Canadian Space Agency
Agence spatiale canadienne

Space Science Research in Canada

2004–2005

THE CSA's REPORT TO THE 36th COSPAR MEETING

BEIJING, CHINA JULY 2006

Canada

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Preface

This report to the 36th COSPAR meeting in Beijing, China, provides an overview of Canadian space science research activities that have been funded or enabled by the Canadian Space Agency (CSA) in 2004–2005. Established in 1989, the CSA is responsible for coordinating all civilian, space-related scientific and technological research policies and programs for the Government of Canada.

This report has been written for a broad audience of science enthusiasts, in a style that makes its contents accessible to a general audience. Its purpose is to provide insight into the strategies that guide the development of the CSA Space Science Program as well as a summary of recent accomplishments and initiatives. It is not intended as a detailed scientific review for researchers.

This report has been prepared by the CSA's Space Science Branch, which is responsible for planning and coordinating space science activities in Canada. These activities span a wide range of interests from studies of the universe, the solar system and the near-Earth environment, to the physical and biological processes that occur in space.

In implementing Canada's Space Plan, the CSA works in close collaboration with Canadian stakeholders in private industry, Canadian research institutions, and other government research-based departments. These departments include, among others, Environment Canada, Natural Resources Canada, and the National Research Council of Canada. The CSA also collaborates with the Department of National Defence in their space activities.

The report has been structured into four main sections. The Overview and Highlights sections provide a summary of the scope of the Canadian Space Strategy and give some of the highlights of the space science activities in 2004–2005. The Canadian Space Science Program Review section provides additional details on approved/future and operating/current missions of the six disciplines within the Space Science Program. This is followed by a series of feature articles highlighting particular research projects in the various program areas. Finally, the reference section provides contact details on Canadian university partners.

The CSA wishes to acknowledge the following people who participated in interviews, reviewed texts, and provided feedback on projects.

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COSPAR in Canada

The National Research Council of Canada (NRC) is the national adhering member of COSPAR, while the 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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Advisory Committees Comprising the Canadian National Committee

There are five Space Science Program Advisory Committees:

- Space and Atmospheric Environment Advisory Committee (SAEAC)
- Joint Committee on Space Astronomy (JCSA) – shared with the Canadian Astronomical Society (CASCA)
- Space Exploration Advisory Committee (with one associated committee: Meteorites and Impacts Advisory Committee)
- Life Sciences Advisory Committee
- Physical Sciences Advisory Committee

Please consult the CSA Web site (www.space.gc.ca/asc/eng/sciences/committees.asp) for more details of these advisory committees, including membership and mandate.

Overview

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 limited 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.

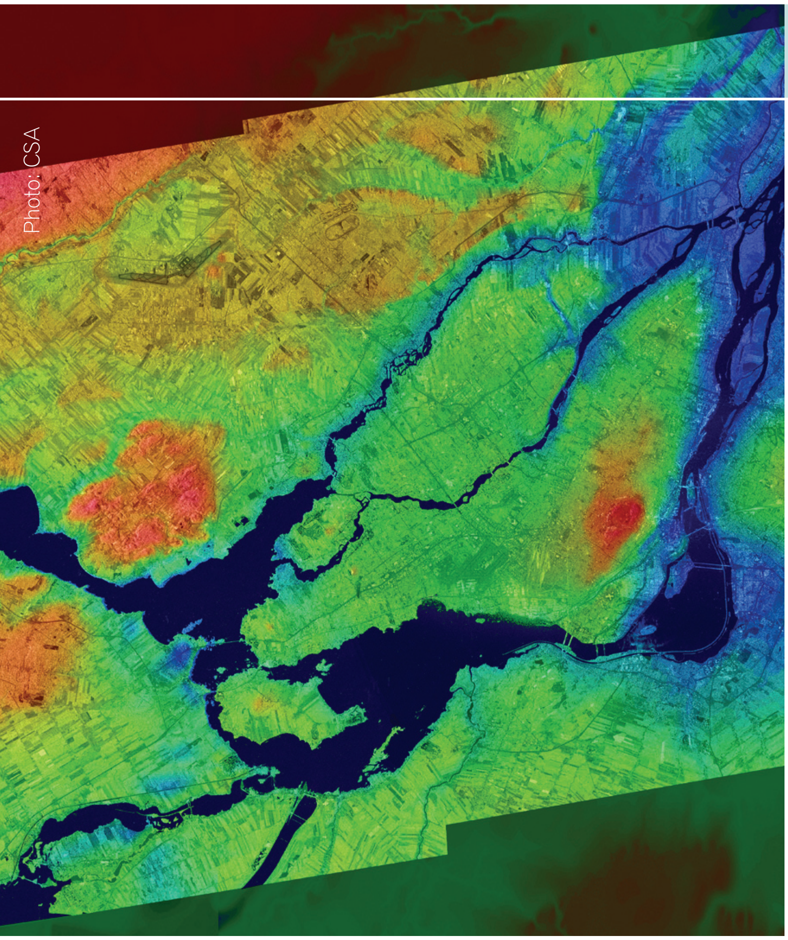
Another important aspect of this strategy is capitalizing on Canada's geographic strengths. For example, its high-latitude location has encouraged its development as a world leader in studying the aurora borealis and Arctic ozone levels. In addition, the remoteness and harsh climate of the Canadian North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

Specialized scientific and technological expertise of this sort has been used both 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."

The framework that guides the development of CSA's programs, known as the Canadian Space Strategy, was approved by the federal government in 2005. 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.



RADARSAT image of Montréal, Canada.

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.

They play a significant role in measuring air and water quality and pollution levels, and they 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 meets its needs for surveillance and law enforcement on land, in coastal waters, and at its borders. They 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;
- the origin and evolution of life on Earth, and whether it exists elsewhere;
- the relationship between the sun and the Earth;
- the 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.

Of necessity, 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 instrument has bought Canadian scientists a ticket to Mars on the unmanned U.S. Phoenix spacecraft, while sharing data collected by the Canadian-built small astronomy satellite MOST will give Canadian astronomers access to data from COROT, a French satellite that will search for planets around other stars.

Photo: NASA

Building the Canadarm resulted in flight opportunities for Canadian astronauts and scientific payloads.

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 government departments 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 Defence 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 spinoffs, and support for academic research resulting from science and technology programs.

The academic community plays a key role in guiding the direction of CSA's Space Science Program. They participate in advisory committees that help to 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 spinoffs, 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 2004–2005

Over 2004 and 2005, a number of Canadian space science research projects achieved notable successes, while others were in preparation for missions taking place in the next few years. These projects span the spectrum of disciplines funded by the CSA's Space Science Program, including astronomy, planetary exploration, solar-terrestrial science, physical sciences, and life sciences. In addition, there were significant achievements in atmospheric research, which contributes to the EO thrust.

These projects support CSA's mandate to use space science to advance fundamental knowledge and provide social and economic benefits on Earth. They have also fostered significant advances in Canada's scientific and technological capabilities as well as the international competitiveness of its space industry.

They include a mix of all-Canadian missions and collaborations with international partners, many of which involve a contribution of instruments or sub-systems, in keeping with CSA's goal of making Canadian companies key suppliers of such devices in the international market.

Astronomy

When it comes to advancing fundamental scientific knowledge, some of the most dramatic results are those being generated by MOST (Microvariability and Oscillations of Stars), a small astronomical satellite that measures tiny variations in the brightness of stars to determine their age, nature and composition. Since this satellite—Canada's first space telescope—was launched by a Russian rocket in 2003, it has put some 400 stars under surveillance, literally staring at them for up to two months at a time.

This has produced a wealth of information—some of it very surprising—that has challenged conventional astronomical wisdom. For example, MOST did not detect any intensity variations in the light from a star called Procyon, which led mission scientist Jaymie Matthews, a University of British Columbia astronomer, to call it a "flat-liner." This controversial finding contradicts Earth-based observations, as well as scientific theories that stars of this type should oscillate.

However, MOST has received even more attention for research that was not part of its original mandate—investigating exo-planets circling other stars. It is currently the only satellite that can observe these planets by measuring their very subtle effect on the brightness of the stars they orbit, producing data that can reveal much about the size and atmospheres of these planets. MOST has examined large gas exo-planets similar to Jupiter, and is looking for Earth-like planets.

These data may help astronomers tackle a major mystery—why many exo-planets orbit their stars so closely. They may also shed light on the nature of our own solar system, and whether its structure may be more unusual than previously thought. This question has major implications for understanding how life evolved on Earth, and whether it may exist elsewhere in the universe.

MOST's findings are helping scientists better understand the Earth, the sun, and our solar system in the context of other stars and planets.

In 2005, Canada participated, with three other countries, in launching a balloon-borne telescope that traveled between Sweden and Northern Canada for five days. The BLAST (Balloon-borne Large Aperture Sub-millimetre Telescope) project was designed to study starburst galaxies as part of the ongoing effort of astronomers to understand the formation and evolution of the stars, galaxies, and other important constituents of the universe.

A group of Canadian scientists, led by Barth Netterfield of the University of Toronto, are members of the research team. Canada is also supplying important components for the mission, including the pointing control system and the gondola that carries the telescope. In addition to doing astronomical observations, a second flight, planned for 2007, will also be used as a test bed for instruments that Canada is building for the European Space Agency's Herschel space telescope.

An artist's rendition of the Mars Science Laboratory rover.

Canada is also contributing to the next generation of large orbiting telescopes. It will provide two important components for NASA's James Webb Space Telescope (JWST), scheduled for launch in 2013.

The successor to the Hubble Space Telescope, JWST will observe a wide range of astronomical objects ranging all the way from our own solar system to distant galaxies. Its science objectives include increasing fundamental knowledge about the origins and early evolution of galaxies, stars and planets. A Canadian science team, headed by John Hutchings of the Herzberg Institute of Astrophysics, will participate in the project.

In addition, Canada will provide the fine guidance sensor (FGS) for the satellite, which will enable precision pointing of the telescope. As part of the FGS, Canada will also supply a very precise tuneable filter and filter wheel, which will, in effect, be an additional scientific instrument.

Canada contributed a device similar to the FGS to the FUSE (Far Ultraviolet Spectroscopic Explorer) Telescope, an international project that also gathers information about the origin and evolution of the universe and its constituents.

Planetary Exploration

In the field of planetary exploration, all eyes are on Mars. Long a subject of fascination, it is now being regularly visited by orbiting spacecraft and robotic landers that are uncovering new secrets about the planet's current conditions and past history, and preparing the way for future human exploration.

Canada has significant expertise in several key scientific and technological fields relevant to Mars exploration, such as atmospheric research, robotics, and lidar, which can be used for both atmospheric observations and navigational control of landers.

A Canadian-designed meteorological station (MET), which includes the first lidar destined for the Martian surface, is currently being prepared for launch in the summer of 2007 aboard the U.S.-led Phoenix Mars lander. A team of scientists from Canadian universities and government agencies, led by Diane Michelangeli of York University, are participants in this mission.

The vehicle is scheduled to touch down in an ice-rich region near the Arctic Circle of Mars a year later, the first to land in such a northerly location. Its primary goal is to search for water. At present, water on Mars exists only as a solid or a gas (ice or water vapour); there is no evidence of liquid water on the surface, although there is evidence that it once existed. The question of water on Mars has always attracted special scientific attention because of its importance to the existence of life.

Phoenix will collect subsurface soil and ice samples and deliver them to on-board instruments for analysis. The MET station will play a key role in documenting weather and climatic conditions at the lander site. It 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.

The station has three temperature sensors and a pressure sensor that will take continuous temperature and atmospheric pressure measurements. It will also measure humidity and calculate wind speeds.

The lidar will be used to detect dust and ice clouds in the lower atmosphere. Clouds, which circulate water and water vapour, are a key element in the water cycle of a planet. Atmospheric dust is also important to understanding weather and climate; it influences the flow of solar energy within the atmosphere and plays a role in cloud formation.

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

During 2004 and 2005, the Canadian scientific team did studies and conducted tests on instruments and components to prepare for the research program when Phoenix will be on Mars. They also conducted tests of ice sublimation—the process whereby ice changes from a solid to a vapour—that resulted in a redesign of the robotic digging instrument to speed up the collection of samples of subsurface ice.

Another Canadian instrument, an Alpha Particle X-Ray Spectrometer (APXS), was selected for NASA's Mars Science Laboratory (MSL), a two-year robotic Mars mission scheduled for launch in 2009 and landing in 2010. The primary objective of MSL is to evaluate whether the Martian environment is or ever was capable of supporting microbial life.

APXS, which is sponsored by CSA and being built in Canada, will be used to measure the chemical composition of Martian rocks and soil as well as processed samples collected from the surface. This type of information can shed light on whether life forms ever existed on Mars. University of Guelph physicist Ralf Gellert is the principal investigator on this experiment.

In order to enhance Canada's capabilities in planetary exploration, the CSA is developing Earth-based analogue sites that can be used to prepare researchers for living and working on other planets. They can be used to study geological and biological processes that may be relevant off-planet, and test new technologies for planetary exploration and research. Such sites also offer researchers the ability to conduct simulated missions to gain insight into the social and safety issues that may affect off-planet expeditions.

It is hoped these studies will also result in new technologies and infrastructure that could benefit remote communities in Canada and other countries.

Three sites have already been chosen for the Canadian Analogue Research Network (CARN), two on islands in the Arctic and one in British Columbia. An Exploration Systems Operations Centre (ExSOC) has been established at Simon Fraser University to support and manage the engineering requirements for the research activities at these sites. CSA also funds proposals from scientists to conduct research projects as well as instrument testing and validation at the CARN sites and other potential analogue sites in Canada, both on land and under the ocean.

The goal of this program is to support and increase Canadian skills in space science research, as well as strengthen co-operation between CSA, Canadian universities, and international partners. The unique Canadian geography is a resource that can be used to benefit the Canadian scientific community.

Solar-Terrestrial Science

Canada's high-latitude location makes it the perfect place to study the aurora borealis and the interaction between the Earth's upper atmosphere and electrically charged particles from the sun in the polar region. Canada has a decades-long history of doing atmospheric research in this field, and this tradition continues with two new projects—ePOP and THEMIS.

ePOP (Enhanced Polar Outflow Probe) consists of eight instruments that will be launched into a polar orbit in 2008 aboard a Canadian-built small satellite called CASSIOPE. Its purpose is to study charged particles flowing upwards from the ionosphere, a region of the Earth's upper atmosphere, into the magnetosphere, the region where the Earth's magnetic field is the dominant influence on charged particles. This "polar outflow" has not yet been extensively studied.

The goal is to increase scientific understanding of this region and, in particular, investigate what influence the outflowing particles have on large solar storms in the magnetosphere caused by outbursts of charged particles from the sun. This "space weather" can cause havoc on Earth by disrupting communications systems, knocking out satellites, and affecting power networks.

The ePOP science team, led by Andrew Yau of the University of Calgary, will be taking simultaneous measurements from the satellite and a string of ground-based observatories located across Canada, known as the Canadian GeoSpace Monitoring Network.

Ground-based observations are also the key element of a Canadian contribution to a NASA-led project called THEMIS, designed to study auroral substorms caused by energy released from the solar wind in the Earth's magnetosphere. (THEMIS stands for "time history of events and macroscale interactions during substorms.")

In 2006, NASA will launch five small satellites to study these storms, and their data will be co-ordinated with ground-based observations. NASA chose to base the mission-critical ground component in Canada because of Canadian expertise in upper atmospheric research and its ideal location under the auroras. Twenty ground observatories will be involved—16 in Canada and four in Alaska.

This network of stations will take images of the auroras every three seconds for two years, generating an enormous flood of data. The Canadian science team, led by Eric Donovan of the University of Calgary, has developed the GAIA (Global Auroral Imaging Array) computer program to manage the data. This program may prove to be useful for handling other large databases.

The THEMIS project has also made other technological advances, including improvements in the sensors used to record digital images of the aurora. Two new high-tech companies have been created to commercialize these technologies.

Physical Sciences

One goal of the CSA's physical sciences program is to exploit microgravity to increase fundamental understanding about the nature and behaviour of materials that is unobtainable on Earth because of the dominant influence of gravity.

One such study, known as SCCO (Soret Coefficient in Crude Oil), was conducted by Dr. Ziad Saghir, an engineering professor at Ryerson University, in Toronto. It focused on how components of oil move and separate in response to temperature gradients between different locations—a process known as thermal diffusion. This is impossible to measure on Earth because it is masked by the influence of gravity.

The goal of this study is to improve computer models used by oil companies to evaluate new oil deposits before they start drilling. Dr. Saghir believes the results will prove useful in two locations in Canada—the oil reservoir off the coast of Newfoundland and the Alberta tar sands.

Tests are currently being done on samples of hydrocarbon fluids that were flown aboard a recoverable Russian Foton satellite in 2005. Further experiments are planned for the International Space Station after 2007.

