Section 1

Preamble:

This report was initiated after discussions held amongst a large majority of the scientists involved in the study of solar-terrestrial relations. The discussions were initiated during a "Space Environment Workshop" that was held in Saskatoon on September 8-10, 2005. In this workshop, we gathered a clear description of the research areas covered in solar-terrestrial relations in Canada, which are closely tied to activities taking place around the world. Going hand to hand with a synthesis of our scientific questions and activities, we evolved our vision for upcoming space science exploration. This vision involves the Canadian Space Agency as a central, though far from sole, partner.

The purpose of the report is first and foremost (1) to make the Space Agency aware of what our research priorities are in the solar-terrestrial field, (2) to highlight the importance of the proposed projects in both a national and international context and (3) to show how our various projects are intimately interconnected, thereby reinforcing one another.

The present report is meant to be the basis for an evolving document rather than being our final word on the subject. The reasons for this should be clear. First of all, as new opportunities arise and new discoveries are made, we are driven to change our research emphasis, at least at times. Secondly, in view of the fact that we are all busy with research and teaching, there is only so much time available to produce a document such as this one out of our 'spare time'.

Section 2

Our Space Environment: what is it and why must we study it?

2.1 What do we mean by our space environment?

The sun is not a star that is content to simply emit radiation at 5800K like a black body. Its ‘atmosphere’ extends all the way to the earth and, in fact, well beyond. The most obvious manifestation of the presence of the solar atmosphere to far reaches is its solar wind. This solar wind is produced when the heated plasma above the surface of the sun is able to overcome the gravitational force and expand through interplanetary space. As the sun goes through its cyclic activity (most notably, its 11-year cycle), the solar wind goes through phases that can be very quiet and have minimal impact on our environment and other phases that can seriously disrupt our electromagnetic environment and our upper atmosphere particularly when explosive events like flares or coronal mass ejections are taking place. The solar variability involves marked variations in the solar EUV flux as well as in the solar wind density and speed.

The regions most directly affected by solar activity are the upper atmosphere of the earth as well as its plasma environment, which includes the ionosphere and the magnetosphere. Much energy can be deposited in our environment as a result. Some of this energy involves low frequency electromagnetic radiation that can affect our power grids and pipelines, among other things. Some of the energy is used to energize charged particles to the point that they can damage our expensive satellite equipment. Finally, much of the energy is dissipated in the upper atmosphere (typically above 100 km), which heats it. In the process, plumes of hot air form in the thermosphere in the auroral regions, where electrical currents are dissipated and high energy particles are stopped. This heating is in addition to the heating produced by added EUV radiation that we receive during the same active solar phases that affect our plasma environment. The added EUV radiation alone is able to heat the thermosphere to the point of shorting the life of many satellites through an increase in the atmospheric drag suffered by these satellites.

By the time it affects our more immediate environment, the solar cycle and related solar activity involve a myriad of physical processes. Not only are the processes themselves not all well understood, but we must also strive to understand how one region couples to another and how processes couple to one another. This is an arduous task because the processes often involve a cascade of scales in both time and space. That is to say, the system can be very turbulent, particularly when driven hard.

2.2 The drive to understand our space environment

We strive to understand a small part of our astrophysical universe, namely, the one centered on our sun. Not only can we study it up close, but the solar system is also the one part of the universe that can and does affect us the most. In the sun-earth context, ‘space physics’ also gives us a unique window on astrophysical processes that take place in much of the universe. We are for example developing a far better understanding of how magnetic fields affect plasmas particularly when plasmas with different magnetic fields are forced to interact with one another. We are also realizing that the large scale picture cannot be understood quantitatively without looking at a huge range of scales in time and space, because turbulence plays a major role in the evolution of the system.

In spite of its complexity, our research offers great fascination to the public in general. This is made manifest through countless books, magazine articles, and much news coverage. The aurora borealis is the primary example of the well deserved fascination borne from our field of study. The spectacular chain of events that starts with sometimes gigantic explosions at the surface of the sun and ultimately unravels into the aurora can now also be watched and enjoyed thanks to the view provided by space probes like SOHO and TRACE.

With our research we are, quite literally, able to work in an astronomical laboratory, through the use of an impressive array of space-based probes and ground-based instruments. We don’t just study the beautiful pictures that make our science so fascinating. We also study plasma waves of all frequencies through magnetic and electric field detectors, plus we study light emissions in great detail to unravel the secrets of particle energization. We also gather information from various types of particle detectors. Finally, we build sophisticated computer models to learn more about how the system actually works. These efforts are well regarded, judging from the number of Canadian Research Chairs, CFI grants, Industrial chairs and by the numerous large projects that have been well funded by many agencies.

