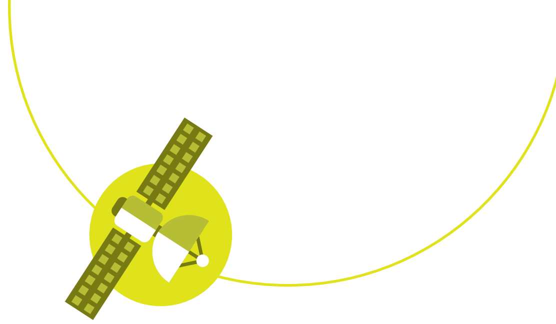
# Building on our research platforms: analytics and visualization

*The Analytics and Simulation and Synthesis* and *Visualization* platforms identified in the University of Calgary's Strategic Research Plan will play a key role in implementing the NEST strategy.

We will draw on our strengths in analytics and geovisualization to exploit the power of big data for different NEST applications. Analytics embraces data-mining methods that promote exploratory analysis, spatial and analytical reasoning, and collaborative decision-making. Geovisualization enables dynamic multi-dimensional representation of spatial and social information, often via interactive techniques. These cross-cutting platforms support improved environmental stewardship and disaster management by combining Earth-space technologies with geosimulation and computational intelligence. And new applications are emerging in our daily lives, such as tracking human activities in urban environments via trajectory visualization and social network data analysis.







# Space Missions

| | Year | Mission | Country | *Description* | UCalgary role |
|---|---|---|---|---|---|
| 1970 | 1971 | ISIS-II | Canada | *ISIS II (International Satellites for Ionospheric Studies) was the fourth Canadian satellite launched in a series to study the ionosphere. It carried the scanning auroral photometer, an innovative instrument that captured the first truly global images of the aurora.* | The auroral photometer was led by UCalgary space physicist Cliff Anger. |
| 1970 | 1972 | RAO | | *Rothney Astrophysical Observatory dedicated. It consisted of a joined pair of ATCO trailers, a Minnaert observing terrace for astronomical laboratories, and a 41-cm telescope and dome for astronomical research.* | UCalgary research and teaching facility |
| 1980 | 1986 | CANOPUS | Canada | *CANOPUS stands for Canadian Auroral Network for the OPEN Program Unified Study, a ground-based instrument array for remote sensing the high-latitude ionosphere. This was the Canadian contribution to a global initiative to study the physics of near-Earth-space. A key CANOPUS instrument was the All-Sky Imager (ASI) which was among the first devices to employ digital (CCD) technology for scientific imaging.* | The CANOPUS ASI was designed, built, and operated (for more than a decade) by a UCalgary based team. For two years at the end of CANOPUS, UCalgary was responsible for the operation of all the CANOPUS instruments. |
| 1980 | 1986 | Viking | Sweden | *Viking, Sweden's first satellite, explored plasma processes in Earth's magnetosphere and the ionosphere. The mission carried an UltraViolet (UV) imager that captured the first sequences (movies) of images of the global aurora, revealing a fundamentally new view of geospace dynamics.* | Built by Canadian industry, UCalgary space physicists provided the scientific leadership of the Viking UV imager. |
| 1980 | 1989 | Akebono | Japan | *Akebono was a satellite to study aurora and Earth's magnetosphere environment. It was developed by Institute of Space and Astronautical Science and launched on an M-3SII rocket on February 22, 1989. After 26 years of successful observation, operation was terminated on April 23, 2015, due to the degradation of solar cells and the decay of orbit.* | Canada's NRC provided a suprathermal ion mass spectrometer for this mission. Starting in 1995, UCalgary assumed leadership of this instrument. |
| 1990 | 1992 | Freja | Sweden | *This Swedish satellite was launched October 6, 1992, carrying two Canadian instruments. These were the Cold Plasma Analyzer (CPA), and an UltraVolet Imager (UVI), both of which supported Freja's science objectives of studying plasma processes in the upper atmosphere.* | The UVI was led by UCalgary, and CPA was led by NRC and later (starting in 1995) UCalgary. |
| 1990 | 1995 | OEDIPUS – C | Canada | *Observations of Electric-field Distributions in the Ionospheric Plasma — a Unique Strategy (OEDIPUS) C was launched on November 7, 1995. It consisted of sounding rocket experiments that used spinning, conductive tethers as a double probe for measurements of weak electric fields in the aurora.* | UCalgary space physicists provided the Thermal Ion Detector for OEDIPUS-C. |