Another study with liquids done on the Space Shuttle has led to the development of a unique evaporator that can be used in many industrial processes from desalinating water to manufacturing medications, powered milk, and liquor. University of Toronto engineering professor Charles Ward based his new evaporator on a previously unknown property of water that he discovered during ground-based tests that resulted directly from the findings of the Shuttle experiment.

Exploiting this property allowed him to develop an evaporator that is much more energy-efficient than existing ones. This system is currently being tested to produce animal feed from corn after it has been used for making whisky.

Life Sciences

CSA's space life sciences program focuses on increasing basic knowledge about the effects of the space environment—notably microgravity and high radiation levels—on the biological processes of living organisms. In Canada, there has been a special emphasis on two areas: the effects of microgravity on muscles and bones as well as the cardiovascular and neurological systems; and the biological effects of space radiation. Both are important to the health and safety of humans on long-duration space missions.

This research is important for developing pre-adaptation protocols and effective countermeasures to protect against the negative physiological effects of living for long periods in space, and improve post-flight rehabilitation programs for astronauts.

In the past, CSA supported the OSTEO research project, which investigated fundamental processes related to the natural dynamic process of creating and destroying bone cells in the human body, and how these processes change in microgravity.

The e-OSTEO program currently underway continues that research. Three experiments are scheduled for launch on a 12-day mission aboard a Russian unmanned spacecraft in 2007. The bone cells will be contained in a Canadian-built automated mini-lab.

Andrew Karaplis of McGill University will examine on the effect of microgravity on a hormone that influences the cells that create bone. Rene Harrison of the University of Toronto will study how microgravity affects certain critical aspects of the development and function of cells that create and destroy bone. Finally, Reginald Gorczynski of the University of Toronto will focus on the role of certain biological molecules in controlling bone formation and bone loss in microgravity.

These experiments may shed light on the processes that cause osteoporosis (bone loss) among the elderly on Earth and help in developing new drugs to combat the condition, both on Earth and in space.

In 2005, two Canadian research teams participated in the first long-term bedrest study involving women. The WISE (Women International Space Simulation for Exploration) project was conducted in France and involved scientists from several countries. Twenty-four healthy volunteer subjects spend 60 days in bed with their heads tilted slightly below their feet—a condition that affects muscles, bones, and the cardiovascular systems in a way that is remarkably similar to the effects of microgravity.

The findings of one of the Canadian teams, led by Guy Trudel of the University of Ottawa, might help to explain why astronauts suffer from anemia, a decrease in red-blood-cell production that causes fatigue and could have serious consequences on a long duration mission.

The second group, led by Richard Hughson of the University of Waterloo, examined the effect of immobility in causing orthostatic hypertension—light-headedness or fainting that may occur when standing up after a long period of lying down or being in microgravity. This phenomenon could potentially affect the performance and safety of astronauts returning from space or landing on another planet.

The researchers found that subjects who did exercises during bedrest recovered their ability to maintain their blood pressure while standing afterwards more quickly than non-exercising subjects did. This and other results confirmed the benefits of doing exercises on long-duration missions, but it remains to be determined how much exercise will be needed.

CSA has also sponsored several projects to examine the biological effects of space radiation. In 2004, it funded the participation of University of British Columbia geneticist Ann Rose in the ICE-First mission, an international pilot project to study the genetic effects of space radiation in C. elegans, a small worm widely used in biological research.

The worms, which were flown aboard the International Space Station, grew and developed normally in microgravity, though some of the organisms had a movement defect after returning to Earth. Rose believes that C. elegans, which possess many genes with human counterparts, may prove useful as biological radiation monitors to assess the genetic damage humans face from higher radiation levels during long duration spaceflight.

Atmospheric Sciences

Over many years, Canada has built up a particular expertise in developing and using space-based instruments to study the Earth's atmosphere—in particular, the ozone layer over the Arctic.

One of its big successes in recent years is the MOPITT (Measurements of Pollution in the Troposphere) instrument, one of five launched aboard NASA's Terra satellite in 1999. MOPITT tracks atmospheric concentrations and global movements of carbon monoxide, a gas produced by the incomplete combustion of fossil fuels and burning biomass, such as forest fires. Carbon monoxide can also be used as a proxy tracer for the movement of other pollutants that cannot be measured directly.

MOPITT is the first space instrument to document the movement of pollutants over long distances across continents and oceans, and this has enabled scientists to create the first global pollution maps. The Canadian science team is led by James Drummond of the University of Toronto.

Another Canadian project, SCISAT, focuses on the state of the ozone layer in the stratosphere, particularly over the Arctic. Stratospheric ozone protects life on Earth from the sun's biologically damaging ultraviolet radiation.

SCISAT, a Canadian-built satellite launched in 2003, carries the Atmospheric Chemistry Experiment (ACE), which measures with great accuracy more than 30 different chemical molecules that affect the distribution of ozone. SCISAT data are also being used in studies related to air quality and pollution. Peter Bernath of the University of Waterloo leads the team of scientists in charge of this mission.

CSA is sponsoring the SWIFT (Stratospheric Wind Interferometer for Transport) instrument that will fly on a Canadian satellite, Chinook, scheduled for launch in 2010. SWIFT will provide the first global view of stratospheric winds and will be able to correlate this information directly with changes in ozone concentrations. Ian McDade of York University heads the SWIFT scientific team.

In addition to satellite-based instruments, CSA sponsors the MANTRA (Middle Atmosphere Nitrogen Trend Assessment) program, which uses balloons to carry instruments aloft to measure important chemical constituents of the atmosphere such as nitrogen and ozone, as well as small particles that also have climatic effects. These studies will help to assess the effectiveness of environmental measures to protect the ozone layer that were implemented after the Montreal Protocol in 1987. Kimberly Strong of the University of Toronto is the science team leader.

In early 2006, NASA's CloudSat satellite was launched to begin the first comprehensive three-dimensional study of clouds. The Canadian science team participating in the project is led by David Hudak and Howard Barker of Environment Canada. Canada also built key components for the radar used for profiling clouds and the electronic receiver.

The project is intended to advance fundamental knowledge of the structure and nature of clouds and how much water and ice they contain. Clouds are known to play a significant role in both weather and climate, but there are still many uncertainties about the exact nature of their role. Scientists hope that CloudSat's findings will help reduce those uncertainties.

These highlights demonstrate that CSA's Space Science Program embraces a broad range of scientific disciplines. It also fulfills the CSA's mandate to foster the development of Canada's scientific and technological expertise, national and international partnerships, and the competitiveness of Canada's space industries, and use the space environment to produce social and economic benefits on Earth.

Review by Scientific Discipline

The Canadian Space Agency's Space Science Program is responsible for managing the scientific missions funded by the agency. Most of these activities take place within two of the four major thrusts of the Canadian government's Space Strategy: Earth Observation and Space Science and Exploration.

The Earth Observation (EO) thrust focuses on all Earth systems—the atmosphere, the oceans, the biosphere, and land surfaces. The Space Science Program makes a significant contribution to the EO thrust, with several initiatives in atmospheric sciences.

The Space Science and Exploration (SSE) thrust includes scientific research in five disciplines: astronomy, planetary exploration, solar-terrestrial science, physical sciences, and life sciences.

Partnerships with the academic community, industry, other government departments and agencies, and international research organizations are a key element of the Space Science Program. The direction of the program is based on the recommendations of scientific advisory committees, which identify issues of national and global interest and importance, and on input from community workshops. Projects are competitively selected and peer-reviewed to ensure that they meet international standards of excellence.

Earth Observation – Atmospheric Sciences

The objective of the 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. Space science activities contribute significantly to EO projects in atmospheric research.

Science themes: chemical and physical processes that control the distribution of stratospheric ozone and other environmentally sensitive species; the role atmospheric winds and waves play in the global climate; and, key factors affecting global climate and how can they be quantified.

Current and Future Missions: Canada has developed a particular expertise in developing and using space-based instruments to study the Earth's atmosphere and the ozone layer, particularly over the Arctic. A prime example is the highly successful WINDII (Wind Imaging Interferometer) program, which spanned 12 years and documented the existence of winds that, every day, wash around the upper atmosphere like tidal waves. These waves play an important role in the circulation of the upper atmosphere.

Understanding the state of the ozone layer is also the mission of a Canadian-built instrument known as OSIRIS, flown aboard Swedish satellite Odin. It collects data on ozone depletion at high latitudes, allowing scientists to construct height profiles of the ozone layer at different locations. These data are also useful in creating maps of other molecules that affect the ozone layer.

Another interesting CSA project is the Canadian-built MOPITT instrument (Measurements of Pollution in the Troposphere) that was launched on NASA's Terra satellite. MOPITT tracks atmospheric concentrations and global movements of carbon monoxide, allowing scientists to create the first global maps that show how pollution moves around the globe. These data are also helping to improve computer models of the atmosphere.

Canada is also participating in NASA's CloudSat program, launched in 2006 to conduct the first comprehensive three-dimensional study of clouds. CSA provided key components for the satellite and Canadian researchers are part of the science team.

Clouds play a significant role in weather, and CloudSat's goal is to increase fundamental knowledge about their structure and nature. The results of this research should improve the ability to understand and predict weather and climate phenomena.

Meanwhile, SCISAT, a Canadian-built satellite launched in 2003, carries an instrument that provides highly accurate measurements of more than 30 chemicals that influence the distribution of stratospheric ozone, particularly over the Arctic. Data from the Atmospheric Chemistry Experiment (ACE) are also being used in studies related to air pollution. The results may make an important contribution to international environmental policy-making.

Balloon-based instruments are an important part of the atmospheric science program. CSA sponsors MANTRA (Middle atmosphere nitrogen trend assessment) that uses balloons to carry instruments aloft to measure important chemical constituents of the atmosphere such as nitrogen and ozone, as well as small particles that also have climatic effects.

In 2010, Canada plans to launch a satellite called Chinook that will carry SWIFT (Stratospheric Wind Interferometer for Transport studies), an instrument similar to WINDII. It will provide the first global view of stratospheric winds and changes in ozone concentrations.

Using space-based technologies to collect data is only the first step in the "value chain" required to exploit the full benefits of earth observation information. The data must be transmitted to Earth, processed, archived and disseminated to those who can analyze and make productive use of it. To this end, CSA invests not only in the space-based technologies that collect data but also in the ground-based infrastructure needed to operate and control satellites and receive, process and archive data.

Atmospheric Science Missions and Major Projects

Launched/Operating Missions

MOPITT (Measurements of Pollution in the Troposphere) Instrument on NASA's Terra Satellite
One of five instruments on-board NASA's Terra satellite, part of NASA's Earth Observing System. MOPITT measures the global distribution of carbon monoxide in the troposphere, producing high-resolution three-dimensional maps that are updated every four days.

Participating Countries	U.S.A., Canada, Japan
Launch Year	1999
Canadian Involvement	MOPITT
Canadian Principal Investigator	Dr. James Drummond, University of Toronto
Canadian University and Government Partners	University of Toronto Canadian Space Agency Natural Science and Engineering Research Council
Canadian Industry Partner	Com Dev International, Cambridge, ON
Web site: www.atmosp.physics.utoronto.ca/MOPITT/home.html	

Atmospheric Science Missions and Major Projects	
OSIRIS (Optical Spectrograph and Infrared Imager System) Instrument on Sweden's ODIN OSIRIS collects data and produces daily maps of ozone concentrations every 1.5 km of altitude in the stratosphere and mesosphere, providing more detailed data than previously possible.	
Participating Countries	Sweden, Canada, France, Finland
Launch Year	2001
Canadian Involvement	OSIRIS
Canadian Principal Investigator	Dr. Edward Llewellyn, Institute of Space and Atmospheric Sciences – University of Saskatchewan
Canadian University and Government Partners	University of Saskatchewan Canadian Space Agency Natural Science and Engineering Research Council
Canadian Industry Partner	Routes AstroEngineering, Kanata, ON
Web site: osirus.usask.ca	
ACE-FTS (Atmospheric Chemistry Experiment – Fourier Transform Spectrometer) and MAESTRO (Measurements of Aerosol Extinction in the Stratosphere and Troposphere Retrieved by Occultation) Instrument on SCISAT This fully-Canadian mission is collecting accurate information on the concentrations of an extended suite of trace gases in the stratosphere, thereby contributing to the study of the chemical processes occurring in the ozone layer.	
Participating Country	Canada
Launch Year	2003
Canadian Involvement	Fully-Canadian mission carrying the ACE-FTS and the MAESTRO instrument

Atmospheric Science Missions and Major Projects	
Canadian Principal Investigators	Dr. Peter Bernath (ACE-FTS), University of Waterloo Dr. Tom McElroy (MAESTRO), Environment Canada
Canadian University and Government Partners	University of Waterloo Environment Canada Canadian Space Agency
Canadian Industry Partners	ABB Bomem, Quebec City, QC (ACE-FTS) EMS Technologies, Ottawa, ON (MAESTRO) Bristol Aerospace, Winnipeg, MB (Satellite)
Web site: www.ace.uwaterloo.ca	
MANTRA (Middle Atmosphere Nitrogen Trend Assessment) A series of high-altitude balloon flights to investigate changes in the concentrations of northern hemisphere mid-latitude stratospheric ozone, and of nitrogen and chlorine compounds that play a role in ozone chemistry.	
Participating Country	Canada
Launch Year	2004
Canadian Involvement	—
Canadian Principal Investigator	Dr. Kimberly Strong, University of Toronto
Canadian University and Government Partners	University of Toronto University of Waterloo York University Environment Canada Canadian Space Agency
Canadian Industry Partner	Scientific Instrumentation Ltd., Saskatoon, SK
Web site: www.atmosp.physics.utoronto.ca/MANTRA	

Atmospheric Science Missions and Major Projects

EIK (Extended Interaction Klystrons) and RFES (Radio Frequency Electronic Subsystem) on CloudSat A NASA-led mission that will study how clouds and aerosols form, evolve and interact. A cloud profiling radar will derive vertical profiles of the clouds' liquid and ice water contents. Part of NASA's A-Train constellation of satellites that will provide insights into the global distribution and evolution of clouds to improve weather forecasting and climate prediction.	
Participating Country	U.S.A., Canada
Launch Year	2006
Canadian Involvement	Canada provided key elements of the cloud profiling radar: EIK, which will generate radar waves that will probe the vertical structure of clouds, and the RFES receiver, a central component of the Subsystem
Canadian Principal Investigators	David Hudak, Environment Canada Howard Barker, Environment Canada
Canadian Universities and Other Government Departments	McGill University Université du Québec à Montréal Environment Canada Canadian Space Agency
Canadian Industry Partners	CPI, Georgetown, ON Com Dev, Cambridge, ON
Web site: www.space.gc.ca/asc/eng/satellites/cloudsat.asp	

Atmospheric Science Missions and Major Projects

Missions in Development	
SWIFT (Stratospheric Wind Interferometer for Transport Studies) on Chinook Chinook is a Canadian mission that will measure stratospheric winds, ozone and temperatures. The SWIFT instrument will provide the first global view of stratospheric winds and the role of transport in changes in ozone concentrations.	
Participating Country	Canada
Launch Year	2010
Canadian Involvement	Canadian-led mission and Canadian SWIFT instrument
Canadian Principal Investigator	Dr. Ian McDade, York University
Canadian Universities and Government Departments	York University Canadian Space Agency
Canadian Industry Partner	EMS Technologies, Ottawa, ON
Web site: www.swift.yorku.ca	

Space Science and Exploration

At the heart of the CSA's space science and exploration 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.

One of CSA's chief goals is to support the continuing development of Canada's space industry as a major supplier of space-borne instruments and systems for national and large international space science projects. Canada is also pioneering the development of low-cost microsatellites for space-based observing programs.

The CSA has established a series of short- (five years), medium- (10 years) and long-term (20 years) goals for its SSE thrust in order to capitalize on previous successes and develop the critical mass of scientific and engineering expertise needed to play a leading role in future missions beyond Earth's orbit.

These "roadmaps" to the future are organized into two groups, one for astronomy and the solar system, and the other for the physical and life sciences. Between them, the two groups cover research projects in five scientific disciplines: astronomy, planetary exploration, solar-terrestrial science, physical sciences, and life sciences.

Astronomy and the Solar System

Astronomy

Access to space—specifically raising telescopes above the obscuring effects of Earth's atmosphere—has revolutionized astronomy. Canada has participated in this revolution by launching its own small astronomical satellite and participating in large international projects, both scientifically and technologically.

The academic community and Canada's space industries are key partners in these endeavours. CSA works closely with the Canadian Astronomical Society (CASCA) and the National Research

Council's Hertzberg Institute. Canadian astronomers lead the science teams on Canadian projects and serve as members of those running international projects. In addition, Canadian companies build key components and systems for both national and international projects.