2.3 Research relevance

Aside from the importance of the science (we are gaining detailed knowledge about important astrophysical processes taking place in our own backyard, so to speak), our research has obvious economic and even social impacts precisely because it deals with powerful processes taking place in our immediate astrophysical environment:

- As mentioned above, our technology has become highly dependent on the part of the environment that's affected by the solar wind and other solar storm-related phenomena. This includes not only our ever-expanding satellite fleet and power and pipeline networks but also the health of astronauts and air passengers, and our increasing dependence on GPS (which are affected by auroral storms).
- As is the case with all space-based research, there is much technological spinoff associated with the development of sophisticated rocket and satellite instrumentation.
- Space allows Canada to build strong research partnerships with other nations, be they the USA, Japan, European nations or, in the coming years, hopefully, China and other Asiatic nations. While the spinoffs of such collaborations should be obvious, we also have to be able to contribute in meaningful ways if we are to remain a part of such partnerships. Having gotten in the space age early, we have created a strong research expertise in the area, which has continued to this day, as exemplified by the many international projects that we have participated in (see Table 1)
- Solar terrestrial relations have a particular impact on the Canadian people, simply because of geography. Canada 'owns' the geomagnetic pole, around which all auroral phenomena and their disturbances are centered. This makes us more vulnerable than most to solar storms, while also adding an international responsibility to be a leader in space research since accessibility to high latitudes is particularly easy in Canada. We could of course let others come and do the research for us, making us dependent on others for primary knowledge that is already in many ways vital to our economy and well-being.

Table 1: a survey of rocket and satellite projects/missions
in which Canada is/has been a major participant

International missions/projects

Name	Instrument	Year
Viking	UVI	1986
Akebono	SMS	1989
Freja	CPA	1992
Freja	UVI	1992
Nozomi	TPA	1998
Interball-2	UVAI	1996
CUSP	SII/SEI	2002
JOULE	SII	2003
JOULE II	SII	2007
THEMIS	GBO	2007
SWARM	CEFI	2010

Canadian projects/missions

Name	Year
Alouette 1	1962
Alouette 2	1965
ISIS 1	1969
ISIS 2	1970
OEDIPUS-C	1995
GEODESIC	2000
ePOP on CASSIOPE	2008

Section 3

The study of solar-terrestrial research in Canada at the beginning of the 21st century

3.1 Overview

Canadians are engaged in just about every aspect of solar-terrestrial research, though it would be fair to say that there is a constant shift in mainstream activities while some fields are, for a while, much more heavily studied than others. This is part of a natural dynamics: as some subfields become better understood, interest shifts to other aspects, exactly how it should be. For example, there is now a more conscious effort to understand processes that start at the sun itself. This is not just a new Canadian interest. Interest into solar processes has grown around the world. In large part, it's because (1) we have learned a lot more about the sun in the past two decades through the advent of new space probes and (2) we have become very aware of the fact that our capabilities to understand the system are very limited unless we go back to where solar disturbances originate. In Canada in particular, the study of solar physics as a separate discipline is still only in its infancy.

At the SEW (Space Environment Workshop) held in Saskatoon at the beginning of September 2005, participants were asked to describe their research interests, coupled with a vision of what the future held in store for their own activities. A summary of the various themes is presented in Table 2. While this summary illustrates the breadth of the research covered by our researchers, it fails to convey the depth into which the themes were being tackled, say in terms of man-years of research efforts. In this respect, it would be fair to state that much of research is actually devoted to physical processes occurring in the magnetosphere and ionosphere/thermosphere, in roughly equal parts. By contrast, one area that was not covered particularly well -at least as far as the SEW workshop went- was the solar wind itself.

We can infer from Table 2 and the balance in presentations at the SEW that the Canadian research efforts in Solar-Terrestrial relations are increasingly focussing on more localized scales. This may reflect the fact that we have achieved a fair understanding of the large scale, global structures, and that further progress depends on unravelling 'meso-scales' and even 'micro-scales'. For instance, there is a strong drive to study the occurrence and development of substorms with an unprecedented dense array of instrumentation both on the ground and in space (THEMIS project). At the same time, ionospheric physicists are coming to realize that both the electric fields and field-aligned currents can be orders of magnitude more intense than average on 100 m scales. Thus, while it would appear that we are studying the same things we were studying 20 years ago, we are doing this in a very different, much more local (i.e. quantitative) context. While the 'grand themes' are therefore in many ways what they were, a very strong continuity and evolution -i.e. progress- have taken place. The grand themes, starting with the sun and moving closer to the surface of the earth, are roughly as follows

- Physical origin of solar magnetic activity cycle through inductive action of solar interior and surface flows.
- Role of magnetic field in channelling, storing and releasing energy in the solar atmosphere and corona.
- Transfer of energy and momentum from the solar wind to the magnetosphere. Magnetic merging is now known to play an important role even when the interplanetary magnetic field (IMF) does not have a geometry that is favorable to strong merging.
- In relation to the energy and momentum transfer, we study the generation of field-aligned currents that result in so-called Region I and Region II

TABLE 2: Summary of the scientific themes that were presented
at the SEW workshop in Saskatoon, Sept 2005

- Solar physics:
    - Origin of solar cycle and its interruptions
    - Flares and messy reconnection
    - Granulation and supergranulation
    - Sunspot extracting energy from acoustic modes
    - Puzzle of solar irradiance variation

- Solar wind:
    - Arrival of energetic particles
    - Shocks
    - Reconnection (Flux Transfer Events)