| Year | Mission | Country | *Description* | UCalgary role |
| --- | --- | --- | --- | --- |
| 1995 | Interball | Russia | *The Interball mission consisted of four spacecraft equipped by an international consortium and launched by the Russian Space Agency to study the correlations between plasma processes in the tail of the magnetosphere and in the Van Allen radiation belt (auroral particles acceleration region) with a high time-space resolution. One of the spacecraft carried the UltraViolet Auroral Imager (UVAI).* | UVAI was led by UCalgary space physicists. |
| 1995 | CGPS | Canada | *The Canadian Galactic Plane Survey (CGPS) uses the Dominion Radio Astrophyical Observatory (DRAO) synthesis telescope to study Hydrogen emissions from the plane of our galaxy, the Milky Way. This project revives national interest in radio astronomy, and secures an exciting future for DRAO.* | CGPS is funded through a major NSERC award led by UCalgary astronomers. |
| 1997 | VSOP | Japan | *The Very long baseline interferometry Space Observatory Program satellite carries an 8m radio antenna that serves as the space-borne counterpart for ground-based radio telescopes for VLBI. The mission delivers 100X better spatial (angular) resolution than the Hubble Space Telescope.* | UCalgary is the Canadian data analysis centre for VSOP. |
| 1998 | ACTIVE | Canada | *The ACTIVE sounding rocket was launched on April 28, 1998, carrying three instruments.* | ACTIVE was led by UCalgary space physicists. |
| 1998 | Nozomi | Japan | *Nozomi was designed to study the upper Martian atmosphere and its interaction with the solar wind and to develop technologies for use in future planetary missions. Due to problems encountered during complex manoeuvres, Nozomi missed Mars and is now in eternal orbit around the Sun.* | UCalgary space physicists led the development of the thermal plasma analyzer on Nozomi. |

**1990**

| | | | | |
| --- | --- | --- | --- | --- |
| 2000 | GEODISIC | Canada | *The Geoelectrodynamics and Electro-Optical Detection of Electron and Suprathermal Ion Currents (GEODISIC) sounding rocket mission studied study plasma in the Earth's ionosphere.* | UCalgary researchers developed a thermal electron imager (TEI) and suprathermal ion imager (SII) for GEODESIC. Sensors measured low energy-charged particles in the earth's atmosphere — electrons and ions — that are energized by the northern lights and escape into outer space. |