Science Themes: developing an understanding of the early universe; measuring the Deuterium abundance in the universe; measuring the key cosmological parameters; identifying the chemical formation of molecular clouds; identifying planets capable of supporting life around other stars; and, determining the nature of dark energy and dark matter, and learning how it shapes galaxies.

Current and Future Missions: One of the most successful current mission is MOST (Microvariability and Oscillations of Stars), which was launched in 2003. Designed to detect tiny variations in the brightness of stars, it has already generated exciting and often surprising findings concerning the nature and evolution of stars and exo-planets circling other stars.

Canada is also participating in the NASA-led international mission FUSE (Far Ultraviolet Spectroscopic Explorer), which is gathering information about the origin and evolution of the universe and its constituents. Canada provided the fine guidance sensor (FGS) for the satellite, which enables precision pointing of the telescope.

Canadian scientists are involved in BLAST (Balloon-borne Large Aperture Sub-millimetre Telescope), an international project focused on studying starburst galaxies. Canada contributed several key components for the mission. The balloon, launched on its first flight in 2005, traveled between Sweden and Northern Canada for five days. A second flight is planned for 2007 and it will be used as a test bed for Canadian instruments being built for the European Space Agency's (ESA) Herschel space telescope.

With CSA support, Canada's astronomical research community and space industries will participate in several missions using advanced space telescopes scheduled for launch over the next five to 10 years. These include NASA's James Webb Space Telescope (JWST), the ESA's Planck and Herschel satellites, and the Ultraviolet Imaging Telescope (UVIT) aboard the AstroSat orbiting observatory, a joint project with the Indian Space Research Organization.

Canada is contributing either instruments or software to each of these projects, fulfilling one of CSA's goals to establish a niche in developing astronomical instruments and sensors and to make Canadian industry a preferred supplier of space-borne instruments and subsystems for astronomy satellites.

CSA also provides support for the Canadian Astronomy Data Centre (CADC), which archives data acquired during astronomical missions and makes them available to researchers from around the world, even after the missions are over. CADC is also developing new tools and processing techniques to increase the scientific value of the data and is collaboration with international partners like NASA and ESA in establishing a virtual observatory that will extend the use of these tools to other collections of astronomical data.

CADC is developing innovative methods for managing and storing large amounts of data that can also be applied to large projects in other scientific fields, such as ocean science research.

Astronomy Missions	
Missions Launched/Operating	
FES (Fine Error Sensors) on FUSE (Far Ultraviolet Spectroscopic Explorer) NASA-led astrophysics mission to explore the universe using the technique of spectroscopy at the far ultra-violet wavelengths. To better understand the origins of the universe, researchers are studying deuterium, a rare element produced immediately after the Big Bang and found in the gas clouds of the Milky Way.	
Participating Countries	U.S.A., Canada, France
Launch Year	1999
Canadian Involvement	The FES instrument that provides accurate images of pointer stars and guides the satellite
Canadian Principal Investigator	Dr. John Hutchings, Hertzberg Institute of Astrophysics
Canadian University and Government Partners	Canadian Space Agency Hertzberg Institute of Astrophysics
Canadian Industry Partner	COM DEV, Cambridge, ON
Web site: fuse.pha.jhu.edu	
MOST (Microvariability and Oscillation of Stars) Canada's first space telescope and microsatellite, MOST, is a fully-Canadian mission designed to probe stars and extra-solar planets by measuring tiny light variations undetectable from Earth.	
Participating Country	Canada
Launch Year	2003
Canadian Involvement	MOST is a fully-Canadian mission
Canadian Principal Investigator	Dr. Jaymie Matthews, University of British Columbia
Canadian University and Government Partners	University of British Columbia University of Toronto Institute of Aerospace Studies Canadian Space Agency CRESTech
Canadian Industry Partners	Dynacon Inc., Mississauga, ON Routes Astro Engineering, Kanata, ON
Web site: www.astro.ubc.ca/MOST	

Astronomy Missions	
BLAST (Balloon-borne Large Aperture Sub-millimetre Telescope) A six-day cosmology mission to identify distant star-forming galaxies, measure cold pre-stellar sources associated with the earliest stages of star and planet formation, and make high-resolution maps of diffuse galactic emission.	
Participating Countries	Canada, U.S.A., United Kingdom, Mexico
Launch Dates	June 2005, December 2006 (second mission)
Canadian Involvement	Design and build of the gondola, the pointing control system, the data acquisition system, the flight and ground stations software, the power system, and overall system integration
Canadian Principal Investigator	Dr. Barth Netterfield, University of Toronto
Canadian University and Government Partners	University of British Columbia University of Toronto Canadian Space Agency Natural Sciences and Engineering Research Council Ontario Innovation Trust
Canadian Industry Partner	AMEC Dynamic Structures, Port Coquitlam, BC
Web sites: cmbr.physics.ubc.ca/blast – chile1.physics.upenn.edu/blastpublic	
Missions in Development	
SPIRE (Spectral and Photometric Imaging Receiver) and HIFI (Heterodyne Instrument for the Far Infrared) on Herschel ESA's Herschel mission, part of its Cosmic Vision Programme, is a multi-user major observatory dedicated to the far Infrared and sub-millimetre range of the electromagnetic spectrum. Key science objectives emphasize the formation of stars and galaxies, and the interrelation between the two.	
Participating Countries and Region	Europe, Canada, USA
Launch Year	2007

Astronomy Missions	
Canadian Involvement	Canada is contributing to two of the three instruments on Herschel: SPIRE – Canada's providing test facility, data analysis and software support, instrument test team and control centre HIFI – Canada's providing the Local Oscillator Unit
Canadian Principal Investigators	Dr. David Naylor (SPIRE), University of Lethbridge Dr. Michael Fich (HIFI), University of Waterloo
Canadian University and Government Partners	University of Lethbridge University of Waterloo Canadian Space Agency
Canadian Industry Partner	COM DEV, Cambridge, ON
Web sites: astro.uwaterloo.ca/HIFI – spire.uleth.ca – www.esa.int/esaSC/120390_index_0_m.html	
HFI (High Frequency Instrument) and LFI (Low Frequency Instrument) on Planck Part of ESA's Cosmic Vision Programme, Planck is designed to image the anisotropies of the cosmic background radiation field over the whole sky. It will be a source of information for several cosmological and astrophysical issues.	
Participating Countries and Region	Europe, Canada, U.S.A.
Launch Year	2007
Canadian Involvement	Quick-look analysis software and real-time analysis software for HFI and LFI
Canadian Principal Investigators	Dr. Richard Bond (HFI), University of Toronto Dr. D. Scott (LFI), University of British Columbia
Canadian University and Government Partners	University of British Columbia University of Toronto Canadian Space Agency
Canadian Industry Partner(s)	—
Web site: www.esa.int/science/planck	

Astronomy Missions

UVIT (Ultraviolet Imaging Telescope) on AstroSat UVIT will be carried on-board India's AstroSat orbiting observatory. The mission is aimed at providing multi-wavelength observations and studies of a variety of galactic and extra-galactic sources from the far ultraviolet to the deep X-ray.	
Participating Countries	India, Canada
Launch Year	2008
Canadian Involvement	Detectors and electronics for the UVIT instrument
Canadian Principal Investigator	Dr. John Hutchings, Herzberg Institute of Astrophysics
Canadian University and Government Partners	Canadian Space Agency Hertzberg Institute of Astrophysics University of Calgary
Canadian Industry Partner	Routes Astro Engineering, Kanata, ON
Web site: www.rri.res.in/astrosat/	
FGS (Fine Guidance Sensors) and TFI (Tunable Filter Instrument) on James Webb Space Telescope (JWST) A successor to the Hubble Space Telescope, the NASA-led JWST is a general-purpose observatory that will carry a suite of astronomical instruments capable of addressing a very broad spectrum of outstanding problems in galactic and extra-galactic astronomy.	
Participating Countries and Region	U.S.A., Canada, Europe
Launch Year	2013
Canadian Involvement	FGS and TFI
Canadian Principal Investigators	Dr. John Hutchings (FGS), Herzberg Institute of Astrophysics Dr. René Doyon (TFI), Université de Montréal
Canadian University and Government Partners	Université de Montréal Canadian Space Agency Herzberg Institute of Astrophysics
Canadian Industry Partner	COM DEV, Ottawa and Cambridge, ON
Web site: www.jwst.nasa.gov	

Planetary Exploration

Canada has a strong interest in participating with international partners in missions to explore other bodies in the solar system, such as Mars, the moon and asteroids. A planetary-exploration program was approved as part of Canada's Space plan in 1999, which includes ground research, network building, and collaborative flight and instrument development.

This program is science-driven, with research projects competitively selected in areas of scientific importance recommended by the CSA's Space Exploration Advisory Committee.

Canada has considerable expertise in key niche technological fields, including space robotics, remote sensing, and advanced instruments such as lidar, SAR and ground penetrating radar. These technologies can be used to probe the atmospheres, surfaces, and subsurface regions of other planets; lidar can also be used to navigate a spacecraft to a safe landing.

CSA's goal is to leverage this technological expertise to acquire access to planetary missions for Canadian scientists. An Announcement of Opportunity, released in 2004, was intended to foster development of instrument concepts that will increase the competitiveness of Canada's scientific community.

Science themes: planetary geology; planetary atmospheres, magnetospheres and ionospheres; solar system small bodies; exobiology and astrobiology; life support systems for human space flight; and, terrestrial analogues of space environments.

Current and future missions: CSA aims to negotiate significant Canadian scientific and technological participation in major international unmanned Mars exploration missions, and take the lead role in at least one robotic mission to Mars within the next decade.

Canada is contributing the meteorological station (MET) to NASA's Phoenix Mars lander mission, scheduled for launch in 2007. The package includes a lidar instrument that will be used to study the lower part of the Martian atmosphere at the northerly landing site. It will be Canada's first landed instrument and the first lidar on Mars.

In addition, Canada will provide an Alpha Particle X-Ray Spectrometer (APXS) for NASA's Mars Science Laboratory (MLS), scheduled for launch in 2009. This two-year robotic mission is aimed at discovering whether Mars is—or ever was—capable of supporting microbial life. APXS will be used to measure the chemical composition of Martian rocks and soil, as well as processed samples collected from the surface. This type of information can shed light on whether life forms ever existed on Mars.

CSA supports the use of Canadian sites to simulate the Martian environment. The Canadian Analogue Research Network (CARN) was set up to develop and manage planetary analogue sites where scientists can gain insight into the conditions and challenges of exploring and conducting research on the moon, Mars and other planets. Three sites—two in the Arctic and one in British Columbia—have already been selected. CSA funds research projects and instrument testing at these and other analogue sites.

Canada is also participating in Earth-based studies of craters, meteorites of Martian origin, and the survival of life forms in harsh environments that contribute to greater understanding of the potential for life on other planets.

Asteroids are also on the agenda. Canada is developing NEOSSat, a microsatellite that will be used to identify and study near-Earth objects such as asteroids that cross Earth's path or those that could potentially hit it. It will identify asteroids that are candidates for robotic missions to collect and return samples. NEOSSat will be the first space-based telescope dedicated to searching for asteroids.

Finally, Canada is contributing to future human exploration missions through research in life sciences, space medicine, and biological life-support systems. For example, it has pioneered research on the use of plants as a sustainable source of food, water and oxygen on long-duration space flights.

Space Exploration Missions

Missions in Development

MET on PHOENIX The NASA-led PHOENIX mission is a fixed Lander that will analyze the soil on Mars' high latitudes, study climate change, the geological past, and traces left by water. It is the first NASA Scout mission to Mars. The Canadian meteorological station, MET, will record daily weather on the Martian Northern plains.	
Participating Countries	U.S.A., Canada
Launch Year	2007
Canadian Involvement	Canada is contributing the MET package to NASA: a pressure sensor, three temperature sensors located on a vertical mast, and a lidar
Canadian Principal Investigator	Diane Michelangeli, York University
Canadian University and Government Partners	York University Dalhousie University University of Alberta Canadian Geological Survey
Canadian Industry Partners	MDA, Brampton, ON, with support from Optech Inc., Toronto, ON
Web site: www.yorku.ca/dvm/Phoenix	
APXS (Alpha Particle X-ray Spectrometer) Instrument on Mars Science Laboratory (MSL) Part of NASA's Mars Exploration program, MSL is a NASA-led long-range, long-duration rover that will determine whether Martian soil offers a hospitable environment for any form of life. The APXS instrument will examine the chemical composition of the soil.	
Participating Countries	U.S.A., Canada
Launch Year	2009
Canadian Involvement	APXS instrument
Canadian Principal Investigator	Dr. Ralf Gellert, University of Guelph

Space Exploration Missions	
Canadian University and Government Partners	University of Guelph Canadian Space Agency
Canadian Industry Partner	MDA, Brampton, ON
Web site(s): —	
NEOSSat (Near-Earth Object Surveillance Satellite) A fully-Canadian microsatellite mission to discover and determine the orbits of near-Earth objects (NEOs) in a manner complementary to current and future planned ground-based NEO search and follow-up telescopes. NEOSSat will be the first dedicated asteroid search telescope to be launched and operated in Earth orbit.	
Participating Countries	Canada
Launch Year	2009 (TBD)
Canadian Involvement	NEOSSat is a fully-Canadian mission
Canadian Principal Investigator	Dr. Alan Hildebrand, University of Calgary
Canadian University and Government Partners	Canadian Space Agency Defence Research and Development Canada University of Calgary, University of Toronto Institute of Aerospace Studies Space Flight Laboratory
Canadian Industry Partners	Dynacon, Toronto, Ontario (Phase A) Routes, Ottawa, Ontario (Phase A)
Web site: www.routes.com/Programs-Systems%20Engineering.html	
Major Projects	
CARN (Canadian Analogue Research Network) To examine places on Earth that best produce either past or present Mars conditions with the aim of providing insight to limiting conditions of life, Mars geological settings, and Mars sampling strategies and technologies.	
Participating Country	Canada
Launch Year	2005

Space Exploration Missions	
Canadian Involvement	Provision of Terrestrial Analogues of Space Environments in Canada for the development of science and scientific instrumentation
Canadian Principal Investigator	Annual competitive process
Canadian University and Government Partners	McGill University University of British Columbia Mars Institute Canada Simon Fraser University Canadian Space Agency
Canadian Industry Partner(s)	—
Web site(s): —	

Solar-Terrestrial Science

In the field of solar-terrestrial science, Canada's legacy goes back 167 years when a magnetic field observatory was established in Toronto. It has pioneered space- and ground-based studies of the interaction between Earth's upper atmosphere and electrically charged particles from the sun for decades. Its high-latitude location, with most of the accessible land mass right under the region where these interactions take place, gives it the perfect vantage point for this type of research.

These studies focus on how energy is generated, transported and dissipated in the connected sun-Earth system. The findings have practical applications on Earth, notably in predicting potentially damaging solar storms that can affect communications and power systems as well as satellite navigation. They are also relevant to understanding the nature of other solar and astrophysical systems in the universe.

This research is aimed at achieving three long-term goals: to establish an operational space weather service for Canadians who are vulnerable to solar and magnetic storms; to achieve a fundamental understanding of plasma physics; and, to determine the role of the sun in climate patterns on Earth.

Science themes: how do magnetic fields originate at the sun, and what is the physics of the solar cycle; how do magnetic fields energize the solar corona and power the solar wind; what is the physics of the solar wind-magnetosphere interaction, and how does this lead to space weather; and, what is the connection between plasma physics and atmospheric dynamics.

Current and future missions: Canada has major solar-terrestrial projects underway both on the ground and in space. The Enhanced Polar Outflow Probe (ePOP) is a group of eight instruments that will fly on a Canadian-built small satellite CASSIOPE (Cascade, SmallSat, and Ionospheric Polar Explorer). To be launched in 2008, they will examine charged and neutral particles flowing upwards from the ionosphere into the magnetosphere. One major goal of this research is to determine the role this outflow plays in large solar storms, or "space weather."

Meanwhile, on the ground, a team of scientists from universities and government research organizations have established the Canadian GeoScience Monitoring (CGSM) network—an array of radio, magnetic and optical instruments stretching across Canada that advance knowledge about the solar-terrestrial relationship and its role in space weather.

An extension of the CANOPUS program operating since 1989, CGSM combines seven ground-based projects into a national program, and is the most comprehensive array of its kind in the world. It will play a key role in the International Living With a Star (ILWS) project, collecting information to complement and validate that gathered by a large fleet of international research satellites launched as part of ILWS between 2005 and 2015.

A team of Canadian researchers will also operate a ground-based network as a key component of THEMIS, a NASA-led study of auroral substorms that also includes a network of five satellites. In addition to providing ground-based observations, the Canadian team has developed innovative new software to store and manage the enormous amounts of data the study will generate. Canadian scientists will receive privileged access to these data because of Canada's technological contributions.