- Magnetosphere
    - Substorms:
        - Trigger (time and place)
        - Origin: 2 main competing theories
        - Evolution
        - Space weather consequences: sats, pipelines, power lines
    - Alfven waves:
        - Field line resonances
        - Particle energization
    - Large scale response to IMF; convection

- Radiation belts
    - How they get populated and depleted
    - How they change with storms and substorms

- Ionosphere
    - Possible role as generator of Alfven waves; conductivity instability
    - Patch formation and evolution
    - SAPS (subauroral polarization drifts)
    - Polar wind
    - Heating experiments; induced airglow
    - E and F region irregularities; turbulence, intermittency
    - Other small scale processes: intense localized currents, particle energization, ion outflows, velocity distributions, radio propagation

- Neutral atmosphere (thermosphere)
    - Localized disturbances with consequences for satellites
    - Joule heating and associated winds and plumes
    - NO production and propagation
    - Escape of neutrals
    - Atmospheric gravity waves
    - Helium budget

currents. The region I currents are directly generated by the merging of the solar wind with the magnetospheric plasma. The solar wind is the primary generator for those currents. Region II currents are produced deeper in the 'closed' magnetosphere and are associated with electric fields that help bring the plasma back to the dayside. In other words the field-aligned current systems are related to the circulation ('convection') of the plasma.

- Population and depopulation of the magnetosphere through coupling mechanisms involving the ionosphere and the solar wind.
- Energization processes, for example through waves or instability mechanisms, or conservation of invariants in the presence of large scale changes.
- How storms and substorms affect the circulation ('convection') of the ionospheric and magnetospheric plasma
- The interaction between the ionosphere/thermosphere and the magnetosphere: not only is the magnetic energy dumped into the ionosphere/thermosphere, but also the ionosphere is known to trigger positive feedback mechanisms (instabilities) that affect the evolution of the system. This has led to a strong focus on the study of small scale processes in the ionosphere.
- There is renewed interest in the inner magnetosphere, where the radiation belts are located. Basic questions such as "How is the region populated and depopulated?", "How are the particles energized in the first place?" and "What role does the inner magnetosphere play in the evolution of magnetic storms and substorms?". From a more ionospheric point of view, people are also asking how the lower latitudes get electrically shielded from the higher latitudes sometimes, and not some other times (particularly at substorm onsets).

Beyond the above, attempts at producing a road map of what we do have met with much debate that was unresolved by the time the SEW was over. Some have suggested that we can regroup the above science themes by identifying the regions that we study, how they couple with one another, and how the whole thing affects the space environment. In following that line of thought, we cover the question of energy and momentum transfer between regions, energy deposition in the thermosphere, and the mechanisms (like instabilities) that make all this possible. An added advantage of the presentation is that the 'space weather and its effect' theme is clearly identified. A disadvantage is that the scientific themes have a tendency to be hidden, to become a subtheme rather than a central theme. Figure 3.1 gives the resulting road map. It seems clear that if used in a future report, the figure will need modifications before representing a full consensus of the views of the researchers.

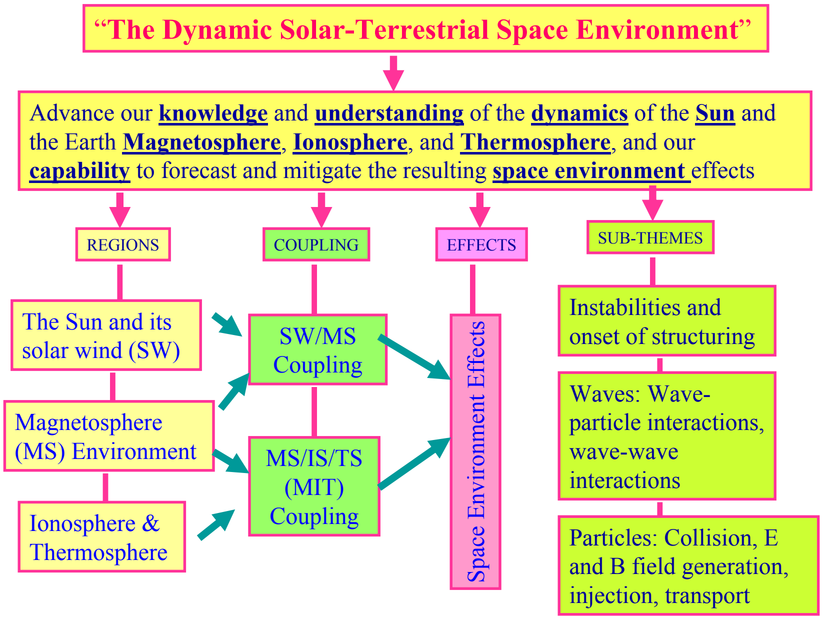

Figure 3.1: First attempt at a 'road map' presented at the September 2005 SEW to succinctly describe the activities of the solar-terrestrial relations research group. The difficulty seen by some with this scheme is that it may well be creating the impression that the science is a subtheme instead of a driver of the research activities.