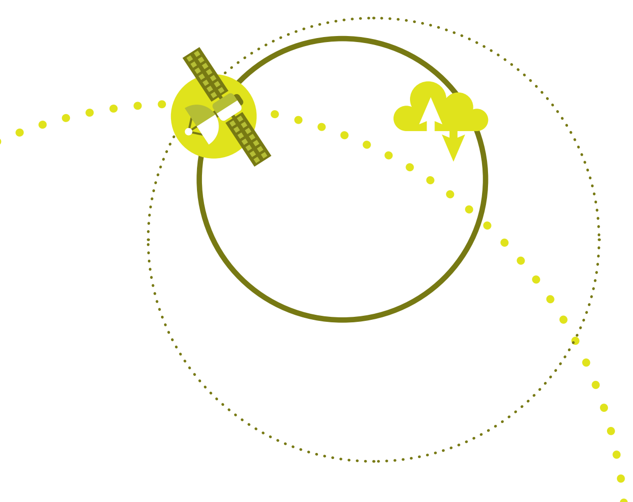
**2000**

2000

| Year | Mission | Country | *Description* | UCalgary role |
|---|---|---|---|---|
| 2000 | S520-2 | Japan | *Sounding rocket that studied ion-heating mechanism near the polar cusp.* | UCalgary space physicists provided an imaging ion mass spectrometer for the mission. |
| 2002 | Cusp2002 | USA | *Probed the dayside cusp ionosphere and detected the first stages of upward ionospheric acceleration.* | UCalgary provided two CCD-based particle imagers. |
| 2003 | CGSM | Canada | *Canadian GeoSpace Monitoring was developed as the CSA-funded 'next phase' of the CANOPUS project. CGSM is a ground-based network of optical, radio, and magnetic field detectors designed to provide a continent-wide view of the dynamics of Earth's ionosphere over Canada.* | UCalgary space physicists led the Canadian community in developing the proposal for CGSM, and led three networks of CGSM instruments (All-Sky Imagers, Meridian Scanning Photometers, and riometers). |
| 2003 | ALMA | USA | *The Atacama Large Millimeter Array, a massive radio telescope, was developed in Chile's high desert. This is one of NSF's largest science infrastructure projects and is used for radio astronomy by researchers around the world.* | UCalgary led a consortium of Canadian universities in the successful application to CFI for funding to support Canada's involvement in ALMA. |
| 2007 | JOULE/ JOULE-II | USA | *Two instrumented rockets measured small-scale electric field and electron density fluctuations in the thin atmosphere from about 60 to 120 miles above Earth's surface. Tracked the transition from magnetospheric to atmospheric control of ion flows and defined a new "edge of space".* | UCalgary provided CCD-based suprathermal ion imagers (SII). |
| 2007 | S520-23 | Japan | *Measured flows of neutral and ionized gases in the ionosphere.* | UCalgary provided an SII. |
| 2007 | THEMIS | USA | *Time History of Events and Macroscale Interactions during Substorms (THEMIS) is a mission to investigate what causes auroras in the Earth's atmosphere to dramatically change from slowly shimmering waves of light to wildly shifting streaks of colour. Discovering what causes auroras to change will provide scientists with important details on how the planet's magnetosphere works and the important Sun-Earth connection.* | UCalgary and UCBerkeley co-led the development and deployment of a continent-wide network of All-Sky Imagers that play a central role in the mission science. |

