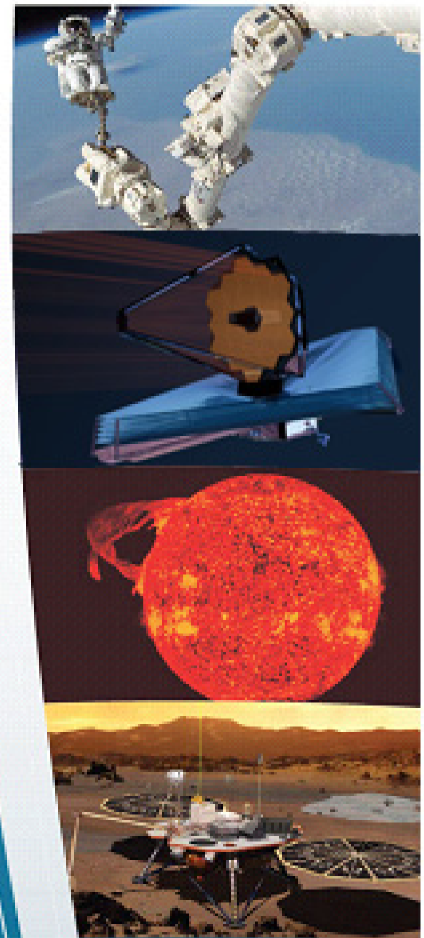
Canadian Space Agency Agence spatiale canadienne



# CANADIAN SPACE AGENCY REPORT
## 37th COSPAR Scientific Assembly
## Montréal, Canada, 07/2008

## SPACE SCIENCE RESEARCH IN CANADA
## 2006-2007

Canada

# Table of Contents

# COSPAR in Canada

The National Research Council of Canada (NRC) is the national adhering member of COSPAR, while the Canadian Space Agency (CSA) is responsible for the Canadian National Committee (CNC) for the Committee on Space Research (COSPAR). COSPAR, established by the International Council of Scientific Unions (ICSU) in 1957, is an international body. Now the International Council for Science (ICS), ICSU is an autonomous body under the auspices of UNESCO (United Nations Educational, Scientific and Cultural Organization) located in Paris, France.

The NRC's Advisory Committee on International Science, Engineering and Technology (CISET) advises both the NRC and CSA on COSPAR issues. Communication between the CNC, COSPAR and the NRC is provided by NRC's International Relations Office. The CNC comprises of existing scientific advisory committees to the CSA Space Science Program. Dr. Gordon Shepherd, Director of the Centre for Research in Earth and Space Sciences (CRESS) at York University, is the Canadian representative to COSPAR and a member of the COSPAR Bureau. Dr. David Kendall, Director General of the CSA Space Science Program, is Chairman of COSPAR's Finance Committee.

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## Overview of Space Science in Canada

From the climate on Earth to the weather on Mars. From the aurora borealis to oil deposits deep beneath the oceans. From cells that create and destroy bone to planets circling distant stars. From the ozone layer to water desalination. These widely diverse topics have one thing in common: they're all subjects of research projects currently sponsored by the Canadian Space Agency's (CSA) Space Science Program. Along with many other projects, they focus on expanding knowledge of the space environment and enabling a growing human presence there, and on using the space environment to better understand our world, other worlds, and the universe as a whole.

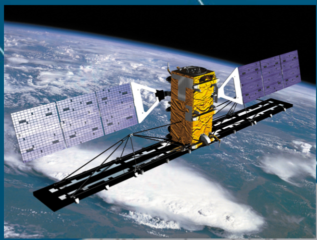
All these projects are embraced by the CSA's mandate, as defined in the *Canadian Space Agency Act* of 1990, "to promote the peaceful use and development of space, to advance the knowledge of space through science, and to ensure that space science and technology provide social and economic benefits for Canadians." They engage Canada's research community in exploring leading scientific questions, often in partnership with Canadian industry, government agencies, and international research organizations. They provide Canadian companies with opportunities for high-tech innovation and participation in large-scale, multinational projects, which, in turn, enhance their global competitiveness.

Space science projects also generate knowledge that helps to improve environmental stewardship and the quality of life on Earth—and off it, as humans continue to expand their reach beyond Earth's orbit.

Because Canada has a modest budget for space activities, and, comparatively, a small community of space researchers and industries, CSA has focused its efforts on fostering world-class expertise and competitiveness in certain key niche fields in science and technology. One important objective is to make Canada's space industry a prime supplier of instruments and systems for spacecraft and space-related ground-based activities.

Another important aspect of this strategy is capitalizing on Canada's geographic strengths. For example, its high-latitude location has encouraged its development as a world leader in studying the aurora borealis and Arctic ozone levels. In addition, the remoteness and harsh climate of the Canadian North has provided a useful simulation of certain conditions on Mars.

Specialized scientific and technological expertise like these have been used to support all-Canadian projects—such as the highly successful small astronomical



satellite, MOST—and to leverage Canada's participation in larger international programs, such as the U.S.-led Phoenix mission to Mars. In some areas of space science, this approach has enabled Canada to, in the words of one researcher, "punch above its weight."

Approved by the federal government in 2005, the Canadian Space Strategy is the framework that guides the development of the CSA's programs. It has four major thrusts:

- Earth Observation: to look down upon Earth to monitor and protect life below;
- Space Science and Exploration: to look out into the depths of space to explore and discover more about the universe and our place within it;
- Satellite Communications: to look upon space as a means of communicating with each other by relaying information via satellites; and
- Space Awareness and Learning: to look upon space as a source of inspiration to inform Canadians about their country's advances in science and technology, and increase the scientific literacy among our citizens.

The missions and research projects supported by the Space Science Program fall primarily within the first two thrusts—Earth Observation, and Space Science and Exploration.

## Earth Observation

Canada is a large country with a small population concentrated near its southern border. Much of its territory, especially in the North, is remote, isolated, and environmentally harsh. Monitoring and managing this sprawling land, its environment and its natural resources is an enormous challenge—one for which space-based observing systems are uniquely suited. No other options offer the same breadth of access in a cost-efficient way.

The objective of the Earth Observation (EO) thrust, which accounts for the largest part of the CSA's budget, is to establish and maintain Canada's leadership in developing and using space-based observations to support national priorities. These priorities fall into three categories: the environment, resource and land-use management, and security and foreign policy.

All Earth systems—the atmosphere, the oceans, land surfaces, and the biosphere—are included. Space science activities contribute significantly to EO projects, particularly in atmospheric research, exploring issues of particular relevance to Canada such as the state of the ozone layer over the Arctic.

At the same time, Canada is an active participant in international programs, and contributes both technology and scientific expertise to studying global environmental and resource issues. For example, data gathered by MOPITT, a Canadian-built instrument carried on a NASA satellite, is being used to map how pollutants migrate around the planet.

The data produced by CSA's EO thrust are intended to assist the government in policy-making and provide Canadians with tangible benefits. Space-based observations are crucial to a wide range of economic, environmental and security services: from forecasting the weather, monitoring sensitive ecosystems, and managing forests, to providing ice monitoring and mapping, surveillance of coastal waters, and protecting people and infrastructure from natural hazards and helping them recover from disasters.

Earth observation data play a significant role in measuring air and water quality and pollution levels, and enhance Canada's ability to employ sustainable management of its natural resources, fisheries, agriculture and land use—four sectors that generate more than 42% of the country's exports and account for 14% of Gross Domestic Product.

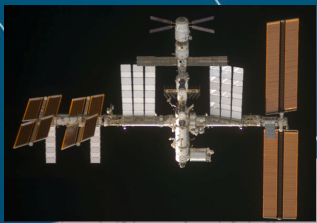
The EO thrust is particularly significant for understanding, monitoring and managing Canada's most challenging environments: the North and its extensive coastline—the longest in the world. These vast regions, containing relatively little infrastructure, are difficult and expensive to monitor using technologies based on Earth.

The EO thrust also play a key role in helping Canada meet its needs for surveillance and law enforcement on land, in coastal waters, and at its borders. EO data are also useful to support foreign policy initiatives, such as peacekeeping activities, treaty verification, and delivering humanitarian aid.

## Space Science and Exploration

At the heart of the CSA's Space Science and Exploration thrust are these three objectives:

- To better understand the solar system and the universe;
- to seek signs of life in extraterrestrial habitats; and
- to prepare for permanent human presence in space and on other planets.



This is a science-driven strategy focused on searching for answers to fundamental questions to increase human knowledge. The questions dealt with include the:

- origin and evolution of the solar system and the universe;
- origin and evolution of life on Earth, and whether it exists elsewhere;
- relationship between the sun and the Earth;
- existence of planets around other stars; and
- the nature of the space environment itself, particularly the unique feature of microgravity and its effects on humans, other life forms and materials.

These issues engage scientists across a very broad range of disciplines—physics, astronomy, geology, biology, chemistry, psychology and medicine—and result in projects that foster multidisciplinary collaboration, both within Canada and internationally.

International co-operation has always been an essential element of Canada's program. Lacking its own launch capability or the funds required to mount large missions on its own, Canada has always leveraged its specialized scientific and technological skills in niche areas to obtain flight opportunities and to gain access to scientific data through international programs. One example was providing robotic manipulators for the Space Shuttle and the International Space Station, which resulted in Shuttle flights for Canadian astronauts as well as access to the both the Shuttle and the Station for Canadian scientific investigators to conduct experiments. Similarly, the provision of a meteorological station has bought Canadian scientists a ticket to Mars on NASA's Phoenix mission.

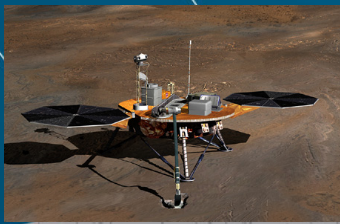
Canada views its participation in Space Science and Exploration activities as an investment that produces many tangible benefits on Earth. They enhance the scientific and technological skills of Canadians, as well as their ability to compete in an increasingly knowledge-based economy. They also generate spin-off technological and economic benefits, and inspire young people to pursue advanced education and careers in science and technology.

## Partnerships

Establishing effective partnerships with federal, provincial and territorial government departments and agencies, the academic community, Canadian industry, and international organizations is essential to achieve CSA's goal of making Canada a world leader in space science and technology.

Several departments of the Government of Canada are both partners in and users of data generated by space-based programs. For example, federal departments like Natural Resources Canada, Environment Canada, Fisheries and Oceans Canada, and the Department of National Defense are major users of EO data. So, too, are provincial and territorial governments because of their constitutional mandate to protect the environment and manage resources such as forests, water, agriculture, and mineral deposits. They also have a direct interest in industrial development, economic spin-offs, and support for academic research resulting from science and technology programs.

The academic community plays a key role in guiding the direction of the CSA's Space Science Program. They participate in advisory committees that help identify fundamental scientific questions and provide counsel on issues of national and global importance, and submit proposals for research activities aimed at finding the answers. They have also spearheaded the development of innovative new instruments and other technologies that have been commercialized through collaboration with existing companies or the creation of new ones. These activities have generated significant local, regional and national economic spin-offs, as well as increased export opportunities for Canadian industry. These activities, which usually involve collaboration on a national and international scale, have helped to advance the development of superior expertise, excellence and leadership in important scientific, technological and engineering disciplines.



## Highlights of the Canadian Space Program

Since the last Canadian Space Agency report to COSPAR in 2006, Canada has made significant advances in its space science program. A number of projects have been successful and are returning a wealth of scientific data that increase our understanding of the space environment and the history and evolution of the universe and its various components. These findings will make important contributions to the future exploration of space, including human exploration of other planetary bodies.

These projects cover the spectrum of disciplines supported by the CSA's Space Science Program, including planetary exploration, astronomy, solar-terrestrial science, physical sciences and life sciences. They further CSA's mandate to use space science to advance fundamental knowledge and provide social and economic benefits on Earth. They have also enhanced Canada's scientific and technological capabilities as well as the international competitiveness of its space industry.

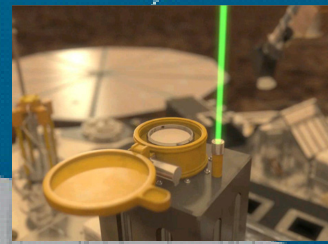
They include a mixture of all-Canadian missions and collaborations with international partners, many of which involve contributions of instruments or sub-systems, in keeping with the CSA's goal of making Canadian companies key suppliers of such devices in the international market. These international collaborations also enable Canadian scientists and engineers to participate in large missions that Canada cannot support on its own, giving them access to the latest data to further their research goals.

### Planetary Science & Astronomy

#### Phoenix Mars Lander

On May 25, 2008, many years of hard work by an international team of scientists and engineers culminated in a dramatic and successful landing of the Phoenix spacecraft in the north polar region of Mars. Canada played a role in this project by building the meteorological (MET) station that is being used to collect data on weather conditions and climate in a region thought to be rich in ice near the Martian Arctic Circle.

The Phoenix mission marked the first time Canada is part of a mission to land on another planet. Just two days after the landing, Canadians were treated to an image of the Canada wordmark on the thermal blanket protecting the lidar (light



detection and ranging) instrument that is being used to probe the Martian atmosphere.

After successfully deploying the solar panels crucial to its survival on the cold Martian surface, Phoenix quickly began sending data back to Earth, including weather reports from the MET station. The lidar, the first to be used on the Martian surface, was successfully activated and tested four days after landing. Canadian science lead Jim Whiteway of York University told a press conference that it was an enormous challenge to “deliver the lidar from the test lab in Ottawa, Canada, to Mars while maintaining its alignment within one one-hundredth of a degree.”

The CSA invested $37-million (Cdn) in designing and building the MET station and supporting its science operations. York University leads the Canadian science team with the participation of the University of Alberta, Dalhousie University, Optech and Natural Resources Canada (Geological Survey of Canada), the Canadian Space Agency and international collaboration from the Finnish Meteorological Institute. MDA Space Missions is the prime contractor for the meteorological station, in partnership with Optech.

The science team is looking forward to a planned 90 days of collecting information about a region of the planet that has never before been investigated at ground level. Phoenix carries a robotic arm that will be used to dig for subsurface soil and ice samples and deliver them to on-board instruments for analysis. The goal is to gain a better understanding of the history of water on Mars and the implications for the existence of life on the planet. At present, water exists only in solid or gaseous form (ice or water vapour) but is highly probable that liquid water once existed on the surface.

Another goal of the Phoenix mission is to characterize the polar climate. The MET station will focus on the boundary layer—the region just above the surface where most turbulence occurs, and where heat, dust, water vapour, and other gases are mixed and transferred between the atmosphere and the surface. It has three temperature sensors (thermocouples) and a pressure sensor that will monitor temperature and atmospheric pressure. Also part of the weather station is a device called a telltale, provided by Denmark’s University of Aarhus, with support from the University of Alberta, which measures wind speed and direction.