3.2 Physical processes that we study

In the previous section we mentioned the grand lines of the research we do, without commenting much on the physical processes involved. While we cannot be too terribly specific unless we turn this report into a book, it seems worth it to go over the list of at least some of the processes we study, if only very briefly.

- Many of us study 'magnetohydrodynamics' (or MHD), which is the form fluid dynamics takes when applied to ionized media like space plasmas in the presence of magnetic fields. The equations assume that the plasma is neutral (very nearly equal ion and electron densities). Currents can be generated through inhomogeneities in the plasma or in magnetic fields, when such regions are connected with regions of finite electrical conductivities (like the ionosphere), thereby allowing electric fields to form as well. MHD equations are used to study solar physics, notably the solar dynamo, from the evolution of the magnetic field in the solar atmosphere and corona, to the onset and acceleration of coronal ejections. The MHD equations also describe the basic interactions between the solar wind and the magnetosphere. The equations are used to numerically model the magnetosphere as a whole, including of course its interaction with the solar wind. Lower down, in the ionosphere, the MHD concept of Joule heating is also used to study how the energy deposited by the aurora ends up heating the atmosphere locally to produce upwelling and atmospheric gravity waves. An important question these days is the role played by scales in the overall Joule heating rate. Sometimes, the presence of smaller scales can be shown to decrease the rate of heating, and other times the opposite can be argued.

- Fluid instabilities: we note that MHD fluids, like ordinary fluids, are fraught with instabilities of all sorts, as soon as large enough shears, pressure gradients or other important departures from equilibrium arise. Some geospace plasmas are clearly associated with instabilities. A spectacular example that our community is currently is trying to elucidate is the instability of the so-called 'inner plasma sheet' which, when triggered, leads very quickly to spectacular formation of auroral substorms on the nightside.
- Magnetic reconnection. This particular form of instability is central to solar and magnetospheric physics. Plasma regions with antiparallel magnetic fields are attracted to one another. Particles cross over one plasma to the next in regions where the net magnetic field goes to zero. Electric fields are generated in the process. The process is intermittent more often than not and frees vast amounts of stored energy that is given to charged particles, while also triggering an exchange between different plasma populations.
- Plasma waves and instabilities. Sometimes, a single fluid description is not sufficient to describe the behavior of the system. We then need to describe ions and electrons as separate gases. In some cases the two species are treated as fluids and in other cases as gases made of individual particles (the kinetic description). For instance, the strong current densities that sometimes flow in the system create electric fields between ions and electrons, and these electric fields can create plasma instabilities. Sometimes, the instabilities are so localized that only the kinetic description can be used to properly describe the system. We see examples of the usefulness of the kinetic description in both magnetospheric research (in research on Field line Resonances) and in ionospheric research (where strong localized currents and shears have been detected).
- Kinetic studies: at times, it is very useful to describe the velocity distribution of the space plasma populations. For one thing, we have instruments that do observe these distributions. For another, an intimate knowledge of a velocity distribution can yield a lot of information about the plasma, be it for the way the particles are energized and the way heat is passing through and other factors creating anisotropic velocity distributions. This kind of work is currently being done both in solar wind and ionospheric research to elucidate the processes that accelerate and move ions and/or electrons.

- Nonlinear plasma processes and turbulence: it's one thing to deem a system unstable and quite another to attempt to describe it once the instability takes control of it. Typically, once a structure becomes dominant it produces substructures, usually smaller ones in space, or faster evolving in time. This is not always the case, however. Other times, smaller structures end up feeding the larger scales. Or the smaller structures become themselves unstable, and a lot of energy can go through them as a result. Either way, the system is deemed to have become nonlinear, which is akin to stating that its behavior is impossible to describe in detail and difficult even to describe on average. We end up with turbulence, that is, a complex network of intermingled scales which all affect one another and the system as a whole. Difficult as it may be to research that topic, it is quite clear that an integral part of space physics depends on how well we can describe the system under turbulent conditions. In particular, turbulence controls the transport properties, that is the rate at which structures dissipate and the rate at which equilibrium is restored, at least locally.

- In more specific types of studies related turbulent processes, we often deal with wave-wave interactions (or mode-coupling) and wave-particle interactions as a means to describe some of the important processes. In the wave-coupling approach, we describe a process by which dominant large amplitude modes couple with one another to become a third mode (or vice-versa). This process is intimately related to cascading from one scale to the next. In the wave-particle interactions, we are concerned with the way by which individual particles get energized by waves, that is, large amplitude structures. Such processes are for instance studied in relation to Alfven wave trains moving towards the ionosphere to explain the particle distributions observed in connection with the wave trains.

