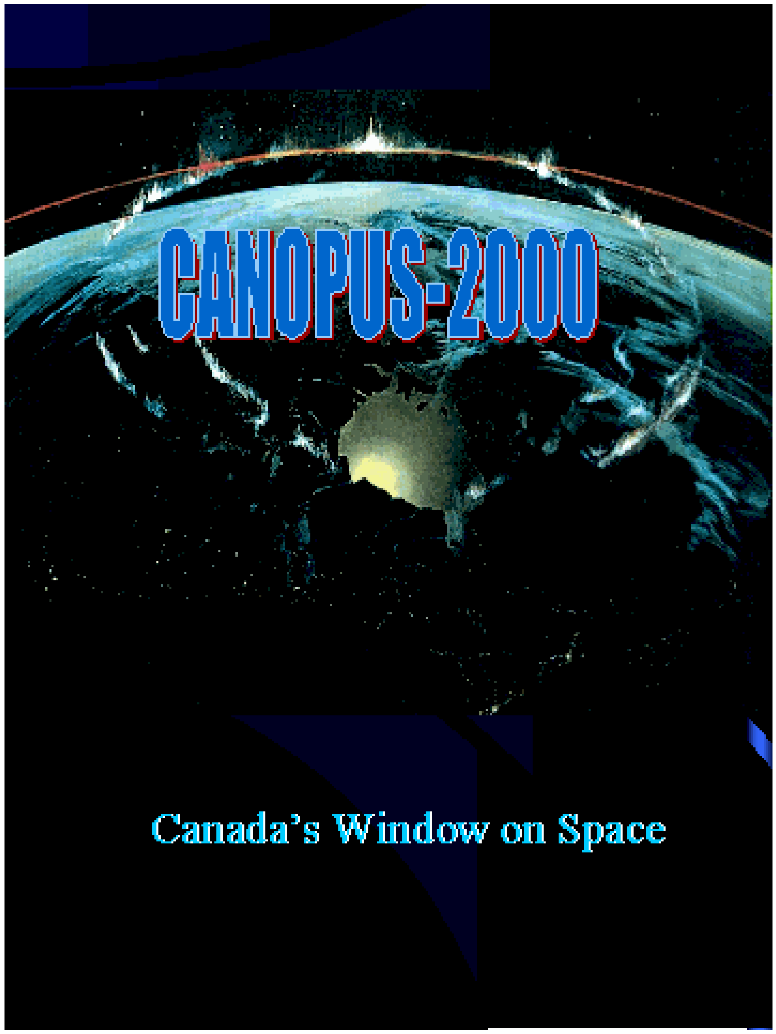

CANOPUS-2000

A Proposal to the Canadian Space Agency
on behalf of
The Canadian Space Science Community

Contents

1 Executive Summary

The vision for CANOPUS-1 evolved in the early 1980s and was documented in the "yellow book" edited by A. Vallance Jones in January 1986 [Vallance Jones, 1986]. CANOPUS-1 [Rostoker et. al., 1995] had an instrument complement of magnetometers, riometers, optical devices, including meridian scanning photometers, an all-sky imager (ASI), and a bistatic auroral radar system. The CANOPUS magnetometer and optical systems have proven to be extremely effective scientific instruments, gaining an international recognition for the importance of the data sets and for the scientific achievements using these instruments. The bistatic auroral radar system (BARS) program was ended in the early 1990's and has now been replaced by the complement of SuperDARN, HF-radars. CANOPUS-2000 will build on the strengths of the CANOPUS-1 magnetometer and optical instruments. A special emphasis will be placed on modern optical devices and their important role in studying auroral processes. It is also now clear that digital ionosondes are often an effective tool for monitoring global magnetospheric dynamics, and CANOPUS-2000 will look at the implementation of a modern ionosonde array. CANOPUS-2000 will take advantage of strong partnerships in Canadian research, including NORSTAR, SuperDARN, and the Multimedia Advanced Computational Infrastructure (MACI) program. Plans include closely coupling infrastructure and CANOPUS programs for a possible Facility for Data Assimilation and Modeling (FDAM, [Liu and Rankin, 1999]), and a Space Weather Program [Liu et al., 1999].

The possibility of limited funding for CANOPUS-2000 suggests a somewhat cautious and evolutionary approach to changes in the instruments in the CANOPUS system. Initially, emphasis will be placed on careful and relatively inexpensive changes to the instrument array, building on strengths from CANOPUS-1. A priority for the CANOPUS-2000 is the modernization of software and facilities for data archiving and retrieval and for the visualization, representation, and analysis of CANOPUS-2000 data. This work can be done as part of the CSA funded program, and by individual researchers at Canadian universities and research institutes.

Equally important is a strong move toward the use of modern concepts in physics for the interpretation of CANOPUS-2000 data sets. Examples include nonlinear magnetohydrodynamics in auroral processes, nonlinear processes in ionospheric irregularities, and wave-particle interactions in the auroral ionosphere and magnetosphere. Major problems to be dealt with include global magnetospheric convection, the substorm, and the formation of auroral arcs and structures down to the small scale sizes of ionospheric irregularities. The design of new instruments and data sets must take into account these rapidly evolving concepts and models of space plasma processes.