The lidar will be used to detect dust, ice clouds and fog in the lower atmosphere. Clouds play a key role in the water cycle of a planet by moving water and water vapour around. Atmospheric dust affects the flow of solar energy and influences the formation of clouds. Documenting dust on Mars is also important because the

planetary surface is subject to frequent and often very large dust storms that could be hazardous to future robotic and human exploration missions.

The data gathered by the MET station will not only improve computer modelling of the Martian climate, but will also help scientists better understand changes in the climate of Earth's polar regions. This project is considered a component of the International Polar Year science program, which runs from March 2007 to March 2009.

**Alpha Particle X-Ray Spectrometer (APXS)**

Another Canadian instrument, an Alpha Particle X-Ray Spectrometer (APXS), will be heading for Mars next year aboard NASA's Mars Science Laboratory (MSL), a two-year robotic mission scheduled for launch in 2009 and landing in 2010. MSL is designed is to evaluate whether Mars is or ever was capable of supporting microbial life. APXS, built by MDA Space Missions, will be used to measure the chemical composition of Martian rocks and soil as well as processed samples collected from the surface. This information can help shed light on whether life forms ever existed on Mars.

APXS is a highly precise instrument that can identify the percentages of elements like sulphur, iron, silicon and magnesium in a sample, and can even detect tiny amounts of trace elements like nickel, chlorine and zinc. "The ability of this instrument to measure rocks and soils will make it possible to perform investigations that no other instrument on the rover can deliver," said University of Guelph physicist Ralf Gellert, the principal investigator for APXS.

He noted that the elements that make up rocks and soil can reveal a great deal about their history, including whether they've likely come in contact with water in the past. Documenting the history of water in Mars is key to determining whether the planet was ever capable of supporting life.

Gellert was a member of a scientific team at Germany's Max Planck Institute for Chemistry that built similar instruments for the Pathfinder mission that landed on Mars in 1997, and the two NASA Mars Exploration Rovers, Spirit and Opportunity, that landed in January 2004, and were continuing to explore Mars into the spring of 2008. In Canada, he has been working to improve the device with significantly increased sensitivity.

The size of a soda can, APXS is scheduled to be delivered to CSA, and then to NASA's Jet Propulsion Laboratory, in the summer of 2008 for integration and testing on the MSL spacecraft.

**Future planetary missions**

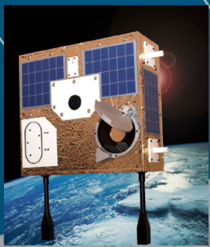
Canada is currently in discussions with the European Space Agency concerning participation in ESA's ExoMars mission. Initially approved in 2005, the mission is undergoing restructuring and must receive new approval from European space ministers in November 2008. The Canadian contribution will be decided within the next few months.

Scheduled for launch in 2013 and landing in 2014, ExoMars includes both a lander and rover and will focus primarily on exobiology. The Canadian company, MDA Space Missions, developed a six-wheeled prototype of the rover, one of two designs that will be evaluated in a simulated Mars environment this summer. One of the designs will be accepted for further development.

Canada has not yet made commitments to other future planetary programs but CSA is investigating several mission concepts for the continuing exploration of Mars. There is particular interest in the potential for three instrument concepts that have heritage in earth orbit to make a significant contribution to Mars: synthetic aperture radar (RADARSAT) for high resolution surface mapping; FTIR (Scisat) for detailed atmospheric composition, and Doppler Michelson (WINDII) for measurements of Mars wind fields. All three of these represent technologies and science in which Canada has significant expertise. Other concepts involve the development and exploitation of terrestrial technologies and expertise where Canada excels for space, including further use of lidar, and drilling systems and exploration geology. The recent development of a Canadian astrobiology community and work in the Canadian north at sites that respresent the frozen desert conditions of the most habitable bodies in the solar system will give Canada the expertise to participate in investigations related to the most compelling science question of solar system exploration: did life evolve elsewhere at any point in solar system history?

Canada has also started looking at the possibility of doing science on the moon but there are, as yet, no formal programs in this area. The CSA is discussing participation in the International Lunar Network program, a NASA-led program currently under study that will support the development of several small robotic landers to carry science instruments to the lunar surface around 2013.

Canada is also considering what role it might play in the Global Exploration Strategy (GES), a framework for international collaboration in planetary exploration that is currently being discussed among the international partner agencies.



In a speech at the CSA in May 2008, Industry Minister Jim Prentice said that Canada "will continue to work as a valued partner in the world's quest to understand and use space to advance our collective goals." He noted that Canada's quality of life will be transformed "if we keep up the momentum we have built on space exploration and development…We stand at the threshold of a new era of achievement for Canada in space."

**Microvariability and Oscillations of Stars (MOST)**

Canada's first space telescope, MOST (Microvariability and Oscillations of Stars), is still going strong as it reached its fifth anniversary on June 30, 2008. This small astronomical satellite measures tiny variations in the brightness of stars to determine their age, nature and composition. In addition, MOST is generating important information on planets orbiting other stars.

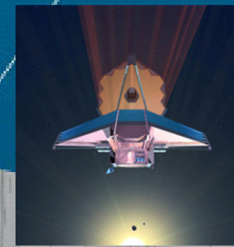
Although studying exoplanets was not part of its original mandate, MOST is able to provide insight about these planets by measuring their very subtle effect on the brightness of the stars they orbit. It has produced data addresses questions about the influence of exoplanets on the host star and the presence of additional planets[g1]. These data help scientists understand our own sun and solar system in the context of other stars and planets.

Originally intended to last only one year, MOST has, instead, spent five years producing a wealth of significant and often surprising data on hundreds of stars and a number of exoplanets. MOST has "exceeded every expectation of mission planners," according to University of British Columbia astronomer and MOST Mission Scientist Jaymie Matthews. In 2007 and 2008, the science team published about 20 research papers.

In June 2007, the MOST science team created an outreach program that allows all Canadians, including students and amateur astronomers, to propose ideas for scientific observations with the MOST space telescope. The science team will work with those whose proposals are accepted to analyze the data.

**Herschel Space Observatory and Planck Surveyor**

Canada is contributing to two of the three instruments on the European Space Agency's Herschel Space Observatory, scheduled for launch before the end of 2008. Herschel is designed to study how stars and galaxies are born; it will focus on extremely cold, distant objects that can help scientists understand the early history and evolution of the universe. Herschel will accomplish this by looking at the far-infrared to sub-millimetre wavelengths. It will be the only space telescope able to cover this spectral range.



The instruments, which must be kept very cold themselves to achieve maximum sensitivity, will be cooled by liquid helium; in addition, the spacecraft will be placed far out in space, in an orbit around the Sun-Earth Lagrange 2 point, about 1.5 million kilometres from Earth.

A team of Canadian researchers, led by physics professor David Naylor of the University of Lethbridge, is contributing to SPIRE (Spectral and Photometric Imaging Receiver), which will look simultaneously at a whole region of the sky with both an infrared camera and a spectrometer. The Canadian team developed a test instrument that was used for calibration and qualification testing, and software for data analysis. Canadians are also working on the instrument test and control teams for the mission.

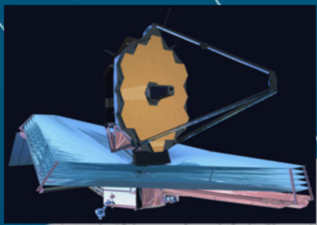
In addition, a team at the University of Waterloo, led by physics and astronomy professor Michel Fich, developed the tuner for Herschel's Heterodyne Instrument for the Far Infrared (HIFI), a spectrometer that will look at a single point in the sky. HIFI will be the first instrument to study the chemistry of our galaxy and, in particular, will look for water in different space environments.

In return for these contributions, Canada is entitled to place five scientists on the Herschel science team who will have guaranteed access to observing time to support their research.

The Planck Surveyor will be launched on the same spacecraft as the Herschel Observatory and will also be placed at the Sun-Earth L2 point, but will assume its own orbit and will operate independently. This telescope includes two instruments (high- and low-frequency radio receivers) and is designed to study the cosmic microwave background radiation left over from the Big Bang nearly 14 billion years ago. The data it produces may help to answer some of the most fundamental questions about the origin, history and future of the universe. Researchers at the University of British Columbia and the University of Toronto's Canadian Institute for Theoretical Astrophysics are providing software for data analysis and calibration facilities for Planck's instruments. Canadians are also participating in the Planck science working groups.

**James Webb Space Telescope**

The James Webb Space Telescope, a NASA-led project with participation from ESA and the CSA, is a large infrared observatory scheduled for launch in 2013 and expected to operate for five to ten years. Like the Herschel and Planck telescopes, it will be placed at the Sun-Earth Lagrange-2 point.



A successor to the Hubble Space Telescope, JWST will observe a wide range of astronomical objects and collect data on the physical processes that control the formation and early evolution of galaxies, stars and planets. This information will improve scientific understanding of the origin and history of the universe.

Canada is contributing two important hardware components: the fine guidance sensor (FGS), which will enable highly accurate pointing of the telescope, and a very precise tuneable filter imager (TFI). The TFI  will, in effect, be an additional scientific instrument; it can, for example, help scientists to search for exoplanets and first light. The instrument carrying both devices is being built by COM DEV in Ottawa, Ontario.

The Canadian science team is led by John Hutchings of the National Research Council's Herzberg Institute of Astrophysics and by Rene Doyon of the Universite de Montreal.  In return for Canada's participation, not only will the science receive guaranteed observing time on the telescope to conduct their research, but the observatory will be available to Canadian astronomers for 5% of the available time.

**ASTROSAT/UVIT**

In the spring of 2009, India plans to launch its first space telescope, ASTROSAT, which will be used to study celestial objects in the ultraviolet, visible and x-ray range of the spectrum, including black holes, neutron stars, pulsars, white dwarfs, quasars, active galactic nuclei, supernova remnants and galaxy clusters. In its first collaboration with the Indian Space Research Organization, CSA is supporting development of photon-counting detectors for ASTROSAT's two ultraviolet imaging telescopes (UVIT).

John Hutchings of the National Research Council's Herzberg Institute of Astrophysics leads a team of Canadian astronomers who collaborated in calibration  the detectors and will share in the UVIT team's ASTROSAT guaranteed observing time. Astrosat will also be made available to Canadian astronomers through a competitive peered reviewed process during the satellite's open time. Routes Astroengineering of Ottawa built the devices and was responsible for their design, assembly, integration and testing for the UVIT telescopes.

**NEOSSat**

Canada is building the world's first space telescope designed to detect and track asteroids and satellites, providing a dramatic improvement in surveillance for

objects that pose a collision hazard with Earth and unprecedented opportunities for tracking objects in orbit high above our planet.

Called NEOSSat (Near-Earth Object Space Surveillance Satellite), this mission will build upon Canada's expertise in compact, microsatellite design. The 65-kilogram spacecraft will be the size of a small suitcase and is cost-effective because its small size and because it can be launched with other payloads. Although NEOSSat's 15-centimetre telescope is relatively small, in orbit approximately 700 km above the Earth's atmosphere it will give it a huge advantage in searching the blackness of space for faint signs of moving asteroids. NEOSSAT's launch is planned for 2010. The satellite will be operated by the CSA. The mission is funded by Defence Research Development Canada and the Canadian Space Agency.

NEOSSat is the first follow up mission to the ground-breaking MOST. NEOSSat also marks the first project using Canada's Multi-Mission Microsatellite Bus. CSA's Space Technology branch launched the multi-mission bus project to capitalize on technology developed for the MOST project by making it applicable to future satellite missions.

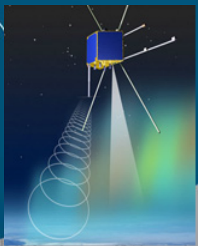
Hildebrand, holder of a Canada Research Chair in Planetary Science in the University of Calgary's Department of Geoscience, leads an international science team for the NESS (Near Earth Space Surveillance) asteroid search mission of NEOSSat.

## Solar-Terrestrial Studies & Atmospheric Science

### Canadian Geospace Monitoring Network (CGSM)

The Canadian Space Agency recently issued nearly $10-million in new contracts for scientific work using the Canadian Geospace Monitoring Network, an extensive series of ground-based stations used to observe geomagnetic space. CGSM includes several different kinds of instruments including all-sky imagers that measure wavelengths of visible light; photometers that measure the intensity of light at different wavelengths, riometers that observe the cosmic background radiation at radio wavelengths and magnetometers that measure the strength of and variations in the Earth's magnetic field.

Also included in the instrument set are solar monitors that measure radio waves emitted from the sun, and digital ionosondes and superDARN radars that send out bursts of radio energy into the atmosphere and measure the reflections, providing information on the state of the ionosphere and the auroras.



Dozens of scientists from six Canadian universities and three government agencies are involved in this project. This network is being used for related projects such as Enhanced Polar Outflow Probe (see below.)

The data collected through the CGMS is also playing an important role in forecasting space weather, disturbances in the space environment above the Earth. CSA is currently negotiating a new contract for the provision of forecasting services with Natural Resources Canada, which runs the Canadian Space Weather Forecast Centre in Ottawa. The centre issues alerts and warnings using data on conditions above the Earth collected by the CGMS network and other international monitoring stations.

CSA recently gave a contract to scientists at the University of Waterloo to improve computer models of the solar drivers of space weather and to build Canada's expertise in using simulation techniques for space weather forecasting.

**Enhanced Polar Outflow Probe (ePOP)**

In June 2009, Canada plans to launch a small satellite called CASSIOPE into polar orbit around the earth. It will carry the enhanced polar outflow probe (ePOP), a collection of eight scientific instruments that will investigate the role of the "polar wind" in causing space weather. This "polar wind" or "polar outflow", which consists of electrically-charged and neutral particles flowing up from the Earth's ionosphere into the magnetosphere, has not been well-studied so far; in fact, scientists didn't even know of its existence until the last few decades.

The key goal of ePOP is to study the effect of this outflowing plasma on space weather occurring in the magnetosphere. The eight instruments (six Canadian and one each from the U.S. and Japan) are in the process of being integrated into the spacecraft and the CSA recently issued the science contract for the mission, which will enable the researchers to start preparing data analysis tools.

This project will take advantage of a high-capacity store-and-forward data system on the spacecraft that will enable it to dump large amounts of information when it passes over receiving stations on the ground. In addition, the ePOP team will take measurements from the ground-based CGSM network. These data will help Canada improve its ability to forecast space weather.