Canada is participating in a European study of Earth's geomagnetic field and how it changes over time. It will supply the Electric Field Instrument (EFI) to the ESA-led SWARM mission. This is another example of CSA's effort to make Canadian industry a leading supplier of space-borne systems.

For the future, CSA is developing two concepts: ORBITALS and RAVENS. ORBITALS (Outer Radiation Belt Injection, Transport, Acceleration and Loss Satellite) is a small satellite designed to study the acceleration, global distribution, and variability of energetic ions and electrons in the inner magnetosphere. It is intended as a Canadian contribution to the ILWS program.

RAVENS (Recurrent Auroral Visualization of Extended Northern Storms) are part of a concept study that has been merged with the Chinese Kuafu mission study. Its goal is to launch two polar-orbiting satellites to provide constant observations of the aurora borealis. It would involve the development of a new instrument called the autocomparative auroral imager that would be carried on the Chinese satellites.

Solar-Terrestrial Missions

Missions in Development

ePOP on CASSIOPE
The ePOP probe will include a suite of eight scientific instruments, including plasma imagers, radio wave receivers, magnetometers and cameras. These will collect data about the effects of solar storms and, more specifically, their harmful impact on radio communications, satellite navigation, and other space-based technologies.

Participating Countries	Canada, U.S.A., Japan
Launch Year	2008
Canadian Involvement	Canada has been invited to provide all three SWARM satellites with a CEFI (Canadian Electric Field Instrument), which will study ionospheric temperature and winds to understand impact on auroral electrons
Canadian Principal Investigator	Dr. Andrew Yau, University of Calgary

Solar-Terrestrial Missions	
Canadian University and Government Departments	University of Calgary York University University of Alberta Athabasca University University of Saskatchewan University of Western Ontario University of New Brunswick Canadian Space Agency Communications Research Centre
Canadian Industry Partners	MDA, Vancouver, BC (mission prime contractor) Bristol Aerospace, Winnipeg, MB (bus provider)
Web site: www.space.gc.ca/asc/eng/satellites/cassiope.asp	
THEMIS THEMIS studies magnetospheric substorm instability, a dominant mechanism of transport and explosive release of solar wind energy within geospace. Includes five space-based probes and ground-based observatories.	
Participating Countries	U.S.A., Canada
Launch Year	—
Canadian Involvement	Canada will operate 16 GBOs (ground-based observatories) to support satellite data through All Sky Imagers that produce a whole map of the auroral network
Canadian Principal Investigator	Dr. Eric Donavan, University of Calgary
Canadian Universities and Government Departments	University of Calgary University of Alberta University of New Brunswick University of Saskatchewan Natural Resources Canada Geomagnetic Laboratory
Canadian Industry Partner(s)	—
Web site: www.space.gc.ca/asc/eng/sciences/themis.asp	

Solar-Terrestrial Missions

SWARM Part of the European Space Agency's Earth Explorer program, SWARM is a constellation of small satellites to study the dynamics of Earth's magnetic field.	
Participating Countries / Regions	Europe, Canada
Launch Year	—
Canadian Involvement	Canada has been invited to provide all three SWARM satellites with a CEFI (Canadian Electric Field Instrument), which will study ionospheric temperature and winds to understand impact on auroral electrons
Canadian Principal Investigator	Dr. David Knudsen, University of Calgary
Canadian Universities and Government Departments	University of Calgary Canadian Space Agency
Canadian Industry Partner(s)	—
Web site: www.esa.int/esaLP/ESA3QZJE43D_LPswarm_0.html	
Major Projects	
CGSM (Canadian GeoSpace Monitoring) Initiative CGSM is a coordinated observation, data assimilation and modeling program. The over-reaching objective is to understand the transport of mass and energy across multiple scales throughout the entire solar system. CGSM is Canada's contribution to the International Living With a Star Program, a multi-agency, multi-spacecraft solar-terrestrial applied and fundamental science program.	
Participating Countries / Regions	—
Launch Year	—
Canadian Involvement	CGSM
Canadian Principal Investigators	Dr. Eric Donavan, University of Calgary Dr. Ken Tapping, Herzberg Institute of Astrophysics Dr. George Sofko, University of Saskatchewan Dr. Robert Rankin, University of Alberta Dr. Ian Mann, University of Alberta Dr. John MacDougall, University of Western Ontario

Solar-Terrestrial Missions	
Canadian Universities and Government Departments	University of Alberta University of Calgary University of Saskatchewan University of Western Ontario Canadian Space Agency Canadian Foundation for Innovation, Natural Sciences and Engineering Research Council
Canadian Industry Partner(s)	—
Web site: cgsm.ca	

Physical Sciences and Life Sciences

One of the unique features of the space environment is the almost complete lack of gravity. One of the primary goals of the Space Science Program is to provide Canadian scientists with access to this unique environment through a wide variety of platforms. Some are space-based, including the International Space Station, the Space Shuttle, and satellites. Others are Earth-based; these include parabolic aircraft flights, sounding rockets and drop towers, as well as simulation environments such as bed rest studies, neutral buoyancy water facilities, underwater habitats, and isolation chambers.

Physical Sciences

The goal of the CSA's physical science program is to exploit the microgravity environment to uncover fundamental knowledge about the nature and behaviour of materials that is unobtainable on Earth because of the dominant influence of gravity.

Tests conducted in microgravity—whether on satellites, the Space Shuttle or the International Space Station—are intended to generate new information about the physical and chemical processes going on within solids, liquids and gases that will have practical applications on Earth. These studies have already lead to improvements in Earth-based manufacturing processes, and they ultimately may lead to new space-based industries as well.

Science themes: The CSA program is focused on three key fields of research: materials science, fluid science, and biotechnology.

Current and Future Missions: CSA is sponsoring SCCO (Soret Coefficient in Crude Oil), a study of the effect of thermal diffusion on components of oil, which is difficult to measure on Earth because of the masking effects of convection influenced by gravity. This study, carried out on a Russian Foton satellite, is intended to improve computer models used by oil companies to evaluate new oil deposits before they start drilling.

Further experiments will be conducted on an ESA-sponsored Foton flight scheduled for October 2007. Another experiment will be conducted on board the European-built Columbus module: a scientific lab is scheduled to be added to the International Space Station sometime after 2007. It will continue the research on thermal diffusion, and examine influence of vibrations on diffusion in liquids.

A CSA-sponsored microgravity study conducted on the Space Shuttle in 1997 has led to the development of a unique high-efficiency evaporator that can be used in many industrial processes, from desalinating water to manufacturing medications and powered milk. Earth-based experiments inspired by the space-based tests demonstrated a previously unknown property of water related to convection, which was exploited in developing the new evaporator. Further studies of convection in liquids are being considered for the International Space Station.

The CSA plans to continue supporting microgravity research on a variety of materials, including metals, liquids, biological tissues, and other substances with the objective of spinning off this fundamental knowledge into industrial and commercial applications for the benefit of Canadians. These projects will be carried out on a variety of space platforms, including satellites and the International Space Station.

Physical Sciences Missions

Launched/Operating Missions

SCCO (Soret Coefficient in Crude Oil)
The ESA-led SCCO mission is designed to prepare an international science team for ISS scientific utilization. The accurate measurements of diffusion and Soret coefficients are of great interest to both scientists and industry because of their impact on the improvement of oil recovery from petroleum reservoirs. The SCCO experiment objective is to calculate the Soret coefficient by measuring temperature, pressure and concentration of various hydrocarbon liquid samples. The experiment requires the reduced-gravity (free-fall) environment of space in order to minimize buoyancy forces that influence the value of this parameter by an order of magnitude here on Earth.

Participating Countries / Regions	Europe, Canada, Russia
Launch Dates	May 31 – June 17, 2005
Platform	Russian Foton Recoverable Satellite
Canadian Principal Investigator	Dr. Ziad Saghir, Ryerson University
Canadian University and Government Partners	Canadian Space Agency CRESTech (Ontario Centres for Excellence)
Canadian Industry Partner(s)	—
Web site: www.space.gc.ca/asc/eng/sciences/scco.asp	

Physical Sciences Missions	
Missions in Development	
IVIDIL / SODI (Influence of Vibrations on Diffusion in Liquids / Selectable Optical Diagnostic Instrument) The ESA-led IVIDIL mission aims to study the influence of vibrations on diffusion in liquids, and is currently scheduled to be integrated into the Microgravity Science Glovebox on-board the ISS. Because of the importance of accurately measuring the diffusion and Soret coefficients of hydrocarbon liquid samples, it is equally important to determine the role of vibrations on diffusion. Canada's contribution is to validate the experimental results through quantitative numerical simulations, and quantify the effect of various levels of vibration on diffusion.	
Participating Countries / Regions	Europe, Canada, Russia
Launch Year	No earlier than 2007
Platform	International Space Station
Canadian Principal Investigator	Dr. Ziad Saghir, Ryerson University
Canadian University and Government Partner(s)	—
Canadian Industry Partner(s)	—
Web site(s): —	
Experimental Assessment of Surface Deformation Effects in Transition to Oscillatory Thermocapillary Flow to Liquid Bridges of High Prandtl Number Fluid The JAXA-led Marangoni convection experiment is one of five that is to be integrated into the JAXA Fluid Physics Experiment Facility. Liquid bridges are of importance to the information technology industry, and exist when a semiconducting material is being fabricated and transitions occur from a liquid to a solid phase. Canada's science objectives are to quantitatively determine the role of vibrations on surface tension driven (Marangoni) convection at various amplitudes and frequencies, and compare the numerical simulations to experimental data.	
Participating Countries	Japan, Canada
Launch Year	No earlier than 2008
Platform	International Space Station – Fluid Physics Experiment Facility

Physical Sciences Missions	
Canadian Principal Investigator	Dr. Masahiro Kawaji, University of Toronto
Canadian University and Government Partner(s)	—
Canadian Industry Partner(s)	—
Web site(s): —	
NEQUISOL (Non-Equilibrium Solidification: Modelling for Microstructure Engineering of Industrial Alloys The ESA-led mission involves experiments on sounding rockets and parabolic flight, and may participate in experimentation on the Material Science Laboratory on-board Columbus and the International Space Station.	
Participating Countries / Regions	—
Launch Year	—
Platform	—
Canadian Principal Investigator	Dr. Hani Henein
Canadian University Partner	University of Alberta
Canadian Industry Partner(s)	—
Web site(s): —	
ICAPS (Interaction in Cosmic and Atmospheric Particle Systems) The ESA-led mission focuses on the behaviour of suspended particles. It is unique in that it has the potential to provide important experimental results with direct impact on almost all of the CSA Space Science disciplines (astronomy, planetary exploration, atmospheric physics, and physical sciences).	
Participating Countries / Regions	—
Launch Year	—
Platform	—
Canadian Principal Investigator	Dr. Rudolfo Slobodrian
Canadian University and Government Partner	Université Laval
Canadian Industry Partner(s)	—
Web site(s): —	

Life Sciences

Life sciences in space focus on increasing basic knowledge about the effects of the space environment—particularly microgravity and high radiation levels—on the biological process of living organisms.

Both have a significant bearing on the ability of humans to live and work for long periods of time in space, whether in Earth's orbit or on exploratory missions to the moon and Mars. It is known that the human body undergoes many changes to adapt to microgravity, and it is important to understand the nature of that adaptation and the implications for the long-term health of humans in space. Equally important is the question of whether and how long it takes the body to readapt to gravity when humans land on planetary surfaces or return to Earth.

In Canada, much of the research emphasis has been on two main areas: the effects of microgravity on muscles, bones, and the cardiovascular and neurological systems; and, the biological effects of space radiation.

Science themes: bone and muscle loss and skeletal-muscular health; neuroscience and psychology; cardiovascular physiology and metabolism; tissue engineering and biosensors; radiation biology and dosimetry; and, developmental biology.

Current and future missions: Canada has sponsored a number of studies on the Space Shuttle and the International Space Station to examine fundamental questions about the human response to microgravity. For example, the H-reflex experiment, conducted on both the Shuttle and the Station, examined the effects of microgravity on the neurological system to determine if there are changes that reduce the effectiveness of the exercises astronauts do to protect the health of their muscles, bones and heart.

The effect of microgravity on accelerated bone loss in astronauts is of particular interest in Canada. Bone loss is one of the most serious health issues facing astronauts on long-duration space flights, including planetary exploration missions.

In 2007, a 12-day CSA-funded project, e-OSTEO (Enhanced-Osteoporosis Experiments in Orbit), will fly a Canadian-built mini-lab aboard a Russian unmanned spacecraft. This experiment will enable three research teams to study the response to microgravity of the cells that control the natural cycle of bone formation and bone loss in the human body. It is hoped this research will lead to treatments and countermeasures that can prevent excessive bone loss on extended missions.

Another experiment, scheduled for 2006 or 2007 aboard the International Space Station, will focus on what causes the loss of hand-eye coordination often seen in astronauts during the early part of a space mission. The PMDIS (Perceptual Motor Deficits in Space) experiment will examine whether the coordination deficits are related to neurological changes, psychological stress, or instabilities in posture.

Meanwhile, the CCIS (Cardiovascular and Cerebrovascular Control on Return from the International Space Station) experiment will examine how the heart and circulatory system adapt to extended periods of microgravity or bed rest.

Ground-based experiments have also been an important element of life science research. CSA sponsored the participation of two Canadian science teams in WISE (Women International Space Simulation for Exploration), an international bed rest study involving 24 women volunteers. The effects of extended bed rest on the human body are similar to those caused by living in microgravity for long periods.

One team of Canadian researchers investigated the influence of bed rest in causing anemia, a decrease in red blood cells that causes fatigue and could have serious consequences on long space flights. The other team examine cardiovascular effects—in particular, the role immobility plays in causing orthostatic hypotension, a phenomenon that can lead to light-headedness and dizziness. Both studies also examined whether exercise had a beneficial effect in preventing these problems.

Astronauts must face a harsh and dangerous environment.

CSA has sponsored several projects to examine the biological effects of space radiation. In 2004, it funded Canada's participation in the ICE-First mission, an international study aboard the International Space Station that focused on the genetic effects of space radiation in C. elegans, a small worm widely used in genetic research.

Canadian researchers have also examined the radiation exposure of astronauts. For example, one experiment involved the use of Canadian-designed radiation detectors that were placed inside astronauts' spacesuits to determine their radiation exposure during spacewalks outside the Space Station.

Canada is participating in three Space Station-based life science projects selected through an international announcement of opportunity in 2004. One is BISE (Body in Space Experiment), which will fly aboard the Station. It will examine the effects of microgravity on the neurological processes that help astronauts orient their bodies by using both internal and external cures that allow them to tell "up" from "down." Orientation issues have important implications for operating machinery and performing emergency procedures.

A second mission will study whether space radiation causes mutations and genetic damage in C. elegans, where the worms are being used essentially as biological radiation dosimeters. The third experiment is aimed at improving understanding of the cardiovascular risks associated with long-duration space flight—in particular, whether microgravity induces an inflammatory response and changes the structure of blood vessels. Both could increase the heart-related risks of long-term space flight.

Another area of life science research that Canada has increasingly focused on is the effect of long-duration space flight on human psychology. On a space mission, especially a long flight to Mars, crew members will find themselves in a harsh, dangerous, closed and isolated environment—a situation that is known to be psychologically challenging even on Earth. The success of these expeditions may well depend on developing tools to assess the psychological health and compatibility of astronauts selected as crewmembers for such missions.

Over the medium and long term, the CSA plans to continue space life science research in the areas in which Canadian researchers have already established significant expertise. One of the ongoing challenges is gaining access to a microgravity platform to conduct these experiments in the aftermath of the loss of the Columbia Space Shuttle and the resulting reduction in International Space Station operations.

The goal is to develop effective methods of protecting astronauts from the potentially damaging effects of long-duration space flight, and apply the fundamental knowledge gained through this research to improving health care for Canadians on Earth.

Some of these life science projects are integrated with CSA's operational space medicine (OSM) program, which is concerned with the health and safety of astronauts. In time, CSA hopes to leverage its growing expertise in space medicine and life sciences to gain access to international human exploration missions to the moon and Mars for its astronauts and scientists.

Life Sciences Missions and Major Projects

Launched/Operating Missions

ICE-First (International Caenorhabditis Elegans Experiment – First Flight)
A study using C. elegan worms as a model system to examine the biological effects of space radiation.

Participating Countries / Region	Europe, Canada, Japan, U.S.A.
Launch Year	2004
Platform	Space Shuttle
Canadian Principal Investigator	Dr. Ann Rose, University of British Columbia
Canadian University and Government Partners	University of British Columbia Canadian Space Agency Institute of Musculoskeletal Health and Arthritis
Canadian Industry Partner(s)	—

Web site(s): —

Missions in Development

CCIS (Cardiovascular and Cerebrovascular Control on Return from ISS)
CCIS will examine adaptations of the heart and circulatory system to extended periods of bed rest or exposure to microgravity.