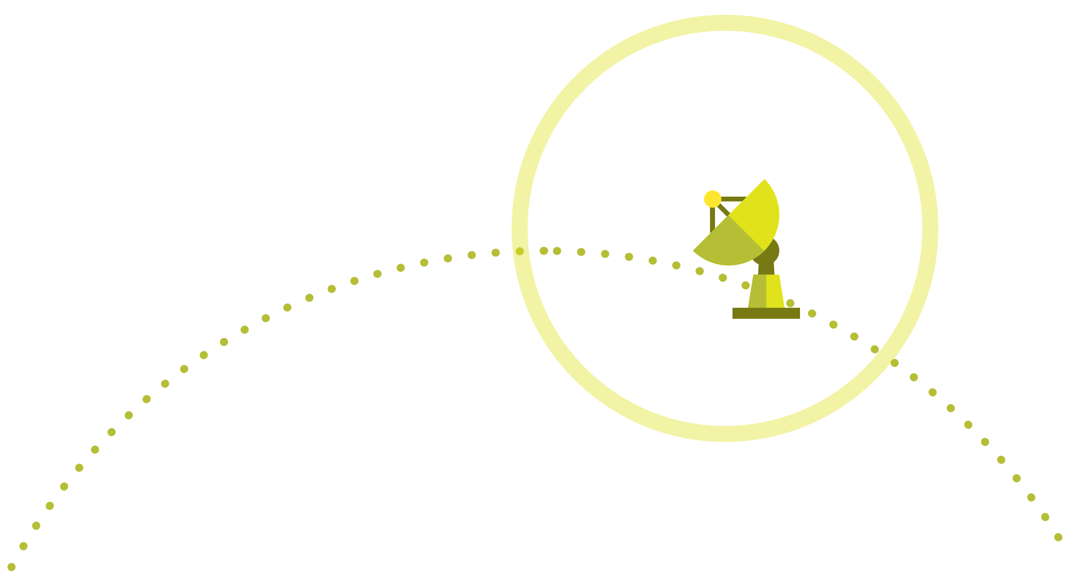
| Year | Mission | Country | *Description* | UCalgary role |
|---|---|---|---|---|
| 2011 | RAO | Canada | *Rothney Astrophysical Observatory solar-observing telescope came online.* | RAO and all of its instruments is a UCalgary program. |
| 2012 | S520-26 | Japan | *A follow-on to S520-23, and a two-section rocket payload to measure neutral and ion winds in the upper atmosphere using chemical release and in-situ plasma measurements.* | UCalgary space physicists provided an imaging ion mass spectrometer for ion velocity measurements. |
| 2012 | RISR | Canada/ USA | *Resolute Bay Incoherent Scatter Radar (RISR) is a powerful ground-based radar that was developed to study how physical processes in near-Earth-space affect Earth's upper atmosphere. It provides detailed measurements of ionospheric parameters (electron number density, plasma velocities, etc.), information that is key to studying the coupling between our space environment and the upper atmosphere.* | RISR is a joint Canada-US initiative. The radar and supporting instruments was funded through the US-NSF and a major UCalgary-led CFI award. UCalgary and US partner SRI-International operate the facility. |
| 2012 | Swarm | European Union | *Swarm is a European Space Agency (ESA) mission to study the Earth's magnetic field. High-precision and high-resolution measurements of the strength, direction and variations of the Earth's magnetic field, complemented by precise navigation, accelerometer and electric field measurements, are providing data essential for modeling the geomagnetic field and its interaction with other physical aspects of the Earth system. The results will offer a unique view of the inside of the Earth from space, enabling the composition and processes of the interior to be studied in detail and increase our knowledge of atmospheric processes and ocean circulation patterns that affect climate and weather.* | Following earlier successes with GEODESIC and Joule, UCalgary space physicists were invited by ESA to lead the Electric Field Instruments on the Swarm satellites. |
| 2013 | NEOSSat | DRDC/ CSA | *The Near Earth Object Surveillance Satellite (NEOSSat) is a dual-use microsatellite of Defence Research and Development Canada (DRDC) and the Canadian Space Agency (CSA). The main objectives are to search the sky near the Sun to discover and track asteroids of the inner solar system, and to track artificial satellites in high Earth orbits. The former activity will further explore the population of small bodies near the Sun; the latter will improve tracking and characterization of spacecraft.* | UCalgary scientists were responsible for mission design, planning and operation, as well as on-orbit testing, calibration, and operation of space telescope. UCalgary was also responsible for coordination of satellite use with DRDC. |

2010



2010

| Year | Mission | Country | *Description* | UCalgary role |
|---|---|---|---|---|
| 2012 | CASSIOPE (ePOP) | Canada | *Enhanced polar outflow probe (ePOP). CASSIOPE is the first Canadian hybrid satellite to carry a dual mission in the fields of telecommunications and scientific research. The main objectives are to gather information to better understand the science of space weather, while verifying high-speed communications concepts through the use of advanced space technologies.* | UCalgary space physicists led the development of the ePOP mission, including the mission design and planning, and the design, build, integration and operation of the 8-instrument ePOP payload. This included the fabrication and testing of 4 of the instruments. |
| 2013 | GO Canada | Canada | *Geospace Observatory Canada is CSA's follow on to CGSM and CANOPUS. This ground-based network of imagers, radars, riometers, magnetometers, and GPS systems provides a world-unique view of ionospheric and auroral processes over much of Canada.* | UCalgary leads four of the arrays that comprise GO Canada (the auroral imagers, riometers, photometers, and VLF receivers). |
| 2014 | ABOVE2 | Canada | *Airborne Balloon Observations of VLF waves and Electrons over ABOVE involves the development of x-ray detectors for flights on three high-altitude balloons, studying the radiation belts and their impact on the upper atmosphere.* | UCalgary leads ABOVE2, and developed the flight VLF receiver and payload integration. |
| 2015 | Astrosat | India | *The Astrosat satellite carries five separate telescopes to image simultaneously in x-rays to visible light, something that until now has only been done with combinations of space- and ground-based telescopes.* | UCalgary astrophysicists provide key support, including calibration, for Canada's contribution of a UV imager. |
| 2016 | OSIRIS-REx | USA | *OSIRIS-REx is NASA's mission to Earth-crossing asteroid Bennu, which will potentially impact Earth in the late 22nd century. The spacecraft will map Bennu's surface, and return a sample of its rocky surface. The science objectives include studying early solar system processes, asteroid compositions, and asteroid geology. A very practical objective is that knowledge of the composition and structure of Bennu will be of pivotal importance for a potential impact mitigation mission if it is determined that Bennu will collide with Earth. The mission will return a sample to Earth in 2023.* | The CSA is a partner in OSIRIS-REx, and is providing the funding for the scanning LIDAR, a key instrument for the mission. Scientific leadership for the Canadian role in the mission is shared by UCalgary and YorkU, and UCalgary planetary scientists will study and curate the Canadian portion of the Bennu sample returned by OSIRIS-REx. |