**Time History Of Events And Macroscale Interactions During Substorms (THEMIS)**

Canada is participating in a NASA-led project to study mysterious auroral substorms caused by an explosive release of energy from the solar wind in the

Earth's magnetosphere. In February 2007, NASA launched five small satellites to observe the aurora from above. Meanwhile, Canadian researchers are using a network of ground stations to take images of the aurora every three seconds. These data are being coordinated with the measurements taken by the satellites to provide a comprehensive look at dynamic events occurring in the aurora.

Themis has already captured data on one large substorm with an amount of energy equivalent to a magnitude 5.5 earthquake that crossed the entire polar zone in a mere 60 seconds. THEMIS has revealed previously unknown magnetic "ropes" that link the sun with the Earth's upper atmosphere and provide a conduit—essentially a superhighway—for the solar wind particles that power the auroras and geomagnetic storms. These and other findings from the THEMIS project will contribute to increased understanding of space weather and its effects on Earth.

Canada is uniquely well positioned to participate in this study because it has most of the landmass underneath the auroras and has a long history of auroral research. Sixteen of the 20 ground stations are located in Canada, with the remaining four in Alaska. Because they produce an unprecedented flood of information, the Canadian science team, led by Eric Donovan of the University of Calgary, developed a new software program called GAIA -- Global Auroral Imaging Access -- to manage the enormous amounts of data.

In return for their contributions to the project, Canadian researchers participate in the THEMIS science team and gain access to the data collected by the satellites.

**The Outer Radiation Belt Injection, Transport, Acceleration, and Loss Satellite (ORBITALS)**

ORBITALS, which is currently in the advanced study phase, involves the development of a new Canadian small satellite that will carry instruments to map and study changes in the Van Allen radiation belts surrounding Earth. Scientists believe this region of the Earth's magnetosphere has been under-explored and that it's important to gain a better understanding of the conditions there for both scientific and practical reasons. Intense radiation in this region, which can be amplified by outbursts of charged particles from the sun, can damage satellites and other spacecraft. Because of the height of their orbits, geosynchronous satellites used for global communications are particularly vulnerable to such radiation.

ORBITALS is intended as a contribution to the satellite infrastructure for the International Living With a Star (ILWS) program, which focuses on improving scientific understanding of space weather, disturbances in near-Earth space

caused by the interaction between materials ejected from the Sun and the Earth's atmosphere and magnetic field.

**Atmospheric Sciences**

Several atmospheric science projects that have been operating for several years continue to work well and are returning a wealth of useful scientific data. These include:

• **SCISAT** is a Canadian-built satellite launched in 2003 that carries the Atmospheric Chemistry Experiment (ACE), which collects data related to the depletion of the ozone layer in the Earth's stratosphere, particularly over Canada and the Arctic. It's providing the accurate measurements of chemicals that affect ozone, which protects Earth from the sun's damaging ultraviolet radiation. ACE has also collected data on water vapour in the stratosphere that have been useful in studies of climate change and it has measured the distribution of molecules correlated with air pollution and biomass burning, data that complement the observations of the MOPITT satellite.

• **MOPPITT** (measurements of pollution in the troposphere) is Canada's contribution to NASA's Earth Observing System, an international environmental research project. One of five instruments aboard NASA's Terra satellite, it tracks atmospheric concentrations and global movements of carbon monoxide (CO), a gas produced by the incomplete combustion of fossil fuels and burning biomass, such as forest fires and agricultural burning. Its measurements are used to assess pollution levels in the lower part of the atmosphere (troposphere.) MOPITT is the first instrument to document the movement of pollutants over long distances across continents and oceans and it has enabled scientists to create the first global pollution maps.

• **OSIRIS** (Optical Spectrograph and InfraRed Imager System) -- this is a Canadian-built instrument flying aboard the Swedish satellite Odin. It is designed to produce global vertical profiles of the ozone layer. The instrument also measures concentrations of the ozone-destroying gases nitrogen dioxide and bromine oxide, as well as water vapour in the upper atmosphere and small sulphate particles. These data are important for understanding climate change and the health of the ozone layer.

__Life And Physical Sciences__

**Perceptual Motor Deficits in Space (PMDIS)**

York University neuroscientist Barry Fowler has completed a study investigating why there are deficits in the ability of astronauts to perform fine motor movements in space. His results were based on tests done in 2007 with astronauts from two Space Shuttle flights, working on the International Space Station, who performed aiming and tracking tasks on a computer.

The findings refute the predominant scientific theory that performance deficits in fine eye-hand coordination tasks are caused by the effects of microgravity on the brain's vestibular (balancing) system. Instead, Fowler concluded the deficits are primarily due to the stresses of living in space, including space sickness, sleep deprivation and heavy workloads. He said the key to reducing these problems is pre-flight training and reasonable scheduling of in-flight tasks. He also found that astronauts' bodies must be restrained while performing fine motor movements but arm restraints are not necessary.

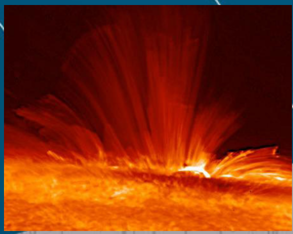
Fowler said the study has implications for future long-duration missions. The findings suggest that using a centrifuge to create artificial gravity and reduce the physiological effects associated with microgravity should not negatively influence fine motor performance.

**ELERAD**

Scientists at Simon Fraser University in British Columbia have confirmed that *C. elegans* worms can be used as biological radiation dosimeters in space. These findings are based on analysis of genetic damage in worms that spent seven months on the International Space Station in 2006 and 2007, producing between five and 10 generations of animals.

The goal of the project was to validate advanced technologies developed by Canadian researchers to analyze genetic mutations caused by space radiation. In this proof-of-concept experiment, the science team successfully used a device called a DNA-array chip developed by the BC Genome Centre to identify genetic mutations in a line of *C. elegans* returned from space.

These worms were chosen because they're widely used in medical research on Earth and their genome is well understood. About half their genes are similar to human genes, so the scientists believe the results of the study will be applicable to humans.



The Canadian Space Agency funded this research because space radiation is one of the most significant risks faced by astronauts on long-duration spaceflight, particularly missions that go beyond low earth orbit, where the Earth's magnetic field provides some protection against radiation.

**Space Radiation**

Recent radiation studies on the International Space Station (ISS) sponsored by the Canadian Space Agency indicate that ISS astronauts are exposed to radiation levels well below the recommended safe annual limits but the dosage of neutron radiation inside the body is higher than expected.

The experiment, called Matroshka-R, involved placing two types of radiation dosimeters developed by Canadian companies inside and on the surface of a Russian-made spherical phantom made of materials that mimic human tissues. This study, which was conducted by the CSA in collaboration with the Russian Federation Institute of Biomedical Problems (IBMP), was designed to investigate the internal radiation doses received by astronauts and how these compare with the surface doses recorded by the personal dosimeters they wear.

One of the Canadian devices, developed by Bubble Technologies Inc. of Ottawa, measured neutron radiation. The other, called MOSFET, developed by Best Medical Canada of Ottawa, measured the high-energy electrically charged particles in cosmic radiation. These particles easily penetrate most materials and can generate secondary neutrons by interacting with those materials. One study found that the neutron dose at the centre of the body is about 70 percent of that received outside the body because of the additional neutrons created when high-energy particles interact with human tissue.

The researchers say the findings underscore the need for astronauts to wear personal dosimeters that can provide ongoing real-time measurements of the actual radiation levels they're exposed to. The Canadian devices have been tested for use as personal and area dosimeters on the Space Station.

The CSA's space science program is funding additional ground-based work by Bubble Technologies to validate and calibrate new technologies for measuring radiation levels and they're also looking at the possibility of conducting further tests on the Space Station. There is, as yet, relatively little information about the space radiation environment and it's important to characterize it in order to develop new technologies and procedures to protect crews on manned spacecraft and planetary space bases in the future.

**Bodies in the Space Environment (BISE)**

It’s well known that astronauts can become disoriented in microgravity because their brains no longer have gravity signals to tell them which way is up and down. Instead they must rely on other cues, such as body position and visual information around them.

Disorientation can cause astronauts to make potentially life-threatening mistakes, such as flipping switches the wrong way or moving in the wrong direction during an emergency. To better understand the causes of this problem, the CSA is funding a research project called BISE (Bodies in the Space Environment) by scientists from York University, lead by psychologist Laurence Harris.

The experiment will be conducted by astronauts on the Space Station over several years. It requires them to view and respond to images on a computer screen in a way that will enable the scientists to determine the relative importance of visual and body cues to their perception of up.

The experiments are scheduled to start in 2009. At present, CSA is preparing the ground support equipment and software, and has begun informed consent briefings with astronaut crews in order to obtain subjects for the experiment.

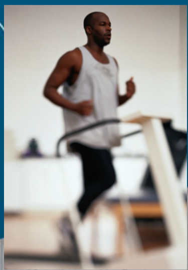
**eOSTEO**

In September 2007, Canadian researchers from the University of Toronto and McGill University successfully flew a 12-day experiment to study bones loss in space aboard a Russian Foton M3 capsule.

Human bones lose mass in microgravity; this could have serious implications for the health of astronauts on long-duration space missions. Bones undergo a natural dynamic process of creating and destroying bone cells and scientists are trying to gain a better understanding of how these processes are affected by microgravity.

The experiment, called eOSTEO, investigated three main questions: 1) the role of certain biological molecules in controlling bone formation and bone loss in microgravity; 2) the effect of microgravity on bone cell architecture and critical aspects of the development and function of cells that create and destroy bone; and 3) the effect of microgravity on a hormone that promotes bone creation and whether it can prevent the death of cells that build bone.

The bone cells used in the experiment were housed in a Canadian-built automated mini-lab developed by Millenium Biologix Inc. and Systems



Technologies of Kingston, Ontario. It was launched on September 14, 2007, and recovered 12 days later. The samples returned to the Canadian scientists are being analyzed and results are expected near the end of 2008. It's hoped this research will enable scientists to develop effective countermeasures and treatments for bone loss both in space and on Earth.

**Cardiovascular Studies on Space Station**

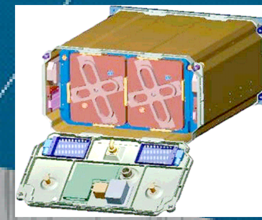
With the support of the CSA, a team of scientists from Canadian universities are currently participating in NASA-sponsored studies of the cardiovascular effects of microgravity by running a series of tests on astronaut subjects aboard the International Space Station. One study, called Cardiovascular and Cerebrovascular Control on Return from the International Space Station (CCISS), has already obtained results from two subjects, which are now being analyzed. The team is looking for four more astronauts to participate in this experiment aboard the Space Station in 2008 and 2009.

Led by principal investigator Richard Hughson of the University of Waterloo, the team also includes scientists from the University of Waterloo, the University of Western Ontario, Simon Fraser University and the University of Tours in France. Their research is focused on understanding the deconditioning of the heart and the blood vessels caused by long-duration exposure to microgravity and how the body adapts when astronauts return to full or partial gravity.

Immediately after returning to Earth from a long stay in space, astronauts often experience faintness when standing upright, and problems regulating their blood pressure. This results from the effects of microgravity on the volume and location of the blood in their bodies during spaceflight, as well as changes in blood vessels. They might experience similar problems setting foot on Mars, which has one-third Earth's gravity, after a long journey in microgravity and this could potentially compromise their safety and their ability to work.

The goal of this research is to develop improved countermeasures and treatments to protect the health of astronauts on long duration spaceflights. It could also benefit people who are susceptible to fainting when they stand up, including the elderly and people who live a sedentary life.

The CSA is funding another cardiovascular experiment led by Hughson that is expected to be performed on the Station starting in late 2009. The team is currently seeking six astronaut subjects that will be staying on the Station for more than 100 days. This study will focus on the effects of long-duration spaceflight on the blood vessels of astronauts. The scientists will collect data on markers the bloodstream that may indicate inflammation of artery walls. They will



also take measurements of cardiac rhythm and blood vessel properties such as diameter, wall stiffness and ability to dilate.

**Bed-rest Studies**

The CSA is supporting four Canadian research teams in a new round of bed-rest studies sponsored by the European Space Agency. This experiment involves having subjects lie in bed for long periods of time to simulate some aspects of the effects of microgravity on the human body. It is a follow-up to the WISE (Women's International Space Simulation for Exploration) study conducted in 2005 that also involved Canadian scientists.

In that study, one Canadian team found evidence of a mechanism to explain why astronauts in microgravity suffer from anemia—a decrease in red blood cell production that causes fatigue. A second group discovered that subjects who exercised while bedridden did not improve their ability to maintain their blood pressure when they stand up afterwards. However, exercise did provide protection against other physiological changes that could lead to heart disease.

The new study will focus on the effects of prolonged bed rest on the heart, muscles, bones and the perception of body orientation. The first five-day test is expected to start near the end of 2008.
v
The goal of this research is to find countermeasures to the negative effects of microgravity on the human body. It will include the use of a human centrifuge that produces artificial gravity to test whether this device could help prevent these negative effects.

**APEX-CAMBIUM**

In 2009, Space Station astronauts will undertake the unusual task of bending willow stems into loops as part of a Canadian experiment to explore the role gravity plays in forming different kinds of wood.

University of New Brunswick tree physiologist Rodney Savidge received funding from the CSA to develop an experiment that will demonstrate whether “reaction wood” is created in trees on Earth as a response to gravity, as scientists have long believed. On Earth, parts of a tree that are not vertical typically grow one kind of wood on one side and another kind on the other; this is known as reaction wood and the mixture of the different kinds makes different trees suitable for different uses, such as in construction or making paper.

The astronauts will loop willow stems and place them, along with unlooped controls, in a NASA-built incubator called APEX (Advanced Plant EXperiments on Orbit). The stems will be grown for about a month and then returned to Earth for analysis. APEX is a joint CSA-NASA project and the incubator will carry a second experiment by U.S. researchers to detect the effects of stressors in space on higher plants. It is scheduled for launch in April 2009.

APEX-CAMBIUM is designed to use the microgravity environment to shed light on the role that gravity plays in fundamental biological process on Earth.

**Binary Colloidal Alloy Test (BCAT-5)**

CSA and NASA are collaborating on a physical science experiment called BCAT-5 that is designed to test the properties of materials in microgravity, where they are not influenced by convection caused by gravity on Earth. The experiment allows scientists to observe physical phenomena that are difficult or impossible to observe on Earth because of the disruptive effects of gravity.