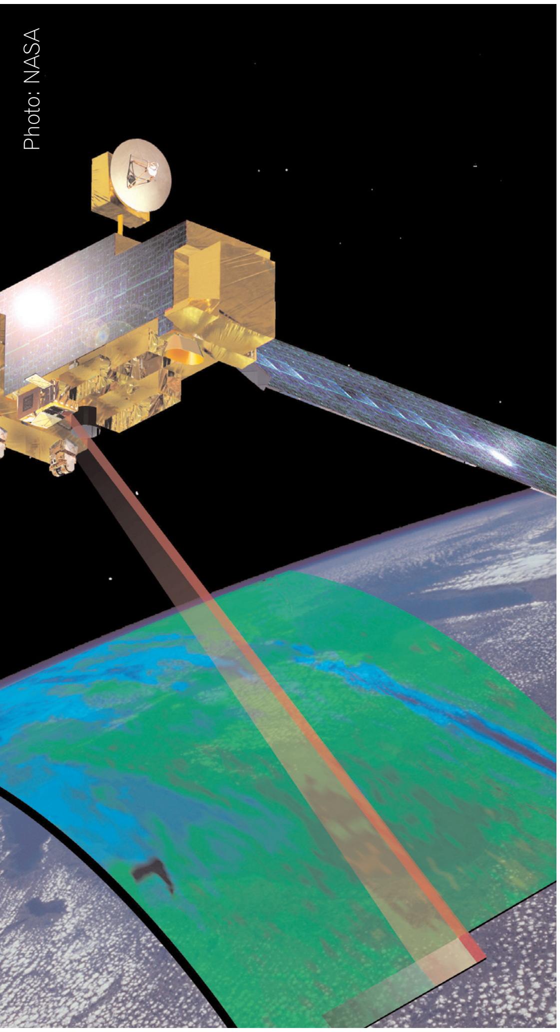
Participating Countries / Regions	—
Launch Year	2007
Platform	International Space Station
Canadian Principal Investigator(s)	—
Canadian University and Government Partner(s)	—
Canadian Industry Partner(s)	—

Web site(s): —

Life Sciences Missions and Major Projects

PMDIS (Perceptual Motor Deficits in Space) PMDIS is an ISS experiment to determine whether the loss in hand-eye coordination often seen in astronauts early in missions is due to neurological adaptation, psychological stress, or postural instability.	
Participating Countries / Regions	—
Launch Year	—
Platform	International Space Station
Canadian Principal Investigator(s)	—
Canadian University and Government Partner(s)	—
Canadian Industry Partner(s)	—
Web site: www.space.gc.ca/asc/eng/sciences/pmdis.asp	
e-OSTEO (Enhanced Osteoporosis Experiments in Orbit) e-OSTEO is a 12-day mission studying bone loss in space, and builds on the previously successful OSTEO missions in.	
Participating Countries / Region	Europe, Canada, Russia
Launch Year	2007
Platform	Russian Foton Recoverable Satellite
Canadian Principal Investigators	Dr. Reginald Gorczynski, University of Toronto Dr. Rene Harrison, University of Toronto Dr. Andrew Karaplis, McGill University
Canadian University and Government Partner(s)	—
Canadian Industry Partner	Millenium Biologix Inc., Kingston, ON
Web site(s): —	

Mapping Chemicals in the Atmosphere



MOPITT on Terra.

Earth's atmosphere is a complex mix of chemicals whose interactions play a vital role in the survival of life on this planet.

Mapping the quantity of these chemicals in the atmosphere, where they're located, where they come from, where they're going and what they're doing is vital to understanding weather and climate, air quality, pollution levels and the health of the ozone layer that protects the Earth's surface from the sun's damaging ultraviolet radiation.

The scientific and technical challenges of measuring these chemicals and understanding their role in the atmosphere are as enormous as the atmosphere itself. However, MOPITT (Measurements of Pollution in the Troposphere) and SCISAT, two of several atmospheric science research projects sponsored by the Canadian Space Agency, are helping scientists make significant strides in meeting these challenges.

MOPITT is a Canadian-built instrument contributed to an international mission. It measures the movement of carbon monoxide on a global scale—findings that are used in assessing pollution levels in the lower part of the atmosphere, or troposphere.

SCISAT, a fully Canadian mission, was launched in 2003 and carries the Atmospheric Chemistry Experiment (ACE), which focuses mainly on observations related to depletion of the ozone layer in the Earth's upper atmosphere, particularly over Canada and the Arctic. ACE measurements have also been used in studies related to air pollution and climate change.

MOPITT

MOPITT 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.

James Drummond, a University of Toronto physics professor who heads the MOPITT science team, said CO is interesting to scientists for several reasons—it's important for understanding the chemical state of the atmosphere, it identifies sources of biomass burning, and it can be used to trace other pollutants that can't be directly measured.

Carbon monoxide is moved around by air currents in the troposphere and "we can track that," Drummond said. He explained that CO is good for this purpose because it remains in the atmosphere for a period of time; it does not disappear too rapidly to measure, but also does not last so long that it becomes evenly spread around the globe.

This means scientists can treat it as a "proxy for other gases," Drummond said. "It tells us how other chemicals with a similar lifetime are being transported. It's not feasible to track all of them. If you're interested in how much pollution from the Northeastern U.S. makes it into Europe, carbon monoxide is a good tracer."

MOPITT is the first instrument to document the movement of pollutants over long distances across continents and oceans, and it is enabling scientists to create the first global pollution maps.

Drummond said it has detected "significant changes" in carbon monoxide concentrations resulting from forest fires in Siberia and North America, as well as deliberate and natural biomass burning in the tropics.

One of the objectives of MOPITT is to track carbon monoxide concentrations over a lengthy period of time to determine trends. Its original mission of five years has been extended to 10. So far, scientists have been surprised by the annual variability in CO concentrations. "This is the first time we've had this global view," Drummond said. Even just 20 years ago, there was nowhere near the same comprehensive coverage, so determining what's typical "is a more difficult question to answer than we anticipated."

Drummond was also surprised by the "quite staggering" amount of carbon monoxide produced in equatorial regions, where biomass burning is part of the agricultural cycle. The amount of CO produced by this source was not previously known.

Drummond said MOPITT's findings have had a significant impact on atmospheric research. For example, its data are used by scientists who study other chemicals and pollutants using instruments on the ground or in aircraft. Real-time maps of where carbon monoxide is moving gives them valuable information about where to target their ground-based or airborne instruments.

MOPITT data are also being used to improve computer models of how chemicals move in the lower atmosphere. Such models did not previously exist because "the knowledge wasn't there," Drummond said. "We're starting to see some quite sophisticated models with predictive capabilities." (See "Modelling" box.)

PEARL

It takes more than satellites to document what's happening in the Earth's immense atmosphere. Instruments in aircraft, balloons and on the ground are equally important, not only for the data they collect themselves, but also for confirming that information gathered by satellites is accurate.

Every scientific satellite must go through a process called validation to prove, in essence, that it's telling the truth. One way of doing this is to have instruments on the ground take measurements at the same time and in the same region of the atmosphere as the satellite, so data from the two sources can be compared.

This is one of the tasks performed by Canada's new Polar Environment Atmospheric Research Laboratory (PEARL), one of the world's most northerly, permanent research stations, located in the high Arctic. Equipped with instruments for measuring temperatures, winds, atmospheric composition, clouds and precipitation, its purpose is to measure the movement of atmospheric pollutants at high latitudes.

These data can also be used to verify the accuracy of data collected by satellites. "The capability of validating at very high latitudes is of great interest to Canada," said University of Toronto physics professor James Drummond, who leads the PEARL project.

Drummond said it's important to have a permanent site because it allows scientists to use many different instruments and do many tests over a long period of time. The more of this type of data that's available, the greater the ability to assess the accuracy of the satellite data.

Drummond emphasized that validation is an ongoing process, not one that occurs solely just after a satellite is launched, and it's crucial to understanding what's happening in the atmosphere over long periods of time. "If you want to understand trends, you have to have a long-term, confident validation program."

SCISAT/ACE

While MOPITT investigates what's happening in the lower part of the atmosphere, SCISAT focuses its attention higher—in the stratosphere, where the ozone layer is located. SCISAT is providing the most accurate measurements to date of chemicals that affect ozone, which blocks the sun's biologically damaging ultraviolet radiation and prevents most of it from reaching the Earth's surface.

It measures more than 30 different molecules, which is "more thorough than anything that's up there," said Peter Bernath, a University of Waterloo chemistry professor who heads the SCISAT science team.

Ozone—comprised of three atoms of oxygen—is constantly being created and destroyed by natural chemical processes in the atmosphere. The amount of ozone present at any given time varies depending on the balance between the processes of creation and destruction.

Industrial activities on Earth produce chemicals—notably chlorofluorocarbons (CFCs)—that affect this balance by destroying stratospheric ozone. They not only reduce the ozone shield around the globe, they actually eat large holes in the ozone layer over the Antarctic each year, and also cause significant losses over the Arctic. In the past two decades, average ozone levels over Canada have dropped about 6%, while severe declines of 20–40% have occurred over the Arctic in the spring.

The Atmospheric Chemistry Experiment (ACE) on SCISAT was launched into a 650-kilometre-high, high-inclination orbit that takes it over the polar regions of the Earth, as well as tropical and mid-latitude locations. It measures chemical molecules that influence the distribution of stratospheric ozone, particularly in the Arctic. These data are making an important contribution to international environmental policy making aimed at protecting the ozone layer, such as the Montreal Protocol that bans certain CFCs.

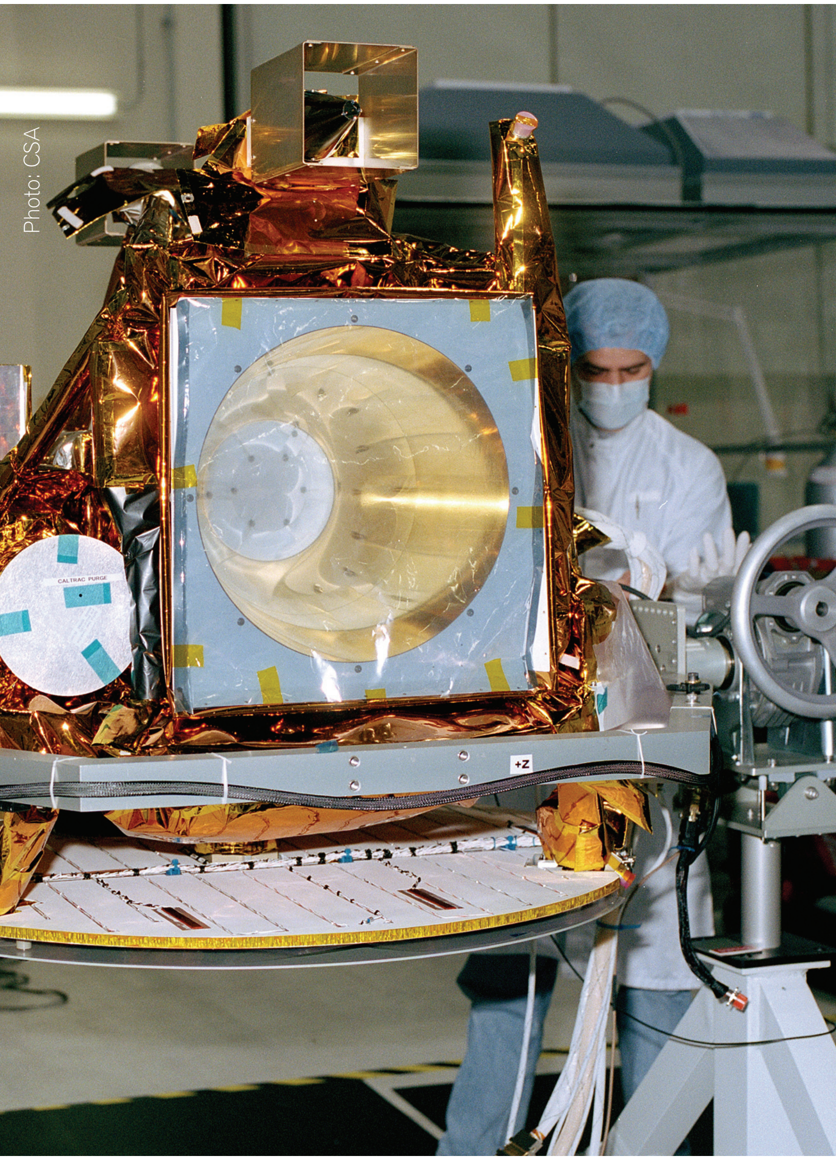
SCISAT observations are also helping scientists better understand the effects of atmospheric chemistry, clouds and small particles (such as aerosols) on Earth's climate.

ACE measures the absorption of solar light by the atmosphere at sunrise and sunset. Different atmospheric constituents absorb different wavelengths of light in characteristic ways—a signature by which they can be identified. This technique is what allows ACE to make extremely accurate measurements.

The trade-off for this precision is that SCISAT takes measurements in a limited number of locations. Other satellites do provide more global coverage, but their data are not as accurate. "That's why there's great value in combining the two," said Bernath.

With its instrument performing so well, SCISAT is now moving beyond its original mandate and providing excellent data related not only to ozone depletion, but also to climate change, and air quality and pollution. "There are many things we're doing now that we really didn't know we could do," Bernath said.

ACE has been used to measure the distribution of several molecules correlated with air pollution and biomass burning, providing data that complements the observations of the MOPITT satellite. "Together, they give you a picture of what's going on, and it's not a good picture. A lot of pollution that come from industrial activity travels all over the globe," Bernath noted.



Canada's SCISAT satellite.

ACE observations are also useful in climate studies. For example, they've shown that previously observed increases in the amount of water vapour being injected into the stratosphere have stopped. Water vapour is the most powerful natural greenhouse gas and plays a key role in the Earth's climate. "No one knew why it was increasing and we don't know why it stopped, so there are quite a few mysteries left," said Bernath.

Originally intended to last two years, the satellite's operations have already been extended to 2007, and Bernath hopes it will continue to function beyond that. "It's been a real success."

Modelling

It's a two-way street between computer models of the atmosphere and atmospheric measurements made by satellites, aircraft, balloons and ground-based instruments. Real-world data can help scientists improve their models, and models can help scientists collect and interpret their data.

"There are sources of uncertainties in both, so we use them both to work back and forth," said University of Toronto physics professor Ted Shepherd, who works on the Canadian Middle Atmosphere Model (CMAM).

Computer models are based on mathematical equations that represent the basic laws of physics and chemistry. Their main purpose is to forecast the future, ranging from tomorrow's weather in a particular city, to global climate changes in the next century.

The more modellers know about what is really happening at different times and places in the atmosphere, the better they can make their models. Shepherd said that different types of observations are needed to provide a comprehensive picture. For example, satellites can provide wide coverage and observe regions that are otherwise hard to reach, such as over the oceans. Aircraft, balloons and ground-based instruments have a more limited reach, but can often provide more detailed data.

"You can improve the models by comparing them with the measurements. At the same time, the models can help you understand the measurements," Shepherd said. "When you take a measurement in one place at one time, it may not be representative of the whole region." By using models to test the consistency of such measurements with known physical laws, scientists can better evaluate such "representativeness errors" in their data.

Models can even be helpful before an instrument starts its work, Shepherd said. "Even before you measure, you can get an estimate of where you think the impact is going to be," said Shepherd. "The model gives us some idea of where to focus attention."

He noted that CMAM has been used to help define the scientific goals and assess the technical requirements for the Stratospheric Wind Interferometer for Transport (SWIFT) instrument that will fly on Chinook, a Canadian satellite. Scheduled for launch in 2010, Chinook will provide the first global view of stratospheric winds and changes in ozone concentrations.

The model is also assisting in developing the validation program for the Stratospheric Wind Interferometer for Transport instrument. Shepherd said it can help scientists assess the best times, places and altitudes to take simultaneous measurements using other instruments to compare with those taken by SWIFT.