| Year | Mission | Country | *Description* | UCalgary role |
| --- | --- | --- | --- | --- |
| 2016 | TREx | Canada | *The Transition Region Explorer is a new network of ground-based auroral imagers viewing the sky over Manitoba, Saskatchewan, and Alberta. TREx deployment begins in 2016, and within three years the array will include cameras operating at more than four wavelengths and with frame rates as high as 30 images every second. The array includes 'stream computing' software to support 'on-the-fly' decision-making by the network itself, and state-of-the-art GPS units for ionospheric investigations and as a test bed to explore how space weather affects satellite navigation systems.* | UCalgary led the successful TREx CFI proposal, is developing and deploying the optical imagers, and is working with researchers in the US to develop the GPS and imaging riometer components of the project. |
| 2017 | EPEx | Canada | *The Energetic Particle Explorer is a stratospheric balloon mission designed to study short bursts of energetic electrons striking the upper atmosphere.* | UCalgary leads the project, and provides the x-ray imager and payload integration. |

2010

| | | | | |
| --- | --- | --- | --- | --- |
| 2022 | SMILE | European Union & China | *The Solar wind Magnetosphere Ionosphere Link Explorer will be a revolutionary satellite mission designed to simultaneously image the solar wind-magnetosphere interaction with an x-ray imager (developed by astrophysicists) and the global aurora with an UltraViolet Imager (UVI). SMILE will be the first scientific satellite to observe the complete causal chain of space weather.* | UCalgary space physicists are leading the design of the SMILE-UVI. |
| 2025 | PCW | Canada | *The Polar Communications and Weather (PCW) system would consist of two satellites in polar orbits to provide Canada with critical weather information and communications capabilities in the high arctic. The operational objective for PCW is to provide continuous imaging of weather, including clouds and ice, everywhere north of 45° geographic latitude. PCW would be Canada's contribution to the global fleet of weather satellites operated by the US, Europe, and China. This proposed mission would have a unique orbit, and would be the first satellite project supporting 24/7 viewing of the polar region. PCW would likely carry a secondary scientific payload (three different such payloads are under consideration by the Canadian government).* | UCalgary leads one of the three possible secondary payloads, namely auroral imagers that would provide 24/7 viewing of the northern hemisphere aurora, providing a globally unprecedented view of space weather and the physics of near-Earth-space. |

2020

The University of Calgary is a leading Canadian university located in the nation's most enterprising city. The university is making strong progress on our strategic direction to become one of Canada's top five research universities, where research and innovative teaching go hand in hand, and where we fully engage the communities we both serve and lead.

This strategy is called *Eyes High,* inspired by the university's Gaelic motto, which translates as 'I will lift up my eyes.' As part of the roadmap to achieve these goals, the university's Strategic Research Plan identifies six research themes that will leverage our distinct capabilities while addressing the unmet needs and challenges of our society as a whole:

- Energy innovations for today and tomorrow
- Engineering solutions for health: biomedical engineering
- Brain and mental health
- Infections, inflammation and chronic diseases in the changing environment
- New Earth-space technologies
- Human dynamics in a changing world: smart and secure cities, societies, and cultures

Learn more about the University of Calgary's Strategic Research Plan and the New Earth-space technologies Research Strategy.

Contact the Office of the Vice-President (Research) at vpr@ucalgary.ca

**ucalgary.ca/research**

FSC
Mixed Sources
Product group from well-managed forests and other controlled sources
www.fsc.org Cert no. XXX-XXX-XXXX


UNIVERSITY OF CALGARY