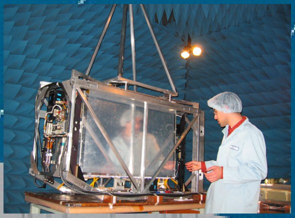
BCAT has flown four time previously with different materials samples; the BCAT-5 payload, which will be launched to the Space Station in 2009, will have 10 samples, of which three will be Canadian. This research will focus is on the amount of energy that can be transported by materials in different phases. One potential application of this information would be to improve the energy efficiency of heat pumps.

**Soret Coefficient in Crude Oil (SCCO)**

This experiment by engineering professor Zaid Saghir of Ryerson University in Toronto is aimed at measuring thermal diffusion in oil samples in microgravity, where they are not affected by convection caused by gravity. His goal is to verify mathematical equations that predict thermal diffusion and could greatly improve computer models of oil reservoirs.

The results are expected to enhance the ability of oil companies to determine the quality and quantity of oil in hard-to-reach underground reservoirs and predict the lifetime of these reservoirs. The experiment should help improve prospecting techniques and the efficiency of oil extraction.

Supported by both the CSA and ESA, SCCO was flown twice aboard the Russian Foton recoverable satellite, once in 2005 and again in 2007. The samples returned in 2007 are currently being analyzed and results are expected around the end of 2008.

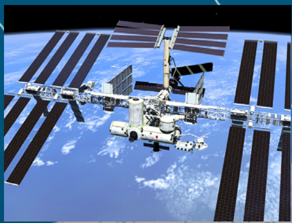


**Microgravity Vibration Isolation Subsystem (MVIS)**

The Canadian Space Agency has contributed a key component to the European Space Agency's Columbus science module, launched by the Space Shuttle in February 2008 and installed on the Space Station. The breadbox sized device, known as the microgravity vibration isolation subsystem (MVIS), is incorporated into Columbus's Fluid Science Laboratory. MVIS is scheduled to be commissioned in 2008, which will entail checking and calibrating the system in its operating environment.

MVIS is designed to protect fluid science experiments, which are vulnerable to even the slightest shaking, from vibrations that occur on the Station as a result of things like human activity, Shuttles docking or thrusters firing. It uses a magnetic field to suspend containers carrying experiments, enabling them to remain free floating and effectively isolating them from any vibrations in the laboratory.

MVIS was developed by the Canadian Space Agency in collaboration with the Magellan Aerospace Corporation (Bristol Aerospace Limited) of Winnipeg; MDA of Ste-Anne-de-Bellevue, Quebec (formerly EMS Technologies); the École de Technologie Supérieure in Montreal; SENER (Spain); and the European Space Agency.



## Selected Project and Mission Descriptions

**<u>Life and Physical Sciences</u>**

**CCISS/VASCULAR**

When the first humans set foot on Mars, it's a good bet that the last thing they want is to fall down in a faint.

Yet this is something that even people as physically fit as astronauts might have to be concerned about, as a consequence of the physiological effects of microgravity on the cardiovascular system during the long journey to Mars. Changes that occur in the circulatory system while astronauts are floating in space can make it difficult for the heart to pump enough blood to the brain when they try to stand up once they're back in a gravity environment. This results in low blood pressure that can cause dizziness, dimmed vision and ultimately fainting.

This is why crews who have been on the International Space Station (ISS) for several months are kept in a reclining position when they first return to Earth. Crews could be at risk of fainting after landing on Mars too—even though it has only one-third the gravity of Earth—because they will have spent months in microgravity getting there. And they won't have the same kind of medical support they have on Earth.

"They'll be longer than six months in flight and they need to be ready to work," said Richard Hughson, a professor in the Cardiorespiratory and Vascular Dynamics Lab at the University of Waterloo, who is studying how microgravity affects several complex mechanisms that control blood pressure and blood circulation.

He added that astronauts who return to Earth after living and working for long periods on the Moon or Mars could also experience blood pressure problems. "You're not working in a normal one-gravity environment when you're on the surface of the Moon and Mars. And the whole time you're in between, you're at zero gravity, so it's a huge issue for long-term spaceflight."

"If you're looking at two or three years that an astronaut's been away, imagine the shock of coming back," said Nicole Buckley, Director of Life and Physical Sciences for the Canadian Space Agency, which is funding Hughson's research. "You're talking about a very real stress on the heart and circulatory system, which has adapted to another condition. On your way back, you don't want to be

fainting or dizzy when you might be called on to respond quickly to an emergency."

Doctors are trying to develop countermeasures to reduce the risks to astronauts and help their cardiovascular systems re-adapt to Earth's gravity more readily. Buckley said Hughson's research "will help us understand how to make that return to Earth a less drastic change for astronauts." She added that it could also help improve the treatment of patients on Earth by advancing the fundamental understanding of how the cardiovascular system works. "This gives us another way of looking at deconditioning of the cardiovascular system. We know that one in four Canadians will die from cardiovascular disease."

About two-thirds of astronauts who return from even short-duration Space Shuttle flights experience symptoms of fainting. "The test is that they were unable to stand for 10 minutes when they came back," said Hughson. Some individuals are more susceptible than others and women are much more vulnerable than men. For instance, in September 2006, a female astronaut experienced pre-fainting symptoms twice during a press conference following a 12-day Shuttle flight and had to be lowered to the floor by her crewmates.

Scientists do not yet know why women are more affected. Hughson said hormonal differences might play a role, and there are also differences in body structure that could affect how much blood is stored lower than the heart.

The incidence of blood pressure problems increases with the length of the flight. Hughson said that Russian cosmonauts, who have set records for long-duration flight, have a high incidence of symptoms despite following a fairly intensive countermeasure program just before they return to earth. To prevent problems, they are taken off their return vehicle "lying down in a reclining position so their heads are not a long way above their hearts."

Hughson's study, called Cardiovascular and Cerebrovascular Control on Return from ISS (CCISS), involves astronauts who'll be staying on the Space Station for at least two months and some as long as six months. He said the findings will be applicable to even longer exploration missions to Mars, which could last up to three years.

He expects to study six subjects in all; the first was launched in June 2007, with a follow-up in October 2007. He hopes to include at least one female, but astronauts' schedules are extremely tight. "It's based on the availability of time and we're quite limited in the number of people we can get."

His goal is to study several different components of the cardiovascular system “that all have to work together to make sure the blood is coming back to the heart and that you’re pumping enough blood to supply the brain with oxygen.” He’ll be looking for changes in how the nervous system regulates the heart and blood vessels, and also for structural changes in the heart and blood vessels.

For example, on earth, blood is constantly being pulled to the lower body by gravity so “the leg arteries have really muscular walls because they’re always being subjected to high blood pressure when standing. Those arteries are going to have less muscle in the wall when they come back from space.” On the other hand, arteries above the heart might have thicker walls because blood pressure in the upper body is relatively higher in space than on Earth, the result of blood being more evenly distributed rather than being pulled toward the legs.

Microgravity can also affect baroreceptors that detect blood pressure in arteries and veins and convey this information to the central nervous system. Their sensitivity, or something in the communications loop between them, the brain and the heart and blood vessels, could change as spaceflight continues, Hughson said.

There is evidence to suggest that these physiological changes increase significantly after about 50 to 60 days in space. Hughson said they must plateau at some point, but “we don’t know where.”

The CCISS experiment will involve taking measurements both on Earth and in space but the in-flight measurements will be “only a small part of what we look at on the ground,” said Hughson. “They have to be simple and easy to do because the crew doesn’t have a lot of time.”

There will be two experimental sessions in space, one within the first two weeks and the other within the last two weeks of the flight. The astronaut will wear finger cuffs to monitor his blood pressure continuously for 10 minutes and a portable heart-rate monitor taking continuous measurements for 24 hours. The 24-hour monitoring will tell the researchers about changes in the way the central nervous system is controlling the heart rate.

These measurements will provide information about how efficiently the heart rate changes to regulate blood pressure. Normally, if blood pressure drops, the heart rate increases to compensate. It is known that the heart rate changes less for any given change in blood pressure after someone has been in space, but it is not known how this phenomenon relates to other factors affecting blood pressure that Hughson is studying.

These data will be compared with the more detailed ground-based measurements taken before and after the space mission. Hughson will use ultrasound to determine the efficiency of the large vein that returns blood to the heart from the lower body. At the same time, he will be monitoring venous blood pressure through a catheter in the right arm.

Then he will then use a Lower Body Negative Pressure device to apply suction to the lower body, which will shift blood out of the central region and back down to the legs. “We can look at changes in the volume or size of the inferior vena cava, and we can look at the pressure to see how the pressure/volume relationship changes.”

When someone comes back from space, the veins are more stretched or “floppy” than they were on Earth. “They hold a greater volume of blood at the same pressure,” said Hughson. “They don’t have good muscle tone to hold the blood near the heart so when you stand up, the blood could go away from the heart to the lower part of the body. There’s less blood going up to the brain and you could faint.”

What happens in the gut is also important. “It will hold a lot of volume, so you need a system that very efficiently shuts down the blood flow going into that region,” said Hughson. “We’ll probably see less shutting down of the blood flow into the gut region when you come back from space than you had beforehand.” This would mean it’s “hanging on to too much blood and once again, there’s less blood coming back to the heart and therefore a poorer ability to regulate blood pressure.”

During the experiment, Hughson will monitor how much blood the heart is pumping out and how well the blood vessels are constricting. He wants to determine how efficiently reflexes in the veins and arteries are controlling the constriction. This “vascular resistance” serves as a kind of traffic cop, making sure blood goes where it’s needed.

“If you’re not putting out as much blood, you need to constrict the blood vessels so the blood doesn’t go to the wrong place,” Hughson said. “You don’t want it going to the gut region or legs; you do want it going to the brain. If blood pressure starts to fall, the blood vessels in the gut and the legs should constrict and the blood vessels to brain should dilate. We’ll be looking at how efficient the brain blood vessels are at dilating in response to a drop in blood pressure.”

The number and complexity of the systems involved regulating blood pressure means that different kinds of countermeasures may be needed to prevent fainting problems. One technique already used in space, called lower body negative pressure, involves a device that uses suction to draw blood to the legs, simulating what gravity does on Earth. Hughson said this is potentially an effective technique for long-duration flight, but it is not clear astronauts could devote enough time to it to make it fully efficient.

He said it would be even better to have centrifuge that would spin people around, forcing blood to the lower body, but it is not likely that this expensive device will be available on spacecraft in the foreseeable future, he said.

There is a drug that constricts blood vessels that might work on “floppy veins” caused by microgravity; it is used on Earth in patients susceptible to fainting and is being tested for use in space. However, it can cause bad reactions in people who are also taking medication for motion sickness, which many astronauts do. “You don’t want to rely strictly on drugs,” said Hughson.

In a related study called VASCULAR (cardiovascular health consequences of long duration spaceflight), Hughson will examine the effects of prolonged exposure to microgravity on the structure and function of blood vessels. Physical inactivity on Earth increases the risk of cardiovascular disease. Being in microgravity mimics physical inactivity and astronauts do experience a reduction in fitness when they return to Earth, despite doing in-flight exercises.

In the earth-based portion of this study, Hughson will look for changes in the thickness of blood vessel walls in both the upper and lower body. He will also use ultrasound to look for changes in the inner lining of the blood vessels, known as the intima-media—the area where plaque accumulates and ultimately causes atherosclerosis.

As part of this experiment, astronauts will also wear portable heart-rate monitors for 24 hours in-flight, to detect changes in the heart’s rhythm. Finally, blood samples will be taken, both in space and on Earth, to test for chemical markers of inflammatory processes that can cause changes in the structure of blood vessels. The goal is to find out whether long-duration spaceflight can accelerate processes that lead to heart disease.

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We're not implying that six months in space is going to cause someone to develop atherosclerosis," Hughson said. "But as we go to the exploration-length missions, we need to be aware of the potential risks. Maybe it's something that has to be dealt with in terms of countermeasures." He added that these studies could provide important insights into the relationship between inactivity and heart disease on Earth.

*CCISS is led by Principal Investigator Richard Hughson of The University of Waterloo, supported by a science team of CO-Is, with project co-management at NASA Human Research Program and the Canadian Space Agency.*

**CHENSS**

Radiation is one of the most significant risks to the health of humans who live and work in space for long periods of time. So far, these risks have been minimized by the fact that most astronauts have stayed in space for relatively short periods and have remained in low-Earth orbit, where they're protected to some extent by the Earth's magnetic field.

However, with the prospect of much longer exploration missions to the Moon and Mars, there is a growing urgency to learn more about the exact nature of space radiation and the biological damage it might cause.

Canadian researchers have been leaders in developing devices to detect radiation levels in space. Astronauts currently wear some of these devices on their bodies so doctors can monitor their exposure during spaceflight, particularly during spacewalks when the spacecraft does not protect them.

Now, a new device, developed by an Ontario company, Bubble Technology Industries (BTI), will investigate one particular component of space radiation that is still a considerable mystery—high-energy neutrons. The device, called CHENSS (Canadian high-energy neutron spectrometry system), is undergoing tests on Earth and the scientists hope to test it on the International Space Station (ISS) within the next year or two.

"This could potentially be a major component of space radiation that we don't know very much about," said Nicole Buckley, director of Life and Physical sciences for the Canadian Space Agency, which is funding development of CHENSS. "We're adding to our knowledge using a unique Canadian technology and we can potentially apply this technology to help make space travel safer."

High-energy neutrons are subatomic particles with no electrical charge; they can interact with the atoms and molecules of living tissues, causing illness, disease and genetic changes. They are produced when cosmic radiation—mainly

positively-charged protons—streaming in from space hit and interact with other atoms and molecules. For example, such interactions with the Earth's atmosphere produces neutrons, particularly at high altitudes.

Cosmic radiation levels are 100 times higher at 10-11 km (35 000 feet), where most commercial aircraft fly, than they are on the ground. The levels increase the farther you go into space, said Les Bennett, a nuclear engineering professor at the Royal Military College in Kingston, Ontario. He and his colleague, Brent Lewis, also an RMC nuclear engineering professor, have been studying neutron levels at altitudes flown by passenger aircraft and he said neutrons comprise about half the radiation up there.

The levels are similar in low Earth orbit, where the Space Shuttle and the Space Station operate. Experiments indicate that "the neutron dose may be approximately half of the total dose that astronauts receive," said Martin Smith, a research scientist with BTI who is working on the development of CHENSS.

Although they are not exposed to radiation levels significantly higher than those experienced by people in high-flying planes, ISS astronauts stay in space for several months at a time so their total exposure is greater. "Anyone on the Space Station will be there for more than an 8- or 10-hour transatlantic flight," said Bennett. "The energies are higher and the intensities are higher." However, they still receive some protection from the magnetic field, which deflects much of the charged-particle radiation streaming in from space. "The ISS is still very close to Earth," said Smith. "What we're really worried about is missions to the moon and Mars. If you get right outside the magnetic field, that's when it gets dangerous."