Stars Under Stakeout

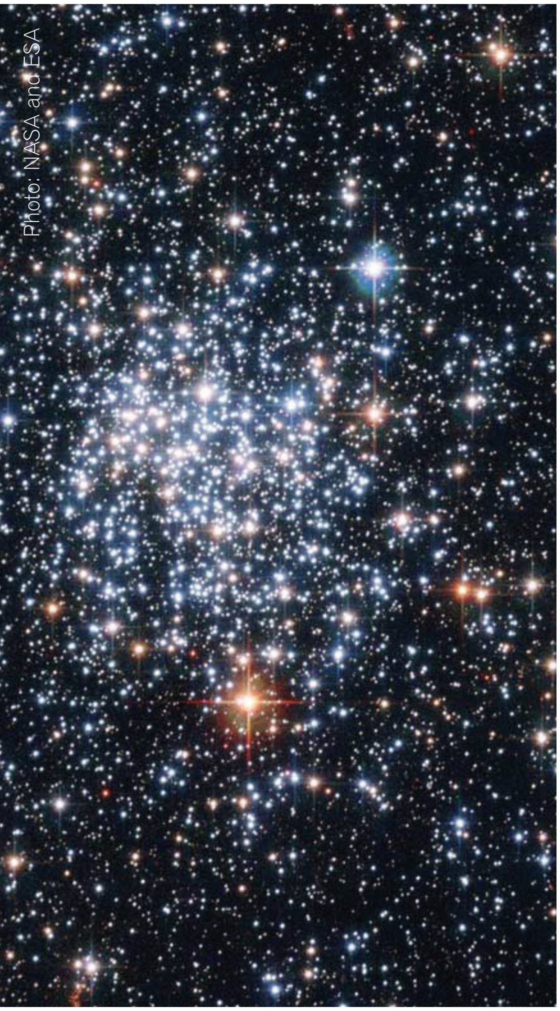


Photo: NASA and ESA

"The search for Earth is now officially on."

Not the Earth we're standing on, explains University of British Columbia astronomer Jaymie Matthews. He's referring to the search for Earth-like planets out there among the stars.

The ability to detect such planets is "within our grasp," Matthews says. In a recent press conference, he suggested that in the next five to 10 years, astronomers will discover an Earth-sized planet, possibly even one in a "habitable zone" orbit that would allow liquid water to exist on the surface—a pre-requisite for life as we know it.

Matthews is head of the scientific team studying data produced by MOST (Microvariability and Oscillations of STars), a tiny, 60-kilogram microsatellite that he affectionately calls Canada's "first suitcase in space." Sponsored by the Canadian Space Agency, MOST consisted entirely of Canadian technology and was extremely effective, producing significant scientific results for relatively little cost.

Launched by a Russian rocket into an 820-kilometre-high polar orbit in 2003, it carries a high-precision telescope with a mirror no larger than a pie plate that measures subtle variations (oscillations) in the brightness of different stars to determine their age and what they're like inside.

While MOST has done what it was intended to do—and very well—it has surprised everyone by doing something it was not specifically designed for: revealing the secrets of planets orbiting distant stars. These are not Earth-sized planets—they're gas giants like Jupiter. "Until very recently, astronomers couldn't even search for 'Earths' outside the solar system, so we don't know how common they might be," said Matthews.

Within the last 11 years, about 170 giant "exoplanets" have been discovered. MOST's observations of some of them are providing intriguing insights into the nature of worlds beyond our own, and raising new questions about how planetary systems—including our own—are born and evolve. "Is our solar system common, rare, or even unique?" asks Matthews. "MOST's findings are helping scientists take the first steps toward an answer. What happened in these other systems, and why didn't it happen here?"

Stellar Stakeout

Matthews describes what MOST does as "putting stars under stakeouts." Above the distorting effects of the Earth's atmosphere, it can see more clearly than ground-based telescopes, and its vantage point in orbit allows it to literally "stare" at target stars for up to two months at a time. This allows it to detect small variations in the intensity of light coming from those stars, which, in turn, enables scientists to determine the age, nature and composition of the stars.

The MOST space telescope and its principal investigator, Dr. Jaymie Matthews from the University of British Columbia.

By the spring of 2006, MOST had put some 400 stars under surveillance, acquiring data impossible to get from the ground. With the satellite performing beyond expectations, Matthew said the biggest problem has been struggling to keep up with sheer volume of data and the startling revelations they've produced. "We're looking at the stars in a way that no one's ever been able to do before," he said. "And we're the only game in town for the moment. We've had a three-year head start."

(Two satellites—France's COROT and the U.S. Kepler—are scheduled for launch in 2006 and 2008, and both will search for Earth-sized exoplanets. The Canadian team shared MOST's pioneering findings with the COROT team to help plan their mission; as a result, they've joined COROT and will have access to its data.)

Stakeouts often reveal unexpected things, and so it was with MOST. When it measures the light intensity coming from a star, this includes any light reflected by planets in the line of sight. When a planet goes behind the star and temporarily disappears from MOST's view, the telescope registers a tiny dip in brightness. Matthews compares it to seeing "the change when a mosquito disappears behind a street lamp 1,000 kilometres away."

At first, the MOST scientists had no idea the instrument could perform this amazing feat. "Even we underestimated what you could do with a 15-centimetre telescope in the right orbit with the right instruments attached to it," Matthews said.

Suddenly, exoplanets were added to MOST's target list. "I'm particularly pleased to say we added this very high-profile science without changing the design one iota, without changing the way we operate and without adding one dime to the budget," Matthews added.

Too Close for Comfort

One of the most mysterious and intriguing features of the large gas exoplanets discovered so far is that many are very close to their stars, unlike Jupiter and Saturn, which are much farther away from the sun. "Nobody really expected to find things like Jupiter that were 20 times closer to their parent stars than the Earth is to the sun," Matthews said.

Dubbed "hot Jupiters," these planets are actually easier to detect and study than ones farther out. The closer they are, the more often they circle the star and the more opportunities for MOST to witness eclipses and other periodic changes.

There may also be "hot Earths" much closer to their parent stars than Earth is to the sun, and MOST is currently the only satellite capable of looking for them. One way to do this is by measuring the timing of a large gas planet's passage in front of the star. "If it's in a simple orbit and there's nothing else there, it's going to pass in front of the star like clockwork every orbital period," Matthews said.

However, if there are smaller planets nearby, their gravitational pull affects the orbital speed of the larger planet. In short, the clock "occasionally might be running a little fast or a little slow," Matthews said. "MOST is the only observatory in existence that can watch tick after tick of that planetary metronome." By measuring these small changes in the timing of the large planet's passage, scientists can calculate the mass and orbit of smaller planets that can't be seen directly.

When the telescope investigated one star with a known large gas planet, it didn't find any Earth-like planets in orbits where scientists would expect them to be. "Had there been an Earth-like mass, or even a sub-Earth-like mass in certain key orbits close to the known planet, we would have been able to detect it," said Matthews.

Far from being a disappointment, this result was actually quite exciting, he added. It's still a mystery how these large gas planets got so close to their parent stars and survived, Matthews said. "Some of them are right on the edge of survivability."

One puzzle is why they didn't spiral into their stars. "Why did they stop where they did?" asks Matthews. "One of the leading theories about why they're in these stable orbits is because there are Earth-mass or smaller planets in complementary orbits near them whose gravities have given them their stability. We were able to test that theory in one system, and what seemed like a very promising explanation turns out not to be the answer there. It's deepened the mystery."

Another mystery is why the same thing didn't happen in our own solar system. The fact that Jupiter sits a considerable distance from the sun has enormous significance for the existence of life on Earth. Matthews described it as a "comet vacuum cleaner" that has protected the inner planets, including Earth, from being hit more often. "Jupiter's out there, acting as a comet deflector; otherwise we'd likely be struck by things of the scale that we believe wiped out the dinosaurs 65 million years ago at a rate maybe 1,000 times higher than now. If it weren't for Jupiter, who knows—the slate could have been wiped clean so frequently that maybe no life would have gotten a foothold."

The recent discoveries about exoplanets are challenging past assumptions that our solar system is typical. "The expectation was different from what the reality has proven to be," said Matthews. "It's still early to draw any conclusions, but we may discover our solar system isn't typical. Maybe we are the oddball."

He said one of the benefits of studying the stars is that they give us added perspective on our own little corner of the universe. "They teach us more about our own star, the sun, and about our own planet, the Earth—how these things got here, how they're changing, and what they're going to be like in the future. We might be able to use this information to make us better tenants on this planet and in this solar system."

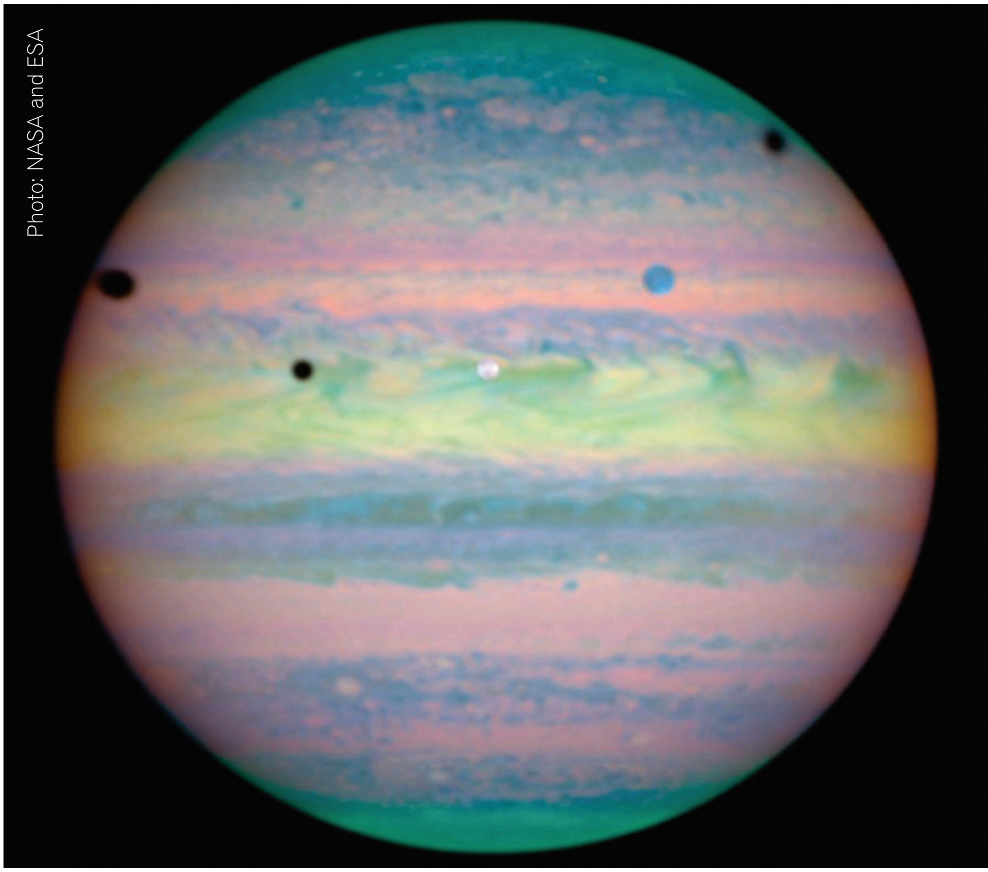


Photo: NASA and ESA

Jupiter acts as a comet deflector protecting other planets in the solar system.

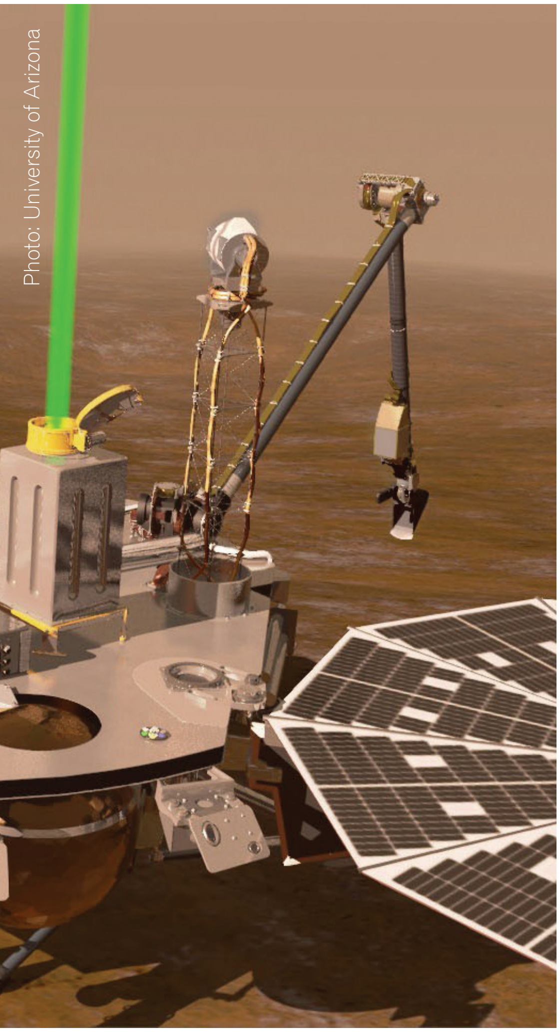
He noted that observations of Venus in the 1960s led to the first awareness of the serious effects of global warming. It forced people to think "if our sister world can have undergone a planetary greenhouse effect, could it happen to us? I truly believe it gave a kick start to that awareness. If it hadn't been for those studies, it might have been decades, or longer, before anybody really started to think about it seriously in context of our own planet."

In Galileo's Footsteps

In Matthews' mind, MOST is carrying on a tradition that dates all the way back to Galileo. "We're still doing the fundamental science that began with Galileo," he said, adding that the astronomical discoveries of recent years, and the ones arising out of projects like MOST, are as transformative.

"I don't think many people are aware of how dramatically our view of the universe has changed in the last century. A little more than a decade ago, we didn't know of any planetary systems other than our own. I suspect that historians and scientists will look back on this era, the last century, and particularly these last few decades, in the same way we look back at the time of Galileo and Copernicus in terms of the revolution of our world view. It's a wonderful time to be an astronomer."

Understanding the Water Cycle on Mars



The Phoenix Lander.

Follow the Water.

That will be the mission of the Phoenix spacecraft when it lands near the Arctic circle of Mars in the summer of 2008. The fate of water on Mars—past, present and future—has always held a special fascination for scientists, because where there's water, there's 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[1] working on the U.S. Phoenix mission, which will be the first to land in such a northerly location (around 70°N).

University of Arizona space scientist Peter Smith leads the Phoenix science team, which includes more than two dozen investigators. The US$386-million mission, which was chosen among 25 proposals in 2003 by the U.S. National Aeronautics and Space Administration, 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 Phoenix will carry is a Canadian-designed meteorological station (MET), which is being built under contract to the Canadian Space Agency in Brampton, Ontario, by MacDonald, Dettwiler and Associates Inc. (MDA) of Richmond, British Columbia, with the support of Optech Inc. of Toronto.

MET will study weather in what's 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 meteorological

1 The Canadian science team includes co-investigators Allan Carswell, Diane Michelangeli, Peter Taylor and Jim Whiteway, York University; Tom Duck, Dalhousie University; Carlos Lange, University of Alberta; Victoria Hipkin, Canadian Space Agency; and, David Fisher, Canadian Geological Survey.

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's 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 will use a robotic arm to collect sub-surface soil and ice samples, and deliver them to on-board 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.

MET will have three temperature sensors and a pressure sensor (provided by Finland) located on a one-metre vertical mast on the deck of the lander; it will take continuous measurements of temperature and atmospheric pressure at the landing site. It will also carry a "tell tale" (provided by Denmark)—a small metal cylinder "wind sock" that will be photographed by the lander cameras and used to determine wind speeds. Humidity will also be measured.

A key instrument 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.

It was pioneering work in the development of lidar systems by York University scientist Allan Carswell that ultimately led to Canadian participation in Phoenix. Several years ago, Carswell's company, Optech, provided a lidar for a study of dust devils in Arizona, and now MDA and Optech are building the instrument that will become the first lidar to operate on the Martian surface.

Ice Clouds and Dust

"The lidar will detect the presence of dust, fog and ice clouds in the lower atmosphere," notes Diane Michelangeli, a York University professor who leads the Canadian science team. "Clouds help to spread water around the planet's atmosphere and send it down to the surface." Understanding cloud formation and evolution as well as the movement of constituents of the lower atmosphere "are key to understanding the water cycle and potential for life," she noted.

Taylor said the lidar should be able to detect water-ice clouds that are "reasonably close to the surface"—up to about 10 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 at 70°N 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're 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.

Michelangeli's group and another York University scientist, John McConnell, will help to interpret 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 Flight

MET is scheduled for delivery in the fall of 2006 for a launch in the summer of 2007. While MDA is building the instruments, the Canadian scientific team has been doing studies and tests to prepare for the research program when the spacecraft is on the planet. The York University team, for example, has been testing components of the temperature sensor taken from the same manufacturing batch as those destined for the spacecraft, and have also built and tested a lidar technically similar to that destined for Mars.

Taylor and his students also 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°C, 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 University that simulates Martian conditions. "We found that if the temperature stays below about -40°C, they're probably okay; these samples won't lose a significant amount of mass over a period of something like eight hours. But if the temperature warms up to -30°C or -20°C, then they'll be gone. Certainly -20°C was a problem.