3.3 Expertise in hand

Our research requires a wide array of expertise that we are proud to have. While this is by no means the end of the story, we note that in addition to a prestigious group of researchers across several universities, 1 Industrial Chair (Andrew Yau, U of Calgary) and 5 CRC's have been awarded in our field to help it develop more rapidly. These Canadian Research Chairs have been awarded to people involved in every aspect of our research, namely, (in alphabetical order) Paul Charbonneau (solar physics, U of Montreal), Martin Connors (auroral physics, U of Athabasca), Eric Donovan (auroral and magnetospheric physics, U of Calgary), Ian Mann (magnetospheric physics, U of Alberta) and J-P St-Maurice (ionospheric physics, U of Saskatchewan). New faculty appointments in the field are also to be noted, with the most recent ones being in New Brunswick (Jay) and soon to-be-filled positions at Calgary and Saskatoon. We should also note the award of a prestigious CSA fellowship to Konstantin Kabin, at the university of Alberta, to further develop his modelling of the magnetosphere.

Irrespective of who does what or has what responsibility, we have proven time and again that we have, as a group, the human resources to tackle the formidable challenges that we face in our inquiries. To start with, we have always built some of the most sophisticated instruments in our field. Our instruments are state-of-the art in the temporal and spatial resolution that they provide. This has been the case in the past (e.g., Viking images, particle imagers on xx) and will continue to be the case (particle detectors 10 times better than anything seen before on the upcoming ePOP project).

Our work also requires that we participate in international collaboration. No single nation can study space physics alone since this requires a large investment in ground-based instruments and space probes. Canada is fortunate enough to "own" one of the geomagnetic poles in a region that is relatively accessible, and it has taken advantage of that fact by deploying impressive arrays of instruments that have culminated with the CANOPUS project and its modern successor, the CGSM project. These projects have legitimately given us access to international space-based projects since the ground-based instruments provide key complementary information for the study of space. We have participated directly in a number of joint space-based missions as well and we continue to do so. Many examples are given elsewhere in this document. Suffice it to say that we have collaborations through Canadian instruments with NASA, ESA countries, Japan, Russia (and the former USSR) and, most recently, China.

Another challenge that we have met successfully is in coordinating the large instrumental arrays that we have installed. Many of the challenges that we now face require large arrays of cameras, photometers, magnetometers, radars, riometers, and ionosondes. Coordinating the observations in such a way that they can provide real time descriptions that tell us how the system evolves globally over scales of a few km is far from trivial. The data stream is very high and must be met with sophisticated computer software. Ultimately all the information has to be processed with data assimilation tools, with which we are also very familiar.

Finally, no matter how much data we can produce, we also require dedicated efforts to make sense out of all the observations. This requires theoretical expertise as well as powerful computer models that have to be built and ran by experts in numerical techniques. We have developed a central node in this area (Rankin and his group in Edmonton), and our modelling efforts are already recognized in MHD and kinetic calculations involving the magnetosphere as a whole or more localized regions to explore physical coupling processes, depending on the problem we want to solve. We also have solid expertise in the important but complex fields of turbulence and chaos (Rankin and his group in Edmonton, Charbonneau and his group in Montreal, Hamza in New Brunswick, St-Maurice in Saskatchewan, and Noel in Kingston).

3.4 Research tools used for our studies of the physical processes

To study specific questions in our science themes the community is involved in several key projects. Several of these are major in that they involve expensive and sophisticated equipment, including satellites, but there are also several projects that are more limited in scope and pertain to address specific less ambitious questions.

Upcoming or present major projects that are driven by Canadian scientists and are Canadian initiatives comprise the following list

- The ePOP project onboard the CASSIOPE satellite. The scientific objective of the Enhanced Polar Outflow Probe (e-POP) payload on the CASSIOPE small satellite is to make observations of mesoscale and microscale plasma and wave-particle interaction processes in the topside polar ionosphere at the highest-possible resolution. The e-POP mission aims to study the microscale characteristics of plasma outflow and related plasma processes, the occurrence morphology of neutral escape, and the effects of auroral currents on plasma outflow, as well as the effects of plasma microstructures on radio propagation. The e-POP payload will carry a suite of 8 scientific instruments, including imaging plasma and neutral particle sensors, magnetometers, dual-frequency GPS receivers, CCD cameras, a radio wave receiver and a beacon transmitter. It will utilize the large (terabyte) data storage and downlink capacity (up to 350 megabits/s and 15 gigabytes per day) onboard to support the planned high-resolution observations. The imaging plasma sensors will measure particle distributions and the magnetometers will measure field-aligned currents on the time scale of 10 ms and spatial scale of about 100 m. The CCD cameras will perform auroral imaging on the sub-second time scale. The GPS and radio-wave receivers will perform near real-time imaging studies of the ionosphere in conjunction with ground-based radars, and the beacon transmitter in conjunction with ground receiving stations.