Researchers are trying to develop shielding materials to protect spacecraft and their crews, but there is a complication: high-energy protons can produce a cascade of neutrons when they hit the molecules of the shielding material, creating higher neutron levels inside the spacecraft than outside. "If you stood outside the spacecraft, there would be some neutron radiation, but it's much worse inside the spacecraft because of the protons interacting with the materials," said Smith.

Gaining a better understanding of the exact nature of the neutron radiation in space is critical to assessing the risk to humans and other living things that venture beyond Earth's orbit. "We haven't really been able to gauge the effect of high-energy neutrons, because it's not something that we experience here on Earth," said Buckley.

Smith described CHENSS as the most advanced device of its kind in the world; it has the unique capability of discriminating among neutrons of different energy

levels, ranging from about 10 to 100 MeV (million electron volts). Previous experiments suggest there are a large number of neutrons above 10 MeV in space, but other than that, little is known about their energy profile.

This is an important issue in evaluating the extent of the biological hazard presented by high-energy neutrons. Smith noted that "the biological effects of radiation are not well known, especially for higher-energy neutrons." However, it is believed that the higher the energy of a particle, the more damage it's likely to cause. High-energy neutrons are certainly more damaging than other types of radiation, such as x-rays and gamma radiation, said Bennett. "They're radiation you need to avoid."

To assess the accuracy of CHENSS in measuring neutrons of different energies, the scientists have been testing the device in particle accelerators, the only source of high-energy neutrons on Earth. There are few facilities that can do the job so they've had to go around the world to secure beam energies covering different parts of the spectrum. Some tests were done in Canada, Germany and South Africa and they're investigating the possibility of using a facility in Sweden. These accelerators provided neutron energies ranging from 2.5 MeV to 200 MeV. Bennett said it's important to calibrate the device in a radiation environment that contains nothing but neutrons—and ones with known energy levels—in order to have confidence in the accuracy of the measurements in space, where the neutron radiation environment is largely unknown.

After the calibration tests in the accelerators are completed, they hope to test the device aboard an aircraft and ultimately, on the International Space Station.

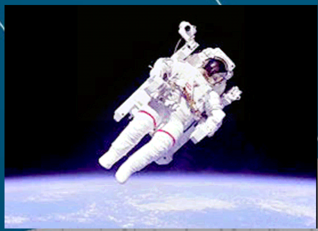
Innovation was required to meet safety requirements for materials used on the ISS. Neutron detectors typically use a liquid, but NASA considers it hazardous because it is flammable and could potentially leak, so BTI developed an innovative gel substance to replace the liquid that has been cleared as space-worthy by NASA.

*CHENSS is led by Principal Investigator Harry Ing of Bubble Technologies Inc., supported by a science team of CO-Is, with project management at the Canadian Space Agency.*

**ELERAD**

David Baillie is sending Nobel Prize winners into orbit to study how space radiation damages their DNA.

These are not, of course, the Nobelists who actually have the medals placed around their necks, but rather the ones that live in test tubes. Known as *C.*



*elegans*, these tiny worms have been intensively studied for many years by scientists all over the world and they were an integral part of research that won Nobel Prizes for medicine twice in recent years.

Scientists probably know more about *C. elegans* than any other complex organism, said Baillie, professor of molecular biology and biochemistry and Canadian Research Chair in genomics at Simon Fraser University. “We have the genome entirely sequenced; we know every neuron in its nervous system. Any information you get is value-added, because we know so much about it in other ways.”

Significantly, about half the genes in *C. elegans* are similar to genes found in humans. Baillie said the organism is a good model for “how human DNA damage might be incurred” and is confident that his research on how space radiation affects them will be applicable to humans. “We wouldn’t do it if we didn’t think so.”

Scientists are concerned about the effect of space radiation on astronauts, particularly those on long-duration missions to the Moon or Mars. These missions will take them far beyond the Earth’s magnetic field, which provides some protection for crews who remain in low-earth orbit on the Space Shuttle or the International Space Station (ISS).

“Radiation is one of the most critical obstacles to long-duration spaceflight,” said Luchino Cohen, a Program Scientist in Space Life Sciences at the Canadian Space Agency, which is funding Baillie’s research. “We expect that, by using the worms, we’ll be able to understand the impact of space radiation on human beings and develop some protective measures.”

The key question Baillie is exploring is whether space radiation causes damage to the reproductive organs of the worms that is then passed on to their offspring. “We’re measuring gonadal damage across several generations. We’re actually going through many generations, which really hasn’t been done before.”

*C. elegans* is particularly suited to this research because it reproduces rapidly, producing a new generation every 5 to 10 days under the conditions in which it is stored in space. Baillie’s research team put a sample of *C. elegans* on the International Space Station in December 2006. The sample was returned on Space Shuttle flight STS-117 in late June 2007, containing worms about 25 generations removed from the ones that were launched.

Because the worms are only about a millimeter long, they do not take up much of the limited and expensive cargo or lab space on the Shuttle or the ISS. They are

also low-maintenance; they live in small bags and feed on a special chemical diet that is automatically changed by a machine every six weeks. The chemical diet, developed by Nate Szewczyk of the University of Pittsburg, is a key component that allows the worms to reproduce in space.

“These very small animals are easily cultured in space with equipment that can be completely automated so we don’t have to devote a lot of crew time to culture them,” said Cohen.

Another important element of the experiment is the use of a particular strain of *C. elegans*, appropriately named eT1. Developed by research associates Raja Rosenbluth and Bob Johnsen from Simon Fraser University in British Columbia, its most significant feature is that it allows the researchers to capture and preserve genetic mutations through many generations.

Normally, genetic damage tends to eliminate itself over time, Bailie said. “Damaged DNA leads to damaged genes, which leads to damaged animals, and damaged animals die.”

However, geneticists have used a “genetic trick,” a process called balancing, that enables them to preserve a multigenerational record of genetic mutations in *C. elegans*. “It allows you to keep the damaged DNA copy over a copy of good DNA and allows you to keep the animals alive so you can analyze then,” Baillie said. “We can keep the damaged DNA so we know where it is. We’ll return the animals alive to earth and determine what mutations they picked up when they were in space.”

The DNA of the space worms will be compared to bits of DNA from normal worms contained on a newly developed device called a DNA-array chip. Baillie said this “bleeding-edge” technology allows them to quickly identify mutations, reducing the “people-time” it takes to analyze the DNA from months to hours.

Baillie’s team has already demonstrated that they can indeed capture what he calls “space mutants,” using samples of the eT1 strain that were flown on missions in 1992, 1996 and 2004. “Our strain works as we designed it to work for capturing mutations,” he said.

However, these animals were only briefly exposed to space radiation (the longest flight was 11 days), so there were only a few mutations, not much more than what occurs spontaneously on Earth. Baillie needed to park the worms on the Space Station for months at a time to gain a better understanding of the potential radiation threat posed by long-duration flights.

There are two basic kinds of space radiation: radiation from the Sun and cosmic radiation streaming in from outside the solar system. In addition, storms on the Sun can cause large flares that occasionally send out a flood of high levels of radiation that greatly increases the danger to astronauts, especially those travelling beyond Earth orbit.

Space scientists are trying to devise ways to shield spacecraft against this radiation, but the task is complicated by the fact that there are still many unknowns about the exact nature and intensity of space radiation and particularly about its biological effects on various organisms, including humans. Canadian researchers have been very active in studying this problem and have developed dosimeters worn by astronauts to monitor their exposure.

Baillie describes *C. elegans* as a “biological accumulating dosimeter” that will provide important clues about the effects of long-term radiation exposure. One issue he is interested in is how organisms respond to the changing radiation environment in space—the varying doses of different kinds of radiation that occur over time.

“Nothing is known about longer-term exposure to the different types of radiation in space,” he commented in a paper describing his project. “The wide range of radiation sources needed to mimic the space environment are not available on the ground; therefore it is imperative that we develop [an] accumulating dosimeter for use in space.”

He also plans to compare how the natural DNA repair mechanisms that exist in all living things work in space versus how they function on earth.

One intriguing possibility is that a brief exposure to low levels of space radiation might provide organisms with the ability to withstand more damaging effects from long-term exposure or pulses of high levels of radiation, such those caused by solar flares. A period of low-level exposure might “turn up” the natural DNA repair system so that it’s better able to cope with higher radiation levels. “We’re beginning to think there may be some evidence for that,” said Baillie. “We have to look more carefully at our data but it may well be the case.”

If this type of DNA repair turns out to be possible in higher organisms, including humans, it would make long-duration spaceflight a much safer and cheaper proposition. Baillie noted that the amount of shielding required to protect astronauts from space radiation is “really enormous” and would significantly increase the cost of space missions.

But an extraordinary amount of shielding might not be needed if a week or two of exposure to the normal background radiation in space equips astronauts' DNA to fight off damage from longer or more intense exposures. "We may luck out that low exposure may pre-adapt the system for higher levels of repair," Baillie said.

*ELERAD was led by Principal Investigator David Baillie of Simon Fraser University, supported by a science team of CO-Is, with project management at the Canadian Space Agency.*

## Planetary Exploration and Space Astronomy

### APXS on Mars Science Laboratory

Sending a robotic vehicle to hunt for rocks on Mars is a high-stakes proposition. Assuming it survives the considerable perils of a long journey from Earth and a risky landing on the surface of Mars, a rover—and the scientists who control it from Earth—still face enormous challenges seeking out the best areas to study and collecting rock and soil samples most likely to reveal the secrets of Mars' history and evolution.

A Canadian-built instrument will play a key role in making this difficult task easier on the Mars Science Laboratory (MSL), a NASA mission scheduled to be launched in 2009 and to land on Mars in 2010. Called APXS (Alpha Particle X-ray Spectrometer), the instrument can quickly determine the elements contained in rock and soil samples before they are sent for more detailed analysis in another instrument on board the rover.

Located on the robotic arm used to dig up the samples, APXS is a pop-can-sized instrument that can be maneuvered into contact with a sample, then bombard it with alpha particles and x-rays. The elements in the sample respond by emitting x-rays in characteristic ways that enable APXS to identify them and measure their abundance.

APXS is a highly precise instrument that can identify the percentages of elements like sulphur, iron, silicon and magnesium in a sample, and can even detect tiny amounts of trace elements like nickel, chlorine and zinc. "We can read out from the elemental composition what the history of this rock or soil is and how it was formed," said Ralf Gellert, a physics professor at the University of Guelph, who heads the APXS project.

For example, some elements, such as iron, silicon or magnesium suggest a rock is volcanic in origin, while those containing more salts, such as sulphur, chlorine or bromine, are likely to have once come in contact with water. Finding evidence of water on Mars is a scientific priority because of its relevance to the question of whether the planet ever supported life.

Gellert was part of scientific team at Germany's Max Planck Institute for Chemistry that built similar instruments for the Pathfinder mission that landed on Mars in 1997, and the two NASA Mars Exploration Rovers (MER), Spirit and Opportunity, that landed in January, 2004, and are still exploring Mars. However, in 2004, Gellert found out that his department was being closed, so he began looking for a new institution where he could continue development of APXS for future planetary missions.

That turned out to be the University of Guelph, in large part through the efforts of Iain Campbell, a Guelph scientist with whom Gellert had already collaborated. Campbell runs a facility called PIXE (proton-induced x-ray emission) that uses a technique similar to that employed by APXS.

The Canadian Space Agency agreed to fund Gellert's research and is supporting development of APXS for the MSL mission, one of only ten instruments selected by NASA in an international competition. "This was an exciting opportunity," said Vicky Hipkin, CSA's Program Scientist for Planetary Exploration. "When a big mission like this comes along, it's a very rare opportunity for Canadian scientists."

Because of the orbital positions of the planets, missions to Mars can only be launched every two years, and relatively few are open to international competition. "Canada has taken a strategic decision not to have its own launch capability so this makes us very much in favour of international collaboration and it makes us a good partner to other agencies," Hipkin said.

MSL will be the largest rover ever sent to Mars, and it will carry the most advanced set of instruments to date. The APXS instrument on this mission, for example, works five times faster than its predecessor on the MER rovers.

The primary goal is to determine whether the environment on Mars is, or ever was, capable of supporting microbial life. According to NASA, investigating the past habitability of Mars gives the scientific community "a better understanding of whether life could have existed on the Red Planet and, if it could have existed, an idea of where to look for it in the future."

One important way of doing this is to study rocks and soils, which contain an invaluable record of Mars' geological and climatic past. Scientists know that Mars once had a considerable amount of liquid water on its surface and that it currently has a great deal of water ice; they speculate there could even be subterranean pools of liquid water.

Gellert said rocks can tell scientists a lot about water on Mars. He noted that the APXS instrument on Spirit found rocks with a high concentration of suphates. “These are called evaporates because acidic brine dissolved the rocks, then evaporated and left a lot of salt. A nice acidic pool of sulphuric acid could have provided a suitable environment for life to persist, if it arose in the first place.”

One of the most important roles for APXS is to help the MSL science team select rock and soil samples for further analysis. The rover’s robotic arm can deliver samples to SAM (Sample Analysis at Mars), a mini-laboratory that takes up half the scientific payload on the rover. It contains a gas chromatograph, mass spectrometer and laser spectrometer that will identify and measure several elements associated with life—for example, carbon, oxygen, nitrogen and hydrogen—found in both the rock/soil samples and air samples. However, SAM has a limited store of “consumables” with which to do its job—it can only process about 70 samples over its entire mission—and this puts a premium on selecting high-quality samples that will deliver the greatest scientific payoff. “You’ve got this precious instrument that you can’t use on everything that comes your way,” said Hipkin. “It will help the science team make operational decisions about what to pursue in more detail.”

For example, Gellert said, if APXS determines the composition of a sample is similar to ones analyzed before, “we won’t feed the SAM instrument with the same samples again. You want to be sure something new is in there. If we find out that one spot looks completely different, then we will raise an alarm flag to the rover and look very closely with the SAM instrument.”

He said APXS will also examine the area surrounding where the samples are collected, which will provide a context to help scientists interpret the SAM results. Gellert added that the APXS can also study samples that SAM cannot. Because SAM requires rock and soil samples in powder form, fairly large rocks must be crushed before being fed into the instrument. “It cannot investigate very small rocks or pebbles,” Gellert said.

APXS will work with other instruments to extract the maximum amount of information from the samples it investigates. For example, by teaming up with a grinding tool, it can probe beneath the surface of rocks. “APXS is surface sensitive, so we don’t look very deep into the rock,” said Gellert. “We can determine if the surface of a rock was altered by water, if there’s a high concentration of salt-forming elements on the surface. Then we grind into the rock and take new measurements. We can tell if this rock has only a thin

alteration rind caused by water flowing over the surface a long time ago. All the instruments are delivering results that are added together, so you look at the rock from different points of view and you get a whole picture."