Photo: Haughton-Mars Project 2005

The Canadian Arctic provides scientists with Mars analog sites to test their experiments.

“Phoenix is now going to incorporate a little drill on the end of the robotic arm that will be able to collect ice samples at a much faster rate. They can analyze them in a couple of hours rather than eight or nine.”

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 can be extended longer than that. Unlike other instruments that will run out of essential materials, the lidar as well as the temperature and pressure sensors don’t require consumables, so “we would 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 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.”

Storms in Space

High above Earth's surface, the top edge of the atmosphere interacts with a barrage of electrically charged particles ejected from the sun that produce dancing lights and fierce storms. Two new Canadian research projects are aimed directly at understanding this complex phenomenon—one from above and one from below.

ePOP

Most people don't associate the word "weather" with space, but, in fact, huge storms do occur above the Earth's atmosphere. These aren't like the storms we get on Earth—they're caused by massive outbursts of electrically charged particles ejected from the sun—but they can still cause havoc down here.

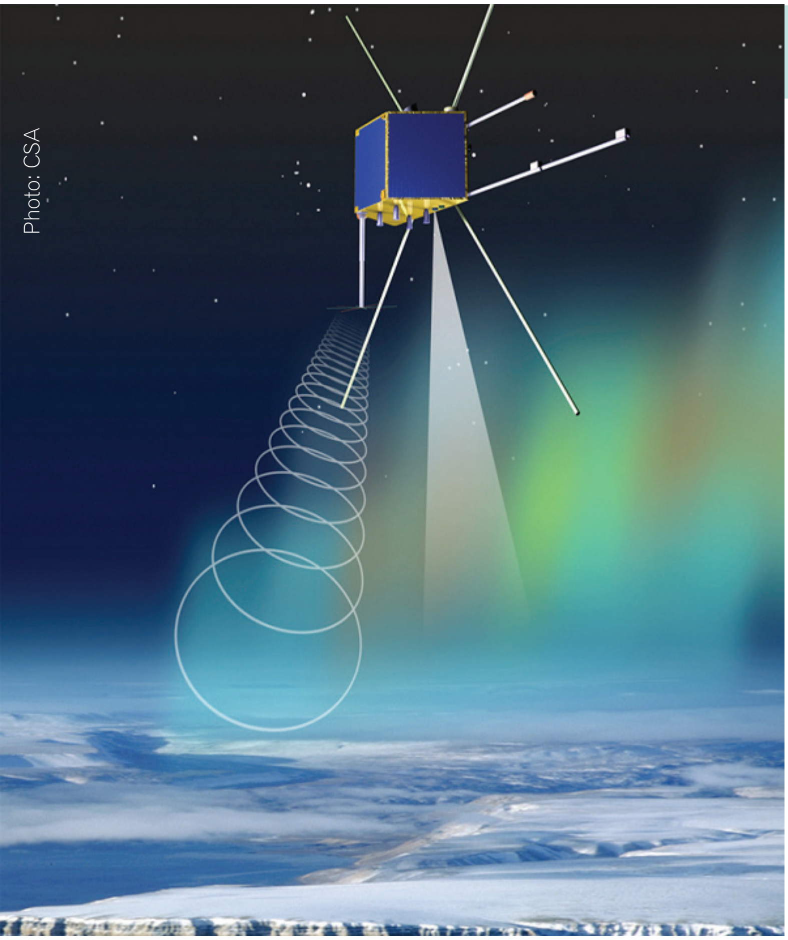
The charged particles, known as plasma, interact with the Earth's magnetic field and the thin upper reaches of the atmosphere in polar regions, producing the dancing lights known as auroras, and, at times, causing serious disruptions in communications systems, satellite navigation, and power networks.

In 1989, a solar storm knocked out Hydro Quebec's electrical grid, causing a nine-hour blackout and multi-million-dollar losses. More recently, storms have caused satellites to malfunction, interrupting media services as well as cell phone and GPS navigation systems.

Until fairly recently, scientists thought the charged particles were on a one-way journey from the sun to the Earth's upper atmosphere. "We used to believe that the particles only come down, they don't go up," said Andrew Yau, Senior Natural Sciences and Engineering Research Council (NSERC) Industrial Research Chair at the University of Calgary's Institute for Space Research. In the last few decades, however, scientists have come to believe that "very often, a significant amount of particles go the wrong way and flow upward from the ionosphere into the magnetosphere."

The ionosphere is a part of the upper atmosphere that contains layers of ionized, or electrically charged, particles. These plasma layers reflect radio waves and play a key role in bouncing communications signals over long distances on Earth. The magnetosphere is a region where the Earth's magnetic field is the dominant influence on the behaviour of energetic charged particles, and it protects the Earth's surface from the damaging biological effects of these particles.

The "polar outflow," or "polar wind," containing both electrically charged and neutral particles, has not been extensively studied to date. It's the primary target of a research project called Enhanced Polar Outflow Probe (ePOP), which will focus on space weather occurring in a transition zone between the ionosphere and the magnetosphere, between 300 and 3,000 kilometres above Earth. Yau, who heads the ePOP project, said plasma density typically peaks at an altitude



CASSIOPE and the ePOP science payload.

of 100–150 kilometres during the day and 300 kilometres at night. "That's the region where space weather does much of its damage."

Funded by the Canadian Space Agency and the NSERC, ePOP consists of eight instruments that will be carried aboard CASSIOPE, a Canadian-built, multi-purpose small satellite scheduled for launch in late 2007 into a polar orbit that will provide the best vantage point for making the observations. The science team includes researchers from 10 Canadian universities and research institutions, and two organizations in Japan and the U.S.

In addition to the space-based measurements, the ePOP science team will also take measurements from a network of ground-based radio, radar, magnetic and optical instruments located across Canada, known as the Canadian GeoSpace Monitoring (CGSM) network. A third component of this project involves theoretical studies using computer models.

The key goal of ePOP is to investigate what influence the outflowing plasma has on space weather occurring in the magnetosphere. Scientists cannot yet say for certain that it "definitely plays a role in the physics of space weather, but there is tantalizing evidence that this might be the case," Yau noted.

The polar outflow may be an "integral part" of the processes going on higher up in the magnetosphere, he said. The particles flowing upwards from the ionosphere are much heavier than those streaming inwards from the sun and Yau said this has led scientists to believe they may influence what goes on in the magnetosphere, perhaps even modifying the conditions that trigger solar storms.

ePOP is more capable of measuring small-scale, localized phenomena within the polar outflow than any previous satellite. "It's 100 times faster and has 100 times better resolution than ever before," Yau said. It will be able to see events on a scale of tens of metres, which Yau likened to "having a microscope in space." It's possible that these small-scale processes play a role in some of the problems associated with space weather, such as disruptions in communications.

Yau compared the current scientific understanding of space weather to that of weather in the Earth's atmosphere two to three decades ago. "We know a little bit about space weather, but not enough. We really need to improve our knowledge and understanding." He said there is some ability to forecast space weather, but there are too many "false positives"—predictions that something will happen when it doesn't. "You don't want to cry wolf too many times."

Better forecasting would enable organizations to take preventative measures, such as temporarily turning off communications satellites or reducing the operation of a power grid to below peak capacity when a solar storm is predicted to hit. Yau also noted that aircraft are becoming increasingly dependent on satellite-based GPS navigation, and solar storms can throw off the accuracy of GPS systems or shut them down entirely. "There is the concern that, unless you have enough provisions to mitigate this, you're always vulnerable when you least expect it."

Maintaining reliable radio communications with passenger aircraft flying across the polar regions is also a major safety concern.

Yau said that improving the ability to forecast space weather is also critical for human space flight. Solar storms can create very high levels of radiation that could harm or even kill astronauts, and the risk increases as they venture outside the protection of the Earth's magnetic field. "If you want to send people to Mars or the moon, the issue of how to deal with radiation is a very serious problem," said Yau. "The more you understand about space weather processes and effects and the more tools you have at your disposal to deal with it, the better off you are."

THEMIS

The aurora borealis, or "Northern Lights," have long been a favourite subject for photographers, but a new scientific project will take scrutiny of these displays of dancing lights to a whole new level.

As part of THEMIS, a NASA-led project to study the Earth's magnetosphere, Canadian scientists will be using a network of ground-based observatories to take images of the aurora every three seconds for two years. These observations will generate an unprecedented flood of data, and the Canadian science team is also responsible for developing the software to manage it all.

Eric Donovan, a University of Calgary professor of physics and astronomy and a Canada Research Chair who heads the Canadian science team, noted that Canada has "the best land mass under the aurora in the world and a 40-year history of world-class, ground-based auroral observation," and this is why NASA wants to base the ground component of the THEMIS project in Canada. (THEMIS stands for "time history of events and macroscale interactions during substorms".)

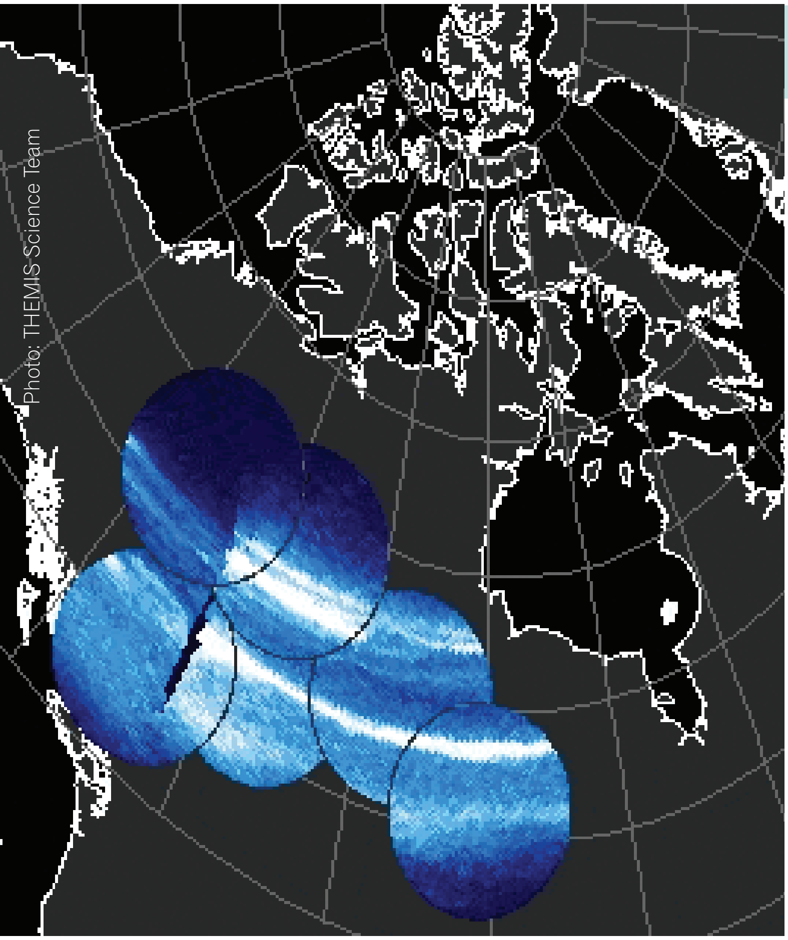
The data collected by the observatories will be co-ordinated with measurements made by five small satellites NASA plans to launch in 2006. The THEMIS ground observations will complement observations made by the CGSM network.

Donovan said that, for the first time in this field of research, NASA has deemed the ground-based observations to be "mission critical—necessary to answering the scientific question they're going after."

The focus of the project is a phenomenon known as magnetospheric substorms. These are caused by an explosive release of energy from the solar wind (charged particles from the sun) in the Earth's magnetosphere—specifically in the drawn-out "tail" of the magnetosphere on the night-side of the Earth. The magnetosphere is a region above the atmosphere where the Earth's magnetic field dominates the behaviour of charged particles.

A total of 20 ground-based observatories will be involved—16 across Canada and four in Alaska. They will create about 100 million images a year, corresponding to 10 terabytes of data annually, said Donovan. "This is a staggeringly large imaging project. We have this enormous data set coming back, and one of the big challenges is dealing with that big data set—how to have it on-line, how to summarize it, how to search it, how to move around in that data in efficient ways."

To do this, they've developed the Global Auroral Imaging Access (GAIA) program, which Donovan describes as a "virtual observatory" that he predicts will be "a very important addition to the world's ability to cruise around in data. This is a very powerful thing."



The THEMIS array in western Canada.

Donovan said that THEMIS is primarily devoted to "fundamental physics and pushing back the boundaries of human knowledge." However, there are practical benefits as well. In addition to developing the GAIA program, the THEMIS team has also improved economically important technologies such as the CCD sensors used by the cameras to record digital images of the aurora. "We've already spun off two high-tech companies from this group," Donovan said.

Living in Space—The Ultimate Challenge

The first OSTEO payload flew in 1998 on the Space Shuttle.

Among the most significant challenges that confront humans exploring space are those that come from within their own bodies.

Bones, blood, muscles, the heart—all are altered in microgravity. Understanding these changes and developing ways to combat their negative consequences in space and upon return to Earth is essential to the future success of human space flight. Research done in microgravity may also lead to new treatments for diseases on Earth.

e-OSTEO: Preventing Bone Loss in Space and on Earth

In the human body, bones undergo a constant natural cycle of construction and destruction. Osteoblastic cells build bone, while osteoclastic cells break it down. Osteoporosis occurs when bone loss exceeds bone creation.

Understanding what effect microgravity has on this process is extremely important because, in space, humans lose bone mass five to 10 times faster than they do on Earth. Their bones essentially experience accelerated osteoporosis, similar to that seen in the elderly on Earth.

This could be as serious an impediment to future long-term exploration of the moon and Mars as any technological challenge. Bone loss is "a major limitation to leaving people up there in microgravity," says Reginald Gorczynski, a researcher with the University Health Network in Toronto and a principal investigator on the e-OSTEO project, scheduled for a 12-day mission aboard a Russian unmanned spacecraft in 2007.

Funded by the Canadian Space Agency's Space Science Program, e-OSTEO offers three science teams an opportunity to explore bone loss in space. The Institute of Musculoskeletal Health and Arthritis of the Canadian Institutes of Health Research and the European Space Agency collaborated on this project.

Andrew Karaplis, a researcher at the Jewish General Hospital in Montreal, will focus on osteoblasts. He will explore an hypothesis that a hormone that normally acts to prevent the death of osteoblastic cells is suppressed in microgravity, thus contributing to increased bone loss. Rene Harrison, a life science professor at the University of Toronto at Scarborough, will use fluorescence microscopy and other techniques to examine how microgravity affects certain critical aspects of the development and function of both osteoblasts and osteoclasts.

Gorczynski's project focuses on understanding the role of certain biological molecules in controlling bone loss and bone formation in microgravity. For many years, he's been studying a molecule called CD200 and its receptor, CD200R, which are important in regulating the immune system. He's demonstrated in his lab that the interaction between them is an important factor controlling the increase or decrease in bone formation.

Photo: CNES

The CSA worked with the ESA, NASA and CNES to support the WISE study.

The purpose of Gorczynski's e-OSTEO experiment is to determine whether, by controlling the interaction of CD200 and CD200R in bone cells in space, "we can actually control bone formation or bone loss. That would be hugely important. If you have a simple drug that you could give as an injection and it returns bone formation back to Earth levels, then you've eliminated the problem of bone loss."

The researchers will manipulate bone cells in several ways and each procedure done in space will be compared with a similar one on the ground. For example, they'll add molecules that they know increase bone growth or bone loss on Earth, and see if they produce the same effects in space.

They'll also fly cells from mice that have been genetically modified either to have more CD200 than normal, or to lack the receptor CD200R. Studies with these cells are designed to further demonstrate how these molecules and their interaction influence bone loss in microgravity.

The tests will be done on bone cells enclosed in an automated mini-lab developed by Millenium Biologix Inc. (MBI) of Kingston, Ontario. MBI developed similar mini-labs for two previous OSTEO experiments on Space Shuttle flights in 1998 and 2003. (The second experiment was lost when the Shuttle Columbia broke up on re-entry into the Earth's atmosphere.)

Gorczynski hopes this research will improve scientific understanding of bone loss on Earth caused by aging and inflammatory diseases such as arthritis, and contribute to the development of new drugs to combat the condition both in space and on Earth. He added that the goal of finding a way to treat bone loss in microgravity was not the only reason for doing the experiments in space. Because bone loss is accelerated in space, he can obtain results in 12 to 14 days that would take about two years to achieve on the ground.

Women International Space Simulation for Exploration

If you can't send people into space, putting them to bed is one of the alternatives. Extended bedrest with the head slightly lower than the feet causes changes in muscles, bones and the cardiovascular system that are remarkably similar to those experienced by astronauts during space flight.