- The Canadian Geo Space Monitoring program: the Canadian GeoSpace Monitoring (CGSM) program researches the inter-connect ion between space physical phenomena that are driven by solar magnetic activity. These include solar wind processes, solar wind-magnetosphere coupling, magnetospheric dynamics, magnetosphere-ionosphere coupling (including ion outflow), auroral physics, ionospheric physics, and the substorm and storm. CGSM research focuses on five grand challenge themes: (1) Driving and control of magnetospheric convection; (2) Triggering and development of magnetotail instabilities and flows; (3) Generation, modulation, and multi-scale structure of auroral processes; (4) Acceleration, transport and loss of energetic particles in the magnetosphere; and (5) Cold plasma injection, transport, and loss in the global magnetosphere. The instruments used to study these questions are made of the following arrays deployed around the auroral regions on Canadian soil: a CADI (digital ionosonde) array; SuperDARN and PolarDARN HF radars; the CANMOS array of riometers and fluxgate magnetometers; the CARISMA array of fluxgate and induction coil magnetometers; the F10.7 solar radio flux monitor (this particular instrument studies the sun and does not require a high latitude station); the NORSTAR array of all-sky imagers, Meridian Scanning Photometers and riometers. The data is accessible through a data portal and other means provided by individual PI's. Finally, the project incorporates an important Facility for Data Assimilation and Modeling as well as a space weather modeling element that facilitates the use of the data to tackle the five grand challenges.

- ORBITALS The Outer Radiation Belt Injection, Transport, Acceleration and Loss Satellite (ORBITALS) is a proposed Canadian small satellite mission to study the dynamics of the inner magnetosphere. The ORBITALS mission will be a voyage of discovery into the inner magnetosphere. This region has been extremely under-sampled by previous satellite missions. This means that ever since the accidental discovery of the Van Allen radiation belts nearly 50 years ago, the processes which accelerate particles to relativistic speeds in the magnetosphere remain largely an enigma. The mission will determine what generates so-called satellite "killer" space-weather electrons, and determine the processes responsible for energetic particle acceleration and loss in the inner magnetosphere.

  The specific mission goals are to determine the dominant processes leading to the acceleration, global distribution, and variability, of energetic electrons and ions in the inner magnetosphere. To this goal the mission will probe the outer radiation belt electrons, the inner radiation belt ions and electrons, the electric and magnetic fields of the inner magnetosphere, the core ion composition on each side of the plasmasphere, and the ring current of the inner magnetosphere, all the way to the near-earth plasmasheet.

  The ORBITALS mission is a Canadian-led mission providing a leadership role for Canada at the heart of the International Living with a Star (ILWS) program. Due to be launched in 2012 the ORBITALS will operate in conjunction with a two-satellite NASA Radiation Belt Storm Probes (RBSP) to provide the global coverage required for science closure. The mission builds on the Canadian communities traditional strengths in ground-based space science, utilizing daily long-lasting magnetic conjunctions from the CGSM network of instruments to provide a unique view of the wave-particle interactions which dominate energetic particle dynamics in the inner magnetosphere.

In addition, Canadians participate in several international projects aimed at answering more of the grand questions currently being asked in space physics. Specifically the following missions, which are either under way or soon to be deployed, have significant Canadian participation:

- THEMIS (Time History and Macroscale Interactions During Substorms). This is a NASA MIDEX mission. At its core, it has five magnetospheric satellites in equatorial orbits. Three of the spacecraft have apogees at 10 Re, while the fourth and fifth have apogees at 20 and 30 Re. The 10, 20, and 30 Re apogee orbits will have periods of 1, 2, and 4 sidereal days, respectively. As a result, all five spacecraft are at or near apogee in the same meridian every four days. These conjunctions will occur over central Canada throughout the mission duration, which is scheduled to last for at least two years. The five satellites all have identical particle and field detectors for measuring the relevant plasma parameters, fields, and bulk velocities of the Central Plasma Sheet. Together with at least two NOAA GOES satellites at geostationary orbit over eastern and western Canada, the THEMIS satellites form a seven spacecraft constellation that will bracket the region of substorm onset. This provides for the first time an opportunity for unambiguous identification of the radial position at which the substorm process initiates. In order to achieve its objectives THEMIS requires high density ground-based observations in Canada. The time and meridian of onset will be identified from the ground using magnetometers, sudden riometer absorption enhancements, and auroral brightenings. Indeed, advancing our understanding of the evolution of the substorm seen in these different ways will be a major focus of THEMIS work. This means that THEMIS has required the deployment of twenty ground-based observatories over and above CGSM, in a continent-wide array covering the North American auroral zone. Sixteen of these observatories have been installed in Canada. The central component of these observatories is a white light All-Sky Imagers (ASI). The ASIs operate with a cadence of at least 1 image every five seconds, and provide mission critical onset and early expansive phase information.

  Considering the number of satellites involved and the vital link with a vast array of ground-based observatories, THEMIS can be viewed as the first true constellation class scientific mission and therefore a technology pathfinder laying important groundwork for even bolder future constellation class missions in the future. THEMIS seeks to answer a genuine grand-challenge problem in space plasma physics, and will have an enormous international profile. The Canadian role in THEMIS is central to the mission's ultimate success, and hence THEMIS is an outstanding international opportunity for Canada in space. The THEMIS ASI project is the largest imaging program of its type in history. As leaders of this element of THEMIS, we will be creating visually stunning data with enormous public appeal.