Gellert said the investigations on Mars will also benefit scientists who study some meteorites on Earth that are believed to come from Mars. They can compare the APXS data on the composition of rocks found on Mars with the meteorites on Earth. "They can prove with another piece of evidence that these Martian meteorites indeed come from Mars."

As principle investigator of the APXS experiment, Gellert will be a member of the MSL project science group that will make decisions about where the rover should go and what samples it should collect for analysis. For the first 90 days of the mission, this team will work out of mission control at NASA's Jet Propulsion Laboratory in Pasadena, California. After that, they will return to their own institutions and consult daily by phone. This is similar to what was done with in the MER program.

"In the beginning, to learn how to operate this complex vehicle, it's best to do this directly at the operations center," said Gellert. "Later on, when you gain experience—everything gets smoother after a couple of months—most scientists go back to their home institution and do remote operations via computer and telephone. You retrieve the newest data, give feedback to the whole science team and discuss what to do next."

Hipkin said that working on a large project like this will provide Canadian scientists and engineers with invaluable experience and enhance Canada's ability to collaborate in even more ambitious missions in the future, including, eventually, human exploration of Mars.

"We'll learn a lot about robotic surface operations and working in these big teams, during both development and operations. And the contacts that our team members will make with scientists and engineers and program staff from other countries is very useful for Canada too. You're very aware that you are at the cutting edge and the challenges are very real. For the engineering teams, it's very motivating to try and develop techniques and technologies that go beyond what we can do at the moment."

As for the risks of Mars exploration, so far the APXS has lived a charmed existence; all three vehicles on which it was riding made it safely to the Martian surface and the missions themselves were extremely successful. Considering that roughly two-third of all Mars-bound spacecraft have failed to complete their

missions, and half of those that landed never sent back any data, APXS has definitely beaten the odds.

Ralf Gellert is realistic about the risks that his newest instrument faces, though. “There are no guarantees in Mars exploration. You simply have to do your best to lower the chances for failure.”

**BLAST**

For Barth Netterfield and the rest of the science team, there was bad news and good news.

The bad news—and it was very bad—was that an errant parachute had dragged their two-tonne telescope more than 200 kilometres across an Antarctic plateau until it became lodged in an inaccessible crevasse field. The problem occurred when the parachute, which had eased the telescope to a safe landing on the icy surface, failed to detach and then was caught by high winds and started parasailing.

“You can’t imagine the emotion of hearing that the telescope is destroyed and we don’t know where the data is,” said Netterfield, the University of Toronto physics and astronomy professor who is the Canadian principal investigator on the project.

But the good news—and it was very good—was that, by some miracle, the box containing the stored astronomical data the telescope had collected had broken off in a place where it could be retrieved. Finding it was also something of a miracle. Flying in a refurbished World War II-era DC3, Netterfield covered hundreds of kilometres of the vast icy expanse, following the faint path carved out in the snow by the dragging telescope.

Then the pilot reported seeing “a piece of debris on the path” and Netterfield spotted the white data vessel as they sped past. This news inspired an “overwhelming combination of thrill, relief and happiness” in the whole team, according to Marco Viero, a University of Toronto graduate student who worked on the project.

Once the data vessel was located, the U.S. National Science Foundation, which operates the McMurdo Antarctic research station, dispatched a Twin Otter to pick up the precious scientific cargo. The balloon that carried the telescope had been launched from McMurdo two weeks earlier.

The recovery of the data meant the mission was scientific success, despite the

loss of the telescope. Although the data still have to be analyzed, “we accomplished all the goals of the flight and then some,” said University of Pennsylvania professor Mark Devlin, the U.S. principal investigator of BLAST.

Given the hazards of the Antarctic environment, it is natural to wonder why the telescope was launched there in the first place. The answer can be found in an even more inhospitable place—galaxies at the far reaches of the universe.

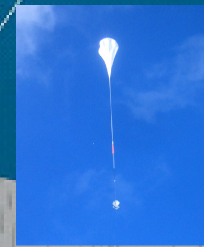
The two-metre telescope, known as BLAST (Balloon-borne Large-Aperture Sub-millimetre Telescope), was designed to address important questions about the formation and evolution of stars and galaxies by collecting data at sub-millimetre wavelengths with an unequalled sensitivity. These wavelengths are largely blocked by the Earth’s atmosphere; in fact, on Earth, the telescope could “barely see across the street, let alone into space” in one of the frequency bands it was designed to study, Netterfield noted. “You’ve got to get out of the atmosphere.”

Perhaps the obvious way to do this is to launch a telescope into orbit, but it is far less expensive to carry it aloft on a balloon. At about $5-million, the BLAST project, jointly sponsored by Canada and the U.S., the U.K. and Mexico, cost a tiny fraction of the hundreds of millions of dollars it typically costs to operate a satellite. Canada’s contribution to the multinational program, largely funded by the Canadian Space Agency (CSA), was to develop and build the pointing control system, the electronics, the software, and the gondola that carried the telescope. The work was done at the University of Toronto and the University of British Columbia (UBC).

A balloon launch presents certain technical challenges of its own. The goal was to get BLAST into the upper stratosphere, above atmospheric interference, and keep it there as long as possible. Because atmospheric pressure drops with altitude, gases in the balloon expand as it rises. If you entirely fill the balloon at ground level, the expanding gases could burst it as it rises, so these balloons are launched only about one half of one percent full. “At 38 kilometres altitude, it’s completely full,” Netterfield said.

However, the volume of gases in the balloon is also affected by temperature; come sunset and cooling temperatures, the volume would shrink and the balloon would drop. If it dropped low enough, this would create several problems that would interfere with the telescope’s ability to collect the desired data. “If you want to get these really long flights, you’d have a hard time doing it without constant sunlight on the balloon,” Netterfield said.

An elegant solution to this problem was developed in the late 1980s by NASA’s Columbia Scientific Balloon Facility. It involves launching a giant balloon near the



poles during periods when it would experience 24-hour sunlight. This is why BLAST was launched from McMurdo in December 2006. In June 2005, a previous five-day BLAST mission was launched over the Arctic from Sweden for the same reason.

BLAST's primary goal was to study starburst galaxies, where star formation occurs at a dramatic pace. These galaxies are important in understanding the structure and evolution of the universe. To find them, BLAST must observe at sub-millimetre wavelengths. Located between the infrared and microwave regions of the electromagnetic spectrum, these wavelengths provide a window through clouds of dust that hide the star-forming areas of galaxies from other types of telescopes, such as optical telescopes that observe wavelengths in the visible range.

Netterfield said that galaxies are filled with dust. “The stars are producing carbon from hydrogen and helium and just spewing it out.” This dust plays an essential role in further star formation, he noted. In order for a star to form, a cloud of gas must collapse under its own gravity so it becomes dense enough to start nuclear fusion, the stellar power source. This will not happen unless the gas cools down.

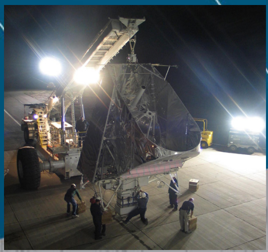
“A really excellent way to cool the gas is to have it mixed with dust,” said Netterfield. Dust radiates heat away, cooling both itself and the gas it lives in, enabling the gas to collapse enough to form a star. “You always find star formation buried in dust clouds.”

Unfortunately, he noted, the dust “also masks everything behind it. You can't see through it in visible light.” Thus, it blocks the view of conventional telescopes.

BLAST, however, can pierce right through the dust and can also measure its properties and behaviour. Sub-millimetre telescopes can reveal what is going on by measuring the temperature of the surrounding dust cloud, which is warmed by the process of star formation. By measuring the average temperature of the dust, scientists can estimate “the total power emitted by the new, bright, short-lived stars and therefore the rate of star formation,” Netterfield said.

BLAST provides a new window on star formation “from relatively nearby stellar nurseries to the most extreme star-bursting galaxies, at ages most of the way back to the beginning of time,” said UBC professor Douglas Scott, another member of the BLAST team. “This has been an extraordinary flight and the data will be very exciting.”

Another key purpose of the BLAST program is to pave the way for the European Space Agency's Herschel Space Observatory, a telescope scheduled for launch



in 2008 that will also collect data in sub-millimetre wavelengths. The BLAST team tested a component of SPIRE (Spectral and Photometric Imaging Receiver), one of three instruments Herschel will carry.

Canada is involved in the Herschel project; researchers from the University of Lethbridge, UBC, the University of Toronto, McMaster University and the Herzberg Institute of Astrophysics are members of the SPIRE team. In addition, the CSA is funding work by the University of Waterloo and an Ontario company, COMDEV, to provide a component for one of Herschel's other instruments.

Jean Dupuis, CSA's Program Scientist for both the Herschel and BLAST projects, said the work done with BLAST will help scientists plan the observations that will be done with the Herschel telescope. It is also a good way to increase the expertise of Canadian scientists and industry in this field, positioning them for involvement in future missions. Even though it was a smaller-scale project than a satellite program, "you can develop instruments that eventually might go in a satellite and get excellent science."

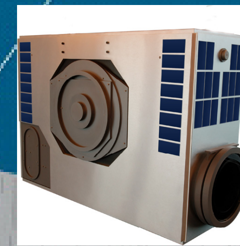
BLAST also provided a vehicle for training Canada's next generation of astronomers, he said. A number of graduate students helped build and operate the telescope, which Netterfield described as "a fantastic pedagogical testbed." The fact that BLAST was relatively inexpensive, compared with a space telescope, made it feasible to use students.

"If you're going to train people to build satellite-type missions, there is no better way than having them build a balloon-borne telescope. You're flying it into a space-like environment but you're doing it on a budget and with risks that are much more appropriate for grad students, who are just learning how to do it."

**NEOSSAT**

In 2002, two asteroids made close approaches to Earth just months apart. In March, asteroid 2002 EM7 passed within 463 000 kilometres of Earth, not far beyond the Moon's orbit. Then, in June, asteroid 2002 MN passed within 120 000 kilometres, less than a third of the distance to the Moon. It was one of the closest asteroid fly-bys on record.

If 2002 MN had intersected Earth, it was large enough, at an estimated 70 metres in diameter, to penetrate the atmosphere and do some damage, on the scale of what happened in Tunguska, Siberia, in 1908.



Media reports of these events characterized them as “near misses” and emphasized the fact that the asteroids were not detected on their way in, but days later as they were leaving Earth’s neighbourhood.

In the case of 2002 MN, much was made of the fact that it approached the day side of Earth, literally coming “out of the blue.” This is a blind spot where objects located near the Sun, as seen from Earth, cannot be detected by ground-based telescopes that monitor asteroid activity. These telescopes can only look for asteroids in the night sky, on the side of the Earth opposite from the Sun.

A tiny Canadian satellite called NEOSSat (Near Earth Object Surveillance Satellite) will help solve this problem. Scheduled for launch in 2010, it will be the first satellite dedicated specifically to searching for asteroids. It will carry a highly precise telescope that will observe near-Earth asteroids, including those that approach Earth on its sunward side.

“The most efficient way of doing it is to get into space so you’re not restricted by the day/night cycle,” said Alan Hildebrand, a planetary scientist at the University of Calgary who heads the asteroid-observing portion of the NEOSSat project. “That’s where NEOSSat comes in. We can look relatively close to the Sun, along the plane of the Earth’s orbit; that’s where these asteroids are concentrated. We’re going to be able to look in front of the Earth and behind the Earth and find these objects before they come to the vicinity of the Earth. In Canada, we have the technology to do this cheaply with a microsatellite.”

The technology used in NEOSSat, which includes a highly accurate pointing system, was originally developed for the first Canadian microsatellite, MOST (Microvariability and Oscillations of STars). MOST was launched in 2003 to study variable stars and its great precision allowed scientists to use it to study extraterrestrial planets as well. NEOSSat’s design is similar to MOST’s but its telescope has been optimized to detect faint asteroids.

MOST was “quite unique” and has been very successful, said Denis Laurin, Senior Program Scientist at the Canadian Space Agency (CSA), which funded both projects. CSA is supporting the development of microsatellites because they are relatively inexpensive but still capable of producing excellent scientific data.

Although Canada often participates in large international observation missions, it can rarely afford to run such expensive endeavours. At about $10-million each, the microsatellites enable CSA to mount entirely Canadian-led missions. “We define the mission and we’re building the spacecraft and payload. It is Canadian technology for Canadian scientists,” Laurin said.

Dynacon Inc. of  Mississauga, Ontario, is the prime contractor building the satellite. It was also the lead contractor for the MOST satellite.

Nevertheless, NEOSSat's asteroid-tracking mission does have an international flavour; about half the science team is from outside Canada, mostly from the U.S, where researchers have been using Earth-based telescopes to search for asteroids for up to two decades. "We don't have as much experience looking for asteroids in this country," said Hildebrand.

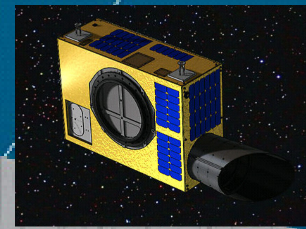
He noted that, while the data collected by NEOSSat will be used in assessing the threat of collisions with Earth, the primary focus of the mission is to gather scientific information on the population of near-Earth asteroids and to document their movements and characteristics. "In terms of understanding the evolution and distribution of the populations of asteroids, it's going to be an exciting contributor. We're going to be able to make a contribution to this effort that is unique and valuable."

In 1998, the U.S. National Aeronautics and Space Administration set a 10-year goal of finding 90 percent of near-Earth asteroids with diameters of one kilometre or larger. The rate of discovery of these bodies exploded after that; the total number jumped from less than 500 to more than 4600 by mid-2007, of which more than 700 are one kilometre or larger.

Not all these "large" asteroids have been found yet; Hildebrand said the population is estimated to be around 1100. He said it is not clear whether 90 percent of them will be found by the target date of 2008 but a "respectable number" will be. "It's a pretty good effort, compared to the near-total ignorance a short time ago."

NEOSSat will be looking specifically for asteroids that have the most Earth-like orbits and spend all or most of their time interior to Earth's orbit. There are two types—Atens and IEO (interior to Earth orbit) asteroids. Atens asteroids cross Earth's orbit and thus represent a potential collision threat. IEOs do not present such a threat right now, but they could if their orbits are preturbed.

Hildebrand said that NEOSSat is going to be a "terrific finder" of both types of asteroids, which are difficult to detect from the Earth's surface. Since IEOs stay wholly inside Earth's orbit, they are only rarely visible in the night sky to Earth-based telescopes. Putting a telescope in space eliminates this problem; out there, the sky is always dark, even when looking close to the Sun, so these asteroids can be more easily detected.