Two teams of Canadian researchers, who participated in an international study of bedrest subjects, discovered significant changes in the human cardiovascular and muscle systems that have implications for the health and rehabilitation of astronauts on long-duration exploration missions and bedridden patients on Earth.

One research team, led by University of Ottawa's Guy Trudel, found evidence of a mechanism that may explain why astronauts in microgravity suffer from anemia—a decrease in red-blood-cell production that causes fatigue and could have serious consequences on long space flights.

The second group of researchers, led by University of Waterloo's Richard Hughson, discovered that subjects who exercised while in bed recovered more quickly their ability to maintain blood pressure in an upright posture after completing bed rest. Exercising also provided protection against other physiological changes that could lead to heart disease.

The Canadian Space Agency worked with the European Space Agency, NASA and the French Space Agency (CNES) to support this study, known as WISE (Women International Space Simulation for Exploration). Additional funding was provided by the Institute of Musculoskeletal Health an Arthritis of the Canadian Institutes of Health Research.

Conducted in France in 2005, WISE was the first long-term bedrest study involving women. The aim was to improve understanding of gender differences in the response to microgravity by comparing the WISE results with those of similar bedrest studies involving men. Scientists are exploring the use of countermeasures, such as diet and exercise, to reduce the negative physiological effects of microgravity.

Twenty-four healthy volunteer subjects were confined to bed for 60 days, tilted with their heads slightly below their feet. They were divided into three groups—a control group, a group that ate a protein-rich diet, and a group that did exercises while remaining in bed. Their responses were studied by several groups of scientists before and during bedrest and during rehabilitation afterwards.

The Cause of Anemia

Trudel's team tested the hypothesis that the inactivity associated with bed rest causes fat to invade bone marrow, the primary source of red blood cells, potentially leading to anemia. Since bedrest conditions simulate the effects of microgravity, they believe fat accumulation may be critical during long-duration space missions.

Preliminary results for 12 subjects indicated that all three groups experienced an increase in fat in the bone marrow. The researchers were surprised that exercise did not protect against fat accumulation and suggested that the types of exercises performed by the bedrest subjects might not have sufficiently stimulated the spine, which could have prevented fat proliferation in the bone marrow.

They hypothesized that immobility might trigger a change in stem cells, which have the ability to turn into different kinds of cells, causing them to become fat cells rather than blood-forming cells.

Trudel, whose work involves rehabilitating people immobilized by illness or injury, noted that the cause of the most common form of anemia is unknown in a large percentage of cases on Earth. Many rehab patients have "clinically significant anemia that remains unexplained," he said. If immobility—or, in space, the physiological effects of microgravity—does, in fact, trigger fat proliferation that impairs red-blood-cell formation, "it would explain some very common problems on Earth."

The implications for astronauts on long-duration missions, such as a trip to Mars, could be serious. For example, fat proliferation in the bone marrow could compromise the ability of their bodies to replace blood in response to a bleeding injury.

It's not yet known if this process continues unabated while someone is in microgravity; if it does, Trudel believes this could cause the body's blood-producing system to fail, which would be fatal if irreversible. His team hopes to extend collecting data from the bedrest subjects to see if and how long fat proliferation continues, and if and when things go back to normal.

Cardiovascular Effects

Hughson's study focused on the cardiovascular effects of bedrest—specifically, the role of immobility in causing a condition called orthostatic hypotension. This often occurs when someone stands up after a long period of inactivity or being in microgravity; the heart can't pump enough blood to the head, so they experience light-headedness or fainting.

There's concern that this could affect the performance and safety of astronauts returning from space, especially those who operate equipment such as flying the Space Shuttle. It might also compromise their ability to react to an emergency.

Hughson noted that women now make up 20–25% of the astronaut corps and there's a significant difference in their ability to tolerate the upright position after returning from space compared with men. About 80% of women returning from space are unable to maintain an upright position comparable to their pre-flight performance, compared with 25% of men.

Similarly, Hughson found a large impact on the ability of women to maintain an upright posture after bedrest. He discovered the benefits of exercising while in bed didn't last long; subjects who did a stand test immediately after the end of bedrest, having done no exercise during the previous two days, showed no improvement in their heart rates. However, exercise did help these subjects recover more quickly: eight days after the end of bedrest, the exercisers were back to normal, while the non-exercisers still had blood-pressure problems while standing.

Hughson also found that the non-exercisers experienced "quite a large reduction in the mass of the heart, whereas the exercise group showed no change."

"This certainly tells us that women who did not exercise had quite a dramatic negative change in their cardiovascular system," said Hughson. "They probably would be less able to do any task required in space, and definitely would be much poorer in recovery back on Earth. There were quite a few benefits to the exercise program."

Hughson's team also studied whether bedrest caused physiological changes that could accelerate the development of heart disease. In the non-exercisers, they discovered changes consistent with the development of atherosclerosis (cholesterol in the arteries). Over 60 days, the changes were not important, but a three-year mission to Mars might be a different story. "In a situation like that, you could have a higher risk of developing heart disease," Hughson said.

These findings underscore the importance of doing exercise in space. It's long been known that astronauts must exercise to maintain their health, but there's concern about just how much exercise will be needed on long missions like a trip to Mars. On the International Space Station, they typically exercise about two hours a day. If they had to exercise for much longer periods on a trip to Mars, it would have a significant impact on mission operations.

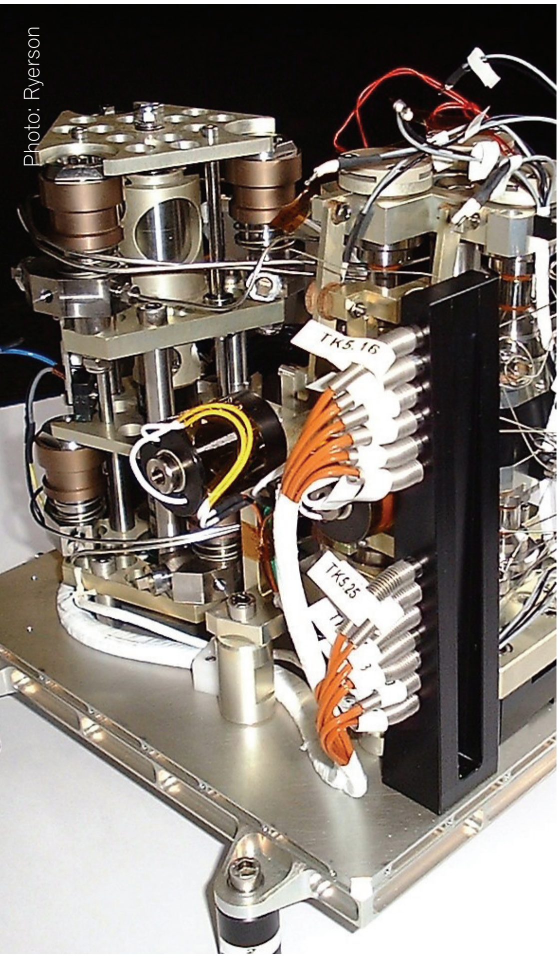
Although more studies are needed, Hughson noted that the bedrest subjects exercised for less than an hour a day and the results "show clearly that they maintained physical fitness."

In future studies, he plans to focus on key "markers" in the blood that can indicate whether astronauts' bodies are experiencing dangerous cardiovascular changes. It's possible a test could be developed to examine these changes inflight.

In 2007, Hughson is planning to monitor the heart rates, blood pressure and physical activity of astronauts on the International Space Station. The goal is to understand the relationship between heart rate and physical activity in microgravity, and "how their heart rate control is changing."

Studies like these are designed to find ways to enable the human body to function safely in two entirely different environments—microgravity and Earth's gravity. Meeting this challenge is essential to the future of human exploration of the solar system.

Oil in Space—An Experiment in Microgravity



The SCCO oil analysis instrument.

Physical Sciences

On Earth, there's no escaping the influence of gravity. That why, for some types of physical science research, space has become an important laboratory. Microgravity is especially effective for uncovering fundamental aspects of the behaviour of liquids and gases that are masked by gravity. Such findings have proved useful in improving industrial processes back on Earth.

This is why the Canadian Space Agency (CSA) has sponsored a number of research projects that depend on reducing the influence of gravity in order to gain a better understanding of how materials form, how fluids evaporate and interact, and other combustion processes. It also funds essential precursor ground-based studies, which are an important element in preparing for space-based research.

Two such projects involve using microgravity to improve oil exploration on Earth and to develop a new evaporator that can be used in a variety of industrial processes.

Oil in Space

There's easy oil, and there's hard oil.

Most of the easy oil—located in shallow reservoirs in accessible regions—has already been found. Other oil deposits, found in remote regions like the Arctic, deep underground or offshore, are more elusive. There are reservoirs off Newfoundland, for example, that are as much as 10 kilometres deep in the sea bed.

The incentive to exploit these more challenging deposits is increasing, in step with the rising global demand for and price of oil. Because of the enormous exploration and development costs involved, oil companies try to evaluate the likelihood of success before they even start drilling. They extract and analyze small samples of the oil and use the resulting data in computer models to estimate how much oil a reservoir contains and how long it will last.

These models are only as good as the accuracy of the data on the properties and behaviour of the underground oil. One of the biggest challenges is including a process known as thermal diffusion—how different components of oil move and separate in response to temperature gradients (temperature differences between two locations).

Thermal diffusion can't be measured in underground oil reservoirs on Earth because it's masked by a stronger effect called convection—fluid movements influenced by both temperature and gravity. "Convection destroys the thermal diffusion measurement," says Dr. Ziad Saghir, an engineering professor at Ryerson University in Toronto.

That's why he turned to space, where convection virtually disappears in the absence of gravity. Dr. Saghir felt the reduced gravity environment provided an ideal opportunity to verify a complex mathematical equation he developed to predict thermal diffusion, which could greatly improve computer models of oil reservoirs.

In May 2005, samples of hydrocarbon fluids similar in composition to those found in oil reservoirs were launched aboard a recoverable Russian Foton satellite. The experiment, which included samples from several other investigators, was funded by the European Space Agency (ESA), the CSA and the oil industry. Dr. Saghir also received funds from CRESTech, a division of Ontario Centres of Excellence Inc.

The fluid samples were enclosed in tubes that were subjected to different temperatures at both ends. Over a two-week period, the components in each sample moved and separated in response to this temperature gradient. They were then "locked" and returned to Earth for analysis by Total, a French oil company that is supporting commercialization of this research.

Dr. Saghir used his equation to predict what the results of the space experiment should be, and his prediction was compared with what the samples actually contained when they were returned. While some of the samples failed, others were successful and the results of their analysis were expected to be available in June 2006.

While waiting for the analysis on the space samples to be completed, Dr. Saghir did computer studies to predict the effects on the samples if equipment on the Foton satellite produced vibrations. This would help him determine if such vibrations could account for any differences between his predictions, and what actually occurred in the samples in space. "We're always trying to pinpoint all the reasons why you're not getting agreement," he said.

Vibrations were detected on the Foton satellite, and the results of the vibration measurements were expected to be available to scientists in May 2006.

In the spring of 2006, Dr. Saghir organized a conference for representatives of international oil companies in Abu Dhabi, United Arab Emirates, to discuss this research. "This is an experiment where we can find immediate application on the ground, and the industrial partners were eager to get the results," he said.

Dr. Saghir is looking for ways in which his research can help solve other problems the industry faces in oil exploration. An important goal of the Abu Dhabi workshop was to enable the oil companies to present these problems so the scientists could develop experiments to solve them. A key question, said Saghir, is "whether we need space to do them."

Dr. Saghir and other scientists are already scheduled to conduct another set of experiments on an ESA-sponsored Foton flight scheduled for October 2007. Dr. Saghir has also received funding from ESA and CSA to conduct experiments on equipment being built for ESA's Columbus module, a scientific lab scheduled to be added to the International Space Station sometime after 2007. This will allow him to run his experiments over a much longer period of time than is possible in short-lived satellites.

The Space Station experiments will involve studying thermal diffusion in samples containing water and alcohol, rather than hydrocarbons. Dr. Saghir explained that water and gas are present in every oil reservoir, as well as hydrocarbons, but studying thermal diffusion in all three simultaneously is too difficult. He chose the water/alcohol mixture because ground-based studies will be done in parallel with the space experiments, and the water/alcohol combination is easier to study on the ground than a water/hydrocarbon mixture.

Dr. Saghir is particularly interested in applying his research in two places in Canada—the oil reservoir off Newfoundland and the Alberta tar sands, the largest oil reservoir in the world. Because companies developing the tar sands use a technology that involves injecting hot steam into the sand, "we strongly believe that, in tar sands and oil sands, thermal diffusion plays a major role," he said.

Evaporation

Evaporation—the conversion of a substance from a liquid to a vapour, or gaseous state—is a key element in many industrial processes, such as desalinating water and producing medications, powdered milk, liquor and ethanol.

"Water evaporation is fundamental to so many different things," says University of Toronto engineering professor Charles Ward, director of the University's thermodynamics and kinetics laboratory. Ward has invented a new type of evaporator based on his discovery of a previously unknown property of water that significantly affects how energy is transported in water during evaporation.

He made this discovery directly as a result of research done on the Space Shuttle, and he hopes to continue his studies on the International Space Station.

Because evaporation requires the application of heat, it's an energy-intensive process. "In all of the industrial processes, a big issue is how efficiently can you evaporate the water, and that becomes more important as the price of energy goes up," Ward said. He said his new evaporator is much more efficient than conventional ones, and this is why a number of industries are currently looking at it.

Ward's discovery of a new property of water occurred when he investigated a phenomenon known as Marangoni convection. Convection is the transfer of heat in a fluid or gas caused by the movement of molecules from one region to another. One form, known as buoyancy-driven convection, depends on differences in density at different locations in liquids and is influenced by gravity. Marangoni convection is a different form of convection and depends on differences in surface tension. (See "Marangoni convection" box.)

Marangoni convection

refers to the flow of molecules in a liquid caused by differences in surface tension. Surface tension, which gives liquid bubbles their rounded shape, is caused by the attraction between surface molecules and those within the liquid, resulting in a surface layer that acts like an elastic membrane. The surface molecules flow away from areas of low surface tension to areas of high surface tension and, in the process, carry molecules from the bulk liquid with them.

The strength of surface tension depends on temperature; Marangoni convection is driven by differences in temperature—a temperature gradient—along the surface, which is the interface between the liquid and the surrounding vapour. The part of the interface at the lower temperature has a higher surface tension, and that surface tension pulls liquid along the interface.

In evaporation, molecules must be converted from a liquid to a vapour and this requires energy to be transported to the liquid's surface. Energy can be transported by both buoyancy-driven convection and Marangoni convection. Ward's goal was to measure the amount of energy transported by Marangoni convection.

On Earth, this is a challenge because buoyancy-driven convection is the stronger influence. Marangoni convection is easier to measure in space because reducing the effect of gravity there virtually eliminates buoyancy-driven convection. However, Ward devised a clever way to test water for Marangoni convection on Earth by exploiting water's unique property of increasing in density as it freezes. (Water reaches maximum density at 4°C, just above freezing.)

Using this property, he devised a laboratory device that eliminated buoyancy-driven convection and proved that Marangoni convection does exist in water—a finding that contradicted conventional scientific wisdom. Ward became convinced that Marangoni convection should occur in water after doing preliminary experiments on the Space Shuttle in 1997 to examine how surface tension moves liquids in the absence of gravity.

In fact, in his laboratory experiments, he made the surprising discovery that Marangoni convection transported up to half of the energy required for evaporation. Designing his evaporator to take advantage of this property, he significantly increased the efficiency of the evaporation process.

The University of Toronto has applied for a patent on this technology and is working to commercialize it. Ward is currently doing a study with Hiram Walker & Sons, a company that makes whisky. After fermenting corn and extracting ethanol, they dry the remaining material and sell it back to farmers as animal feed. Ward said a test of his technique in the lab demonstrated “a much improved efficiency” in removing water from the corn.

He got a similar result in tests done for another company that makes desalination units, which use evaporation to remove salt from water. “One of the huge problems that’s going to be confronting us by the middle of this century is the desalination of water,” said Ward. It’s already important in regions like the Middle East and some parts of the western U.S.

Ward said his technique would also be useful in making drugs because it allows evaporation at low temperatures. Some medications are damaged if heated to 100°C.

He’s also planning to investigate Marangoni convection in ethanol production. Ethanol, which is produced from plants using a distillation process that involves evaporation, is considered a potentially important renewable energy source. The ethanol molecule is not like the water molecule, but it may still be possible to use Marangoni convection to improve energy transport during evaporation of ethanol on Earth.

However, Ward cannot eliminate buoyancy-driven convection under these circumstances, so he’d like to study ethanol in space and has applied to the CSA for funds to prepare an experiment for the International Space Station.

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