- SWARMS:The European Space Agency's Swarm mission will make precise measurements of terrestrial geomagnetic and electric fields, at altitudes between 300-530 km, during a four-year mission scheduled for launch in early 2010. The mission science objectives encompass fields originating both internally - in the terrestrial core, mantle, and crust - and externally, in the ionosphere and magnetosphere. Canadian Electric Field Instruments (CEFI's) will be included on each of Swarm's three, polar-orbiting satellites. E-fields will be derived from precision measurements of 3-D ion drift vectors having 2σ resolution and accuracy of 5 and 100 m/s, respectively, at a rate of 2 Hz. The corresponding E-field resolution and accuracy are 0.3 and 3 mV/m. The CEFI's will also measure ion temperature and density, and will include a Langmuir probe from the Swedish Institute of Space Physics (Uppsala) to measure electron temperature and density. Swarm measurements have potential application to all areas of Canadian space environment research – including electrodynamics (from global to small-scale), formation of auroral arcs, field-line resonances, and plasma heating, convection, instabilities, and outflow, in addition to space weather-related and internal field studies. Electric and magnetic field measurements combined will produce estimates of Poynting flux to a resolution of 1 μW/m^2, making Swarm an excellent potential tool for studies of ionosphere-thermosphere coupling.

- The Ravens/Kuafu project:Global auroral imaging is essential for quantifying energy input into the ionosphere and thermosphere, and for observing the 2D ionospheric projection of the dynamic global magnetosphere. The original Ravens concept consists of two satellites on identical elliptical polar orbits to accomplish that goal. Each satellite was to be outfitted with a complement of imaging instruments including a twin-head LBH imager (for LBH-L and LBH-S imaging), an FUV imaging spectrograph (for Doppler shifted Lyman-alpha proton auroral imaging), a wide field of view FUV imager (for perigee imaging), and an ENA imager (for ring current observations). The satellite pair would provide 24/7 global imaging of the LBH-L, LBH-S, and Lyman-alpha proton aurora, as well as stereoscopic imaging of the ring current. Together with ground-based networks of ASIs, Ravens would allow for simultaneous imaging of all relevant auroral spatial scales. Ravens was designed to be the first-ever mission that would provide 24/7 global imaging, systematic conjugate imaging, and (in coordination with ground-based projects) simultaneous imaging across all scales, as well as the best ever wavelength resolution obtained in the FUV band on global scales. These technical firsts would support many scientific firsts. The Ravens team was approached by Chinese researchers who wanted to incorporate Ravens into the proposed Chinese KuaFu mission. It was agreed to include the entire Ravens instrument complement on the two "KuaFu-B" satellites which would have orbits as specified in the Ravens concept study. The likelihood for the project to come to fruition appears to be very good.

In addition to the satellite projects, we note a very strong Canadian participation in various international projects dealing with space research, using ground based instrumentation. Particularly worthy of note are

- The international SuperDARN project, which comprises 18 radars in both hemispheres and counting. SuperDARN radars operate at HF frequencies and are built to study the ionospheric plasma circulation over a large area, particularly near the auroral regions. The ionospheric circulation, which is often called the 'convection pattern', responds, in the polar cap region, to changes in the solar wind and, in the auroral regions, to inputs that originate in the tail of the magnetosphere (in the plasma sheet). The network of radars is usually organized in pairs so as to be able to get real vectors (by making measurements on common volume from two different directions). In Canada, the Canadian Saskatoon radar is paired with the US-funded Kapuskasing radar while the Canadian Prince George radar is paired with the US-funded Kodiak radar. Recently, a Canadian-built radar was added, in 2006, in Rankin Inlet, in the northern part of the auroral region, to study the plasma circulation over the polar cap region. The second radar in the pair is being built in Inuvik and should come online before the end of 2007. The capability of the radars to produce the circulation pattern over a large area is quite valuable when studied in conjunction with other instruments, be they other kinds of radars (like the AMISR radar in Resolute Bay), satellite and other ground based measurements like all sky imagers and magnetometers or riometers. They therefore fit very well within the CGSM project.

- The US AMISR initiative: the US have built a 'Advanced Modular Incoherent Scatter Radar (AMISR) that's modular and mobile. It is used to conduct studies of the upper atmosphere and to observe space weather events. The novel modular configuration is designed to allow relative ease of relocation for studying upper atmospheric activity around the globe. Remote operation and electronic beam steering allow researchers to operate and position the radar beam instantaneously to accurately measure rapidly changing space weather events. AMISR consists of three separate radar faces, with each face comprised of 128 building block-like panels over a 30x30 meter roughly square surface. The first face was constructed in Poker Flat, Alaska in 2006. Following completion of the first face, the remaining two faces will be built in Resolute Bay, Nunavut, Canada. Two Canadian PI's have been added to the US team as a result of this move of two panels on Canadian soil. The Resolute Bay location has also led the Canadian PolarDARN team to position Resolute Bay in the central part of their echo regions so as to take advantage of the many possibilities for joint studies that the radar and attendant observatory will bring.