"Because we can look close to the Sun, we're going to be able to find dozens of them," Hildebrand said. "NEOSSat is irreplaceable as an IEO finder and it's also going to observe a very large number of Atens asteroids." The science team has estimated that the microsatellite could find more than half of Atens asteroids one kilometre or larger within three years of operation. Overall, the spacecraft is expected to discover about a thousand near-Earth objects.

Scientists are interested in these asteroids not just because of the risk they might hit Earth, but also because they are excellent candidates for future visits by manned or unmanned spacecraft and potentially a source of materials that could prove useful in space operations.

"If you're interested in asteroids to study them, to mine them, or to prevent an impact, you want to find the ones that are close to us dynamically, the ones with Earth-like orbits," said Hildebrand. "It just happens that NEOSSat finds the objects that are potentially the most hazardous and potentially the most interesting as exploration targets, so it's one of those happy projects where everything you do is useful and people are interested in what you find for different reasons."

He says that NEOSSat may well discover the asteroids that humans will someday visit because the ones in Earth-like orbits will be the easiest and least expensive to reach. Such asteroids would also be the best potential sources of minerals and other materials for space construction. "Launching things off the Earth is very expensive and dangerous and it environmentally degrades our planet," Hildebrand said.

For example, he suggested that asteroid resources could play a key role in two large space projects that scientists have speculated about for years—building large solar power satellites to beam energy to Earth, and building orbiting mirrors to reflect sunlight and reduce planetary warming. Solar power satellites would be "much more economic if we can build those satellites with extraterrestrial resources," he said. It would also be cheaper to get aluminum from an asteroid and process it into a reflective mirror surface in space.

Moreover, if an asteroid contains water, it can be split into hydrogen and oxygen and used as rocket fuel. Laurin said propellant is one of the most expensive things about space travel because "it's heavy and you need lots of it." If water were discovered on an asteroid, he said it might be possible to use it "as a resource for people inhabiting the Moon or to provide for a mission to Mars."

Finally, there is the question of evaluating the risk of an asteroid hitting Earth and what kind of damage it might cause. This is a question Hildebrand has pondered

since the early days of his research career; he was one of the scientists who discovered an impact crater in Mexico's Yucatan Penninsula that is widely believed to have caused climatic changes that doomed the dinosaurs.

He described the surveys being done by NEOSSat and ground-based telescopes as an insurance policy. "If we find all the asteroids that cross the Earth's orbit and we determine their orbits and project them into future, odds are we're going to discover that none of them is going to impact the Earth any time soon and we know that we're safe. But until we do that, there's this chance that one of them is going to impact us."

"The key is to detect a hazardous asteroid as early as possible," said Laurin. "The earlier you know its position, the better chance you might have to deflect its orbit or prepare for it. If you can detect it from very far away, several orbits ahead of time, you don't need to deflect it very much."

Hildebrand noted that new telescope networks being planned will look for even smaller Earth-crossing asteroids, down to around 200 metres in diameter. It's estimated there may be some 30,000 of them. Asteroids of that size could have a significant regional impact, such as wiping out a major city, but they're unlikely to cause a planetary-scale environmental disaster like the one that hit the Yucatan, which Hildebrand estimates at about seven kilometers in diameter.

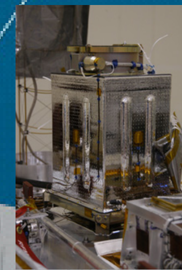
*NEOSSat is managed through a Joint Project Office (JPO) of CSA working in collaboration with DRDC. The detailed development and construction contract for NEOSSat was awarded in July 2007 to Dynacon, now inherited by Microsat System Canada Inc. The two NEOSSat science missions focus on "Near Earth Space Surveillance (NESS)", led by the University of Calgary, and "High Earth Orbit Space Surveillance (HEOSS)" led by DRDC.*

**Phoenix**

Follow the water.

That is the mission of the Phoenix spacecraft, which landed near the Arctic circle of Mars on May 25, 2008. The fate of water on Mars—past, present and future—has always held a special fascination for scientists because where there is water, there is at least the possibility of life.

"Life as we know it is always dependent on the presence of water, so if they're going to find life on Mars, they expect it will be linked to water," said Peter Taylor, a professor of Earth and Space Science and Engineering at York University in Toronto. Taylor is one of several Canadian scientists working on the U.S. Phoenix mission, the first to land in such a northerly location.



The Phoenix Mission is led by Principal Investigator Peter H. Smith of the University of Arizona. The team includes more than two dozen investigators. Selected in 2003 by the NASA from among 25 proposals, Phoenix is part of NASA's Scout program to develop smaller, lower-cost planetary exploration missions. Named after the mythical bird that rises from the ashes of its predecessor, it will use an existing lander that was mothballed after the cancellation of a previous mission.

One of the instruments on board Phoenix is a Canadian-designed meteorological station (MET), which was built in Brampton, Ontario, by MacDonald, Dettwiler and Associates Inc. (MDA) under contract to the Canadian Space Agency (CSA).

MET is studying weather in what is known as the "boundary layer," the first few kilometres of the atmosphere above the Martian surface. These meteorological observations—the first ever to be made on the Martian surface in the polar region—will be important in understanding the planet's water cycle.

"There's all this ice just under the surface at these latitudes and it isn't at all clear what the cycle of water is between the atmosphere, the polar ice caps and this subsurface ice," said Taylor. "The motivation is to try to understand something about conditions at these latitudes because previous landing missions have been nearer the equator." He added that no other meteorological measurements have been taken on the Martian surface except those made by Viking in the mid-1970s and Pathfinder in 1997.

Currently, water on Mars exists only in solid and gaseous form—ice and water vapour. Scientists believe that interactions between water vapour in the atmosphere and ice at or just below the surface are key elements of Martian weather and climate. There is no sign of liquid water on the Martian surface at present, but previous missions have found evidence that it once existed. Operating in an ice-rich region identified by the Mars Odyssey orbiter, Phoenix uses a robotic arm to collect sub-surface soil and ice samples and deliver them to onboard instruments for analysis. Scientists hope the findings will shed light on the history of liquid water (which may have existed in the Martian Arctic as recently as 100 000 years ago) and also on the potential of the sub-surface soils to support microbial life.

The MET station consists of three temperature sensors and a pressure sensor (provided by Finland) located on a one-metre vertical mast on the deck of the lander. Since landing, the MET has been taking continuous measurements of temperature and atmospheric pressure at the landing site. It also carries a "tell tale" (provided by Denmark)—a small metal cylinder "wind sock" that is

photographed by the lander cameras and used to determine wind speeds. Humidity is be measured by the Thermal and ElectroConductivity Probe.

A key part of the MET is a lidar (light detection and ranging) that will gather data on atmospheric dust and ice particles. Lidar operates on the same principle as radar, but sends out pulses of laser light instead of radio waves. The light is reflected off the particles and, by measuring the return time and intensity, scientists can determine their location and number.

The pioneering work in the development of lidar systems by York University scientist Allan Carswell was a major factor that led to Canadian participation in Phoenix. Several years ago, Carswell’s company, Optech Inc. of Toronto, provided a lidar for a study of dust devils in Arizona. The lidar on board Phoenix, built by MDA and Optech, is the first lidar to operate on the surface of another planet.

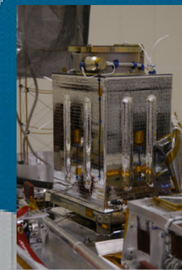
*Ice clouds and dust*

The lidar will detect the presence of dust, fog and ice clouds in the lower atmosphere. Clouds help to spread water around the planet’s atmosphere and send it down to the surface. Understanding cloud formation and evolution and the movement of constituents of the lower atmosphere are central to understanding the water cycle and potential for life. Taylor said the lidar should be able to detect water-ice clouds that are “reasonably close to the surface”—up to about 20 kilometres high.

Measuring dust particles is also important to understanding Mars’ weather and climate because they influence the flow of solar energy within the atmosphere and play an important role in forming clouds. On Mars, dust can be whipped up by the winds into anything from small, localized “dust devils” to long-lived storms that cover large regions of the planet.

These storms are a potential hazard to future human exploration missions and can also affect the performance of unmanned vehicles, which often depend on solar energy for power. “If you get a lot of dust in the atmosphere, that cuts down the amount of solar radiation reaching the surface, so you can’t charge up your batteries during the day,” Taylor said.

The lidar’s ability to detect dust will help scientists gain a better understanding of the boundary layer on Mars. This is a region just above the surface where most turbulence occurs and where heat, dust, water vapour and other gases are mixed and transferred between the atmosphere and the surface. Taylor said the



boundary layer on Mars is generally higher than on Earth—perhaps four to five kilometres during the day in the Arctic because of solar heating, and less at night.

“We think the lidar will be able to tell us is how deep the boundary layer is,” he said. “We’re hoping it will detect a horizon—a change in the dust concentration at levels corresponding to the top of the boundary layer.” This will depend on the size of the dust particles. If they are large enough to settle out of the atmosphere sufficiently rapidly at night, scientists will see the top of the boundary layer. Unfortunately, some Martian dust is very fine and, once stirred up, settles very slowly, if at all.

The MET science team is interpreting the data collected on the planet by using computer models similar to those used for weather forecasting and climate prediction on Earth to analyze the atmospheric chemistry of Mars and the role played by dust.

*Preparing for the mission*

Long before landing, while MDA was building the instruments, the Canadian scientific team conducted studies and tests to prepare for the research program during spacecraft operations. The York team, for example, tested components of the temperature sensor taken from the same manufacturing batch as those destined for the spacecraft and also built and tested a lidar technically similar to that destined for Mars.

Taylor and his students participated in an investigation that prompted a design change in the instrument used to collect sub-surface ice samples. From his previous research on blowing snow, Taylor knew that when snow is blown around, it sublimates—changes from a solid to a vapour. He began to wonder if this would happen to the ice dug up with a fork-like device on the end of the robotic arm on Phoenix—a laborious process that would take several hours.

“It seemed to us that scraping these little chips of ice up and delivering them to the analysis instrument several hours later could be a problem. We thought these ice chips would sublimate. If it takes them several hours to collect a large enough sample, they’ll never be able to do it because the sample will vaporize.” His initial calculations suggested that, at a temperature of –30 degrees Celsius, the chips would last only half an hour.

This theory was greeted with some skepticism so Taylor had a student who was working in the Canadian Arctic do some experiments up there. He and some other students also conducted experiments in a chamber at York that simulates Martian conditions. “We found that if the temperature stays below about –40

degrees Celsius, they're probably okay; these samples won't lose a significant amount of mass over a period of something like 8 hours. But if the temperature warms up to –30 or –20 degrees Celsius, then they'll be gone. Certainly –20 degrees Celsius was a problem.

The answer was to "incorporate a little drill on the end of the robotic arm that is able to collect ice samples at a much faster rate. They can analyze them in a couple of hours rather than eight or nine hours."

Phoenix is designed to operate for 90 sols or Martian days, which are about 40 minutes longer than Earth days, but the scientists hope the mission might be extended longer than that. Unlike other instruments that will run out of essential materials, the lidar and the temperature and pressure sensors do not require consumables, so "we certainly hope to keep the meteorological experiment going," Taylor said.

However, Phoenix's days will be numbered by the changing seasons. Unlike its namesake, which rose out of fire, it will probably not rise out of the Martian ice. With only the sun for energy, Phoenix is not expected to survive the polar region's long, dark winter. "There'll be no power to keep the batteries alive and things will get too cold," said Taylor. "The expectation is that it will not awake the following summer."

But, he added hopefully, "you never know."

*York University leads the Canadian science team with the participation of the University of Alberta, Dalhousie University, Optech and Natural Resources Canada (Geological Survey of Canada), the Canadian Space Agency and international collaboration from the Finnish Meteorological Institute. MDA Space Missions is the prime contractor for the meteorological station, in partnership with Optech. The telltale on the meteorological station's mast was contributed by the University of Aarhus, with support from the University of Alberta.*

*The Phoenix Mission is led by Principal Investigator Peter H. Smith of The University of Arizona, supported by a science team of CO-Is, with project management at NASA's Jet Propulsion Laboratory and development partnership with Lockheed Martin Space Systems. International contributions are provided by the Canadian Space Agency; the University of Neuchatel, Switzerland; the universities of Copenhagen and Aarhus Denmark; the Max Planck Institute, Germany; and the Finnish Meteorological Institute.*

## Solar-Terrestrial and Atmospheric Research

### Canadian Geospace Monitoring Project

When most people hear the words “weather forecast”, they expect to hear something about clouds, rain, snow or winds.

But now, Canadian scientists are working to provide another kind of forecast—a space weather forecast that will predict turbulent events in the highest reaches of the Earth’s atmosphere where it meets a flood of electromagnetic radiation and electrically charged particles flowing out from the sun.

The solar radiation and particles interact in complex ways with both the outer atmosphere and the Earth’s magnetic field, causing a range of effects including the auroras and large geomagnetic storms that can damage satellites and spacecraft, disrupt communications around the world and overload power networks on the ground.

Events like these make this vast and often tumultuous area of geospace of great economic as well as scientific importance. “That area of space is where there are billions dollars of space assets,” said John Manuel, a program scientist with the Canadian Space Agency (CSA), one of the agencies funding the effort to improve forecasting of space weather. “When that weather is rough, those assets can be damaged and sometimes destroyed.”

In 1989, a solar storm knocked out Hydro Quebec’s electrical grid, causing a nine-hour blackout and multi-million-dollar losses. In 1994, two Canadian communications satellites, Anik E-1 and E-2, were disabled by solar storms and had to be replaced at a cost of hundreds of millions of dollars. Many other satellites have malfunctioned, interrupting media services and cell phone and GPS navigation systems.

Manuel noted that high-flying aircraft, especially those that follow polar routes, are also affected by space weather and the higher levels of radiation they can create. “There’s an increasing number of flights across the North pole and those regions are more exposed to disturbances in space,” said Manuel.

The CSA is working with Natural Resources Canada to improve the prediction of space weather events. “Just as we have a meteorology service that monitors the weather and climate to make forecasts so that people can prepare themselves for whatever’s coming, we have the beginnings of a space weather forecast

service on the way.” Natural Resources Canada has set up Space Weather Canada as a regional warning centre of the International Space Environment Service.

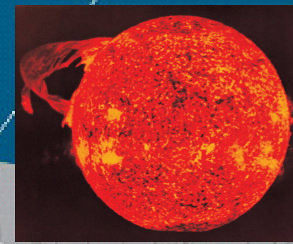
The ability to predict space weather events depends on the travel time between the sun and Earth. Solar radiation reaches Earth in just a few minutes, and some charged particles also arrive quickly, but others can take several days. A coronal mass ejection, for example, is “slower moving,” said Manuel. “These are blasts of billions of tonnes of material that come off the sun during flares. If the Earth is in the way of one of those, it can cause massive disturbances in the magnetic field. They take a few days to arrive, so if we know they’re coming, we can issue the appropriate warnings to the airline industry, satellite operators and hydro systems so they can brace themselves.”

There are things these industries can do to reduce their vulnerability. Airlines can divert or cancel flights and power companies can make adjustments on their electricity grids. Satellite operators can put their spacecraft into low-power safe modes and shut down critical or vulnerable components.

Manuel said Canada is in a unique position to study space weather because it is the country with the largest landmass beneath the auroras and geomagnetic disturbances in the ionosphere, a region containing electrically charged particles where the auroras are located. “By virtue of its location, Canada has a front-row seat. The auroras are shifted further south over Canada than any other country and this allows us to put instruments underneath them.”

For many years, Canada has used this geographic advantage to study solar-terrestrial interactions in the upper atmosphere and has become a leader in this field. Now it is building on previous monitoring programs and infrastructure to create an even more extensive network of ground-based instruments to observe geomagnetic space. Called Canadian Geoscience Monitoring (CGSM), this network, when completed, will include several different kinds of instruments:

- **all-sky imagers:** cameras that measure different wavelengths of light and can observe the colors of the aurora. These colors are the result of charged particles from the sun colliding with atoms in the upper atmosphere so observing them provides important information about the processes involved in the interaction between solar particles and the atmosphere.
- **meridian scanning photometers**: instruments that measure the intensity of light at different wavelengths. These devices precisely measure the characteristics of the light coming from the aurora.



- **riometers**: instruments that observe the cosmic background radiation at radio wavelengths. This radiation is disrupted by auroras, so these instruments provide an indirect measure of the strength of auroral activity.
- **Canadian Advanced Digital Ionosondes (CADI)**: instruments that send out bursts of radio energy high into the atmosphere. The reflections will provide information on the state of the ionosphere.
- **superDARN radars**: these send out bursts of radio energy and measure the reflections from the active regions of the aurora. Unlike the CADI instruments, which look straight up, the superDARN radar signals go out at a more horizontal or oblique angle. These radars can be used to detect horizontal movements (essentially winds) of electrically charged gases in the ionosphere, caused by heating from the aurora. Combining the data from the CADI and superDARN instruments can provide greater insight into activity within the ionosphere and the auroras.
- **fluxgate magnetometers**: instruments that measure the strength of the Earth's magnetic field in their vicinity with great precision. Magnetic fields and electrical currents are inextricably linked. The ionosphere is awash in electrical currents caused by solar-terrestrial interactions and these currents affect the Earth's magnetosphere; measuring magnetic field strength on Earth can reveal important information about the state of the electrical currents high in the atmosphere.
- **induction coil magnetometers**: instruments that detect very fast variations in the Earth's magnetic field, caused by disturbances in geospace.
- **solar monitor:** a device that monitors radio wavelengths emitted from the sun. Variations in the intensity of this radiation are correlated with sunspots, relatively dark areas on the sun associated with intense magnetic activity.

Some of these instruments were part of a pre-existing network and are already in place, mostly in Western Canada and the North. The Canadian Foundation for Innovation provided funding to add new instruments to the network. When it is completed, scientists will be able to observe events happening in the ionosphere with far greater resolution over time and space than ever before.

The science team that will collect and analyze all this data is also large and diversified. It includes nearly three-dozen researchers from five Canadian universities (the University of Alberta, the University of Calgary, the University of Saskatchewan, the University of Western Ontario and the University of New Brunswick) as well as three government agencies (Natural Resources Canada, the National Research Council's Dominion Radio Astrophysical Observatory and the Canadian Space Agency.)

The amount of data generated by the network will be staggering. “Collecting and storing all that data is no small thing,” said Manuel. “It has required a lot of technological development.” Although data will be transmitted from the instruments to various university groups, the University of Alberta has been contracted to maintain a central repository and share the information with the rest of the world.

The University of Alberta also has facility that runs computer models of the Earth’s magnetosphere. The CGSM data will be used to improve these models and make them as realistic as possible so they can eventually be used to predict space weather events. Models are already used to forecast weather and climate on Earth, but “at the moment, it’s impossible to run the magnetosphere on a computer like the ones used for weather forecasting,” said Manuel. “The magnetosphere is really complex to simulate.”

However, he said it might be possible to link a series of computers from around the world to evaluate the threat posed by something like a coronal mass ejection if it is detected by the monitoring network a few days before the disturbance arrives on Earth’s doorstep.

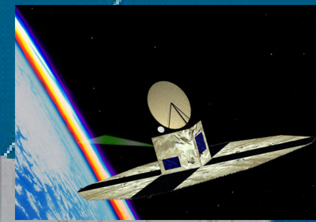
**OSIRIS**

They said it couldn’t be done.

Even after a team of Canadian researchers did it, the scientific community still said it couldn’t be done. “It took us four years before people stood back and said, that’s the way we have to do it,” recalls Ted Llewellyn, emeritus professor of engineering physics at the University of Saskatchewan.

He is referring to a technique known as atmospheric tomography—a method he likens to taking a CAT scan of the atmosphere to reveal previously unknown aspects of its three-dimensional structure. It is being used by a Canadian-built instrument called OSIRIS (Optical Spectrograph and InfraRed Imager System) to map the ozone layer in the upper atmosphere that protects the Earth’s surface from the sun’s biologically damaging ultraviolet radiation.

Llewellyn, who is the principal investigator on the OSIRIS project, said it is the only instrument capable of doing atmospheric tomography at present. Orbiting the Earth aboard the Swedish satellite Odin, its main task is to produce global vertical profile maps of the ozone layer. In one day it can produce a height profile that would take a month to create using other techniques.



The instrument also measures concentrations of the ozone-destroying gases nitrogen dioxide and bromine oxide, as well as water vapour in the upper atmosphere, which can be used as an indicator of climate change. And it maps small sulphate particles or aerosols, produced by industrial activities, which significantly influence both ozone and climate.

Launched in 2001 for what was scheduled to be a two-year mission, OSIRIS is still going strong. Initially funded by the Canadian Space Agency, it was recently given a new lease on life when the European Space Agency (ESA) agreed to support the operation of Odin and OSIRIS for at least a seventh year and perhaps a few more, depending on the scientific results.

This support is “a recognition of the value of the data,” said Stella Melo, Project Scientist at the CSA, which continues to fund ground-based processing of the raw data before it is sent to ESA. She said OSIRIS is making a significant and unique contribution to understanding processes going on in the upper atmosphere and providing data that will be valuable for computer models used to project future changes in the ozone layer and the climate.

Llewellyn described OSIRIS as a development instrument that will help scientists design the next generation of satellites to monitor global environmental changes. “We’ve gone through that teething stage and we’re at the point where we can say to people, this is what you need to do.”

“We still think we can wring a lot more out of it,” said Doug Degenstein, associate professor of engineering physics at the University of Saskatchewan and co-principal investigator of the OSIRIS project. He said one reason why OSIRIS’s data is so valuable, and why ESA is providing continuing support, is because “a lot of the spacecraft instruments that have been making similar measurements over the last 10 years have now died,” As a result, scientists are relying on OSIRIS to maintain continuity in the data on long-term trends until new spacecraft can be launched.

Monitoring the health of the ozone layer in the upper atmosphere has been a priority for three decades, since scientists discovered it was being damaged by industrial chemicals called chlorofluorocarbons (CFCs). Ozone, which is comprised of three atoms of oxygen, is constantly being created and destroyed by natural chemical processes, so the amount of ozone present at any given time varies depending on the balance between the processes of creation and destruction.

Because of this, “measuring ozone alone is not sufficient,” said Melo. Instead, it is necessary to measure a variety of different chemicals and to understand the dynamic processes that lead to ozone formation and destruction.

CFCs affect the balance by destroying stratospheric ozone. They not only reduce the ozone shield around the globe, but also create large ozone holes over the Antarctic each year and significant losses over the Arctic. Many of these chemicals were banned nearly two decades ago and there is evidence that the ozone layer is slowly starting to recover.

To produce its maps of the vertical profile of ozone in the atmosphere, OSIRIS depends on two phenomenon: the scattering of sunlight in the atmosphere and the airglow, faint emissions caused by chemical processes in the upper atmosphere. When sunlight falls on the atmosphere, different atoms and molecules both scatter and absorb it at specific wavelengths and OSIRIS can identify these characteristic signatures.

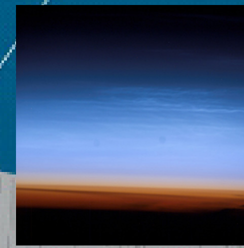
“Both the absorption of sunlight and the airglow are fingerprints of the atoms and molecules in the atmosphere,” said Llewellyn. “If you can measure their brightness very accurately, you can measure their abundance very accurately.”

This is a challenge, however, because the instrument records all the signatures it finds in the atmosphere. “You’re not able to pick out just one little piece,” said Llewellyn. Heavy-duty computing and modelling are needed to tease out the specific fingerprints that are of greatest interest.

Different techniques are used to detect the fingerprints of different atmospheric components at different altitudes. In the stratosphere, the region of the upper atmosphere where ozone is most abundant, both it and nitrogen dioxide are detected by measuring the absorption of sunlight shining through the atmosphere. Sulphate particles in the stratosphere are detected using a new technique that measures how the particles scatter sunlight.

Some ozone also exists in the mesosphere, the region above the stratosphere; although the volume is not as great, it still plays an important role. This ozone is measured using airglow emissions, as is mesospheric water vapour.

OSIRIS’s unique process of atmospheric tomography enables scientists to look for structures in the airglow. Like the CAT scan that Llewellyn compares it to, the process requires a series of stacked two-dimensional images which are then analyzed by computer to produce a three-dimensional representation of the internal structure of the object being studied—in this case, components of the atmosphere such as mesospheric ozone and water vapour.



In addition, the scientists use what Llewellyn describes as a tomography-like technique to process images obtained by detecting the absorption of sunlight passing through the atmosphere. These types of images are used to measure stratospheric ozone and nitrogen dioxide.

The amount of data processing required is staggering. At first, Llewellyn, who came up with the idea along with a colleague, Ian McDade, thought there was simply no practical way to do it. “We realized that no matter how fast computers were, it was going to be a very slow process; we would never keep up with the rate at which the data came in.”

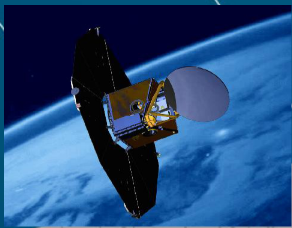
However, never one to say never, Llewellyn set Degenstein, then a graduate student, to the task. With the approval of the Canadian Space Agency, which was funding the research, Degenstein spent two years working with the Ottawa company, Routes AstroEngineering, that was building the instrument. During that time, he developed a system that can process 100 minutes of data in five minutes—20 times faster than “real time.”

“He did make it sit up and beg,” said Llewellyn proudly. “We were overjoyed, but we still hadn’t flown at that stage.” Several people told him that it was “a wonderful idea but it can never work.” Even when they got their first flight results and presented them at an international conference, the skepticism persisted. Llewellyn said: “People looked at it and said, ‘Yeah, fine; we don’t believe you.’ ” It took a few years for them to convince the skeptics but “now it’s the accepted way of looking for structures in the atmosphere. Everybody knows what they have to do next.”

In the meantime, the science team has been expanding the range of atmospheric components that OSIRIS is looking at. Melo noted that the instrument unique in its ability to measure water vapour at altitudes of about 80 to 90 kilometres. This is in the upper mesosphere, one of the highest regions of the atmosphere.

The water content of the atmosphere is a key component in cloud formation and OSIRIS is currently studying an intriguing phenomenon called polar mesospheric clouds, the highest clouds in the atmosphere. Some scientists believe they’re occurring more frequently and could be “a true canary in the coal mine for global change,” Llewellyn said.

However, Melo noted that “the processes that lead to the formation of these clouds are not fully understood and that’s where OSIRIS is contributing.” She said that measuring polar mesospheric clouds started out as a secondary



objective of the OSIRIS project, but the quality of the data turned out to be better than anyone anticipated.

She noted that researchers have paid much attention to what is happening in the stratosphere, the atmospheric region below the mesosphere, but they are now realizing that “to fully understand the processes there, we need to look further up and understand the water content.”

OSIRIS is also gathering data on polar stratospheric clouds. They are known to accelerate ozone depletion and play a key role in creating ozone holes over the poles. Ironically, the ideal conditions for their formation – extremely cold temperatures in the stratosphere – occur because the greenhouse gases that cause global warming trap heat closer to the Earth’s surface, resulting in stratospheric cooling.

Finally, OSIRIS is being used to detect another type of high-altitude clouds: ultra-thin or sub-visual cirrus clouds, which are also believed to play an important climatic role. This work is being done by graduate student Adam Bourassa, who has just completed his PhD. He has also been using OSIRIS to study sulphate aerosols, industrial pollutants in the atmosphere that influence cloud formation.

Melo said OSIRIS is producing unique three-dimensional maps of aerosol pollution. Measurements of how these pollutants are transported around the globe can be used as an indirect measure of the movement of air parcels in the upper atmosphere. “We don’t have any direct measurements of the winds in the stratosphere,” she said. “This adds one extra component to the collection of information.”

The loss of several other satellites that were studying ozone and other atmospheric constituents has put OSIRIS in the important but unexpected position of bridging a gap in data collection. It is difficult to meld data from different satellites and instruments but fortunately, there is an overlap of about three and a half years between the OSIRIS data and those from other satellites, which should enable scientists to correlate the information and produce continuous trend information.


“When they get the next set of satellites up, hopefully we’ll have another overlap and we can get them to agree as well, so everybody gets bridged,” Llewellyn said.

*The OSIRIS instrument built by Routes AstroEngineering, is led by Principle Investigator Dr. Doug Degenstein of the Institute of Space and Atmospheric Studies at the University of Saskatchewan and supported by a science team of Co-I’s. OSIRIS flies on the Odin satellite which is a Swedish led mission with co-operations from The Swedish Space Corporation, on behalf of the SNSB Swedish National Space Board and the space agencies of Canada (CSA), Finland (TEKES), France (CNES) and ESA. The science return from the OSIRIS project has also been generously supported by NSERC (www.nserc-crsng.gc.ca/ ) and scientists within Environment Canada (www.msc-smc.ec.gc.ca/).*