There are many other projects that address more specific questions and require smaller teams or operations but remain a vital part of the research initiatives and the training that they provide. Experimental programs include Connors' AUGO at Athabasca University, Hussey's VHF radar research at the University of Saskatchewan, Jayachandran's U of New Brunswick CHAIN funded project to deploy CADI's, GPS receivers All Sky Imagers, and Meridian Scanning Photometers at judiciously chosen locations over the polar cap, Trondsen's

Portable Auroral Imager at the U of Calgary, Donovan's NORSTAR dense array of cameras at the U of Calgary, numerical and theoretical modelling of magnetospheric processes under Rankin's and Samson's groups at the U of Alberta, St-Maurice's (U of Saskatchewan), Kagan (UWO) and Noel's (RMC, Kingston) efforts to study and model small scale ionospheric processes. There are many other projects -too numerous to list- that, in the end, are linked to the larger ones in one way or the other.

Section 4

The funding structure that we depend on to enable research in solar-terrestrial relations at the beginning of the 21st century and beyond in Canada.

Funding for our research comes primarily from several agencies often working in strong partnerships. The primary government agencies are the CSA and NSERC. However, other programs and sources have played a pivotal role for several projects. In particular, we stress the role played on the Canadian scene by the Canadian Research Chairs (CRC) program and the Canadian Foundation for Innovation (CFI), and ASRIP from Alberta. Important matching contributions for several of these programs have come from provinces and universities.

Beyond immediate funding considerations, international partnerships with agencies from other countries have also had a strong impact on our research programs. Thus, we have had, and continue to have, several instrumental collaborations with NASA on rocket flights (notable recent examples being OEDIPUS and JOULE) and satellites (THEMIS being the most recent example). We also have had several extremely fruitful collaborations through Canadian instruments flown with the Japanese space agency (the Akebono satellite being a prime example) with European nations and with ESA (the past Freja and Viking missions with Scandinavian countries and the upcoming SWARM project with ESA) or Russia (Interball). In terms of ground-based projects we also are deeply involved in the international SuperDARN project and have two Canadian co-I's on the powerful US-built AMISR incoherent radar which will soon be installed in Resolute Bay.

4.1 Specific examples of partnerships in existing or upcoming projects

- CGSM is an example of a project that has required partnership from several agencies or programs in one way or the other. A central role for CGSM is obviously played by the CSA, which funds the operations of the project. However, CGSM works in close collaboration with the Canadian SuperDARN radars and helps funds some of the operation, while the bulk of the maintenance and operating budget comes from NSERC MFA's. Many of the CGSM instruments have required funding from the CFI (Mann's magnetometers, Donovan's NORSTAR cameras, St-Maurice's PolarDARN radar), which themselves have required matching funds from provinces and even universities in Donovan and Mann's cases. Other NSERC sources have involved Special Opportunity Grants for Rankin and Mann at the U of Alberta. Also, CRC's for Donovan, Mann and St-Maurice are providing funding for the funding of scientific teams and operating expenses, again with matching funds from provinces.
- ePOP is another excellent example of a project that involves a large number of scientists and has been possible through funding from both the CSA (instruments, flight, operations) and NSERC (hefty science budget contribution).

4.2 Should there be a means to cope with the constantly evolving funding structure?

In spite of our successful track record, it could be argued that the forever changing funding structures uses up a lot of the energy spent by many of the leaders in our field. For example, NSERC keeps changing the structures of the large programs. We have had Major Facilities Awards coming and going, Special Research Opportunities coming and going, with changing priorities, and CRO's in conjunction with CSA missions which seem to meet with tentative approval. On the CSA end, the budgets change with priorities set by governments or with special opportunities. And we have seen the near-catastrophic end of the Solar-Terrestrial Physics group at the Herzberg Institute, which was forced to cease its research in space physics. In the end, we lack what many other countries have in space science, which is an institute of some sort. Maybe the time has come to seriously envisage the creation of a funding structure that is more stable, so that a core team of engineers and researchers can be supported on a long enough time scale, say 5 years at a time, to ensure that we will take full advantage of the research done in this field.

Section 5

Appendix: summary of resolutions that were passed at the Saskatoon 2005 SEW

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The following motions were passed by the members of the community that were present at the SEW2005 workshop. Note that the first 2 motions had to do with a debate regarding the next cycle in the CGSM funding, for which a new competition was deemed by the CSA to be necessary.

- Motion 1: It is too early in the CGSM program to have a significant competition-based reorganization of CGSM in 2005-6. This motion applies only to the upcoming deadline of CGSM contracts. Moved: Donovan. Seconded: Rankin. Carried: Unanimous, with two abstentions.

- Motion 2: For the upcoming competition, the community encourages a coordinated bid from the CGSM program elements. Moved: David Boteler. Seconded: Mann. Carried: Unanimous, with three abstentions.

- Motion 3: International collaborative opportunities, in which Canada provides instruments to space or ground-based missions led by other countries, have been and remain a vital component of our program. We urge CSA to maintain mechanisms to support this program into the future. Moved: Knudsen. Seconded: Yau. Carried: Unanimous.

- Motion 4: The space environment community strongly supports the ORBITALS mission in the solar-terrestrial science discipline which addresses high-priority scientific issues, around the time frame of the next solar maximum. Moved: Yau. Seconded: Knudsen. Carried: Unaninmous, with one abstention.