2 Introduction and Summary

CANOPUS-2000 : An array to study "Energy and mass transport and scaling in the Earth's ionosphere and magnetosphere."

Building on the strengths of CANOPUS-1, the CANOPUS-2000 project will provide valuable scientific infrastructure, data sets and services to both the national and international space science communities. On the national level, CANOPUS-2000 will provide a high quality data set suitable for world class space science and for undergraduate and graduate student research projects, ground-based support for a possible Canadian small satellite program, and context for other ground-based campaigns. CANOPUS-2000 will also provide an excellent data set for a program in "space weather" based on computer models of the magnetosphere (Liu et al., 1999). For Canadian researchers CANOPUS-2000 gives the added advantage of a "buy in" to international satellite projects and international space weather programs.

CANOPUS-2000 observations provide a means of remote monitoring of the configuration and dynamics of the magnetosphere through the ground based measurement of ionospheric processes. This provides a time evolving two dimensional view of the ionospheric projection of magnetospheric processes. Mapped to the magnetosphere, this information is very useful in interpreting satellite data and, on an ongoing basis, gives Canadian space scientists the opportunity to collaborate in international satellite missions.

Due to its location under the auroral ionosphere, CANOPUS-2000 will be in a position to supply a number of key parameters for use in evaluating magnetospheric and ionospheric conditions. These include:

- auroral activity index, including energy deposition in the ionosphere (magnetometer and optical data)
- magnetic activity indices (magnetometer data)
- an index of energy storage in the magnetosphere, including cross polar cap potential, (from magnetometers, optical data, and digital ionosondes)
- indices for the risk of magnetic storm and substorms (based on the index of energy storage)
- ionospheric irregularity index, including global positioning system (GPS) risk assessment (from digital ionosondes, riometers, and optical data)
- ionospheric electrojet strengths and locations (magnetometer data)
- magnetospheric plasma densities (from field line resonances seen in magnetometer data)

The revitalized CANOPUS-2000 will involve five "cornerstone" efforts: 1) optical instruments; 2) magnetometers and riometers; 3) ionosondes; 4) data integration and partnership with NORSTAR, SuperDARN, and international satellite projects such as Cluster; 5) a renewed data acquisition network in partnership with the Facility for Data Assimilation and Modeling (FDAM).

Based on experience gained during the first phase of CANOPUS, it is reasonable to expect that data generated by CANOPUS-2000 will help us resolve important scientific problems in ionospheric and magnetospheric process, such as:

- the coupling of solar wind energy to large scale convection in the magnetosphere, and the storage and distribution of energy in the magnetosphere;
- the explosive release of energy in storms and substorms;
- the physical mechanisms leading to electron and proton energization and auroral arcs formation;
- energization of very high energy particles in the inner magnetosphere.

Among these important open scientific topics, the auroral arc and the substorm are both considered to be "grand challenge" problems in space physics and in plasma physics in general.

3 The Scientific Program

3.1 Science goals and objectives

3.1.1 An overview: Scaling and transport of mass and energy in the magnetosphere and ionosphere

Our Earth's environment in space, including the magnetosphere and ionosphere, is a dynamic plasma environment. The input of energy to the plasmas of the magnetosphere comes largely from the solar wind through two distinctly different processes. The first is merging and reconnection, with possibly some viscous drag on the magnetopause, that drives the large scale (global magnetospheric scales) convection in the magnetosphere. The second is the direct propagation of magnetohydrodynamic Alfvén waves driven by the solar wind and by instabilities due to the solar wind flow. The variety of scale sizes found in the magnetosphere is remarkable. Global convection driven by the solar wind has a scale size of hundreds of thousands of kilometers; substorm intensifications near the Earth have scale sizes of ten thousand kilometers; the more homogeneous auroral arcs have scale sizes down to tens of kilometers; discrete arcs and structures have kilometer scales; kinetic wave processes and irregularities in the auroral ionosphere have scales of tens of meters. A complete and consistent model of magnetospheric and ionospheric plasma processes requires the explanation of this remarkable scaling of structures. More importantly, it must explain the cascading of energies from the global scales driven directly by the solar wind to the local scales observed within the magnetosphere-ionosphere system. This scaling problem has not yet been fully solved. As mentioned above, the energy transport from the magnetosphere scale into the substorm-associated local energy storage and release, and restructuring of the global convection into discrete arcs, remain "grand challenge" problems.

In the descriptions below we concentrate on processes whose signatures might be succesfully measured by the CANOPUS-2000 instruments, and the CANOPUS-2000 partners, NORSTAR and SuperDARN.

3.1.2 The Canadian advantage: Polar regions and the auroral oval

Canada's high geographic and geomagnetic latitudes, and the fact that the geomagnetic pole is located near Alert (Nunavut), gives us an incredible advantage for studies of ionospheric and magnetospheric plasma physics, as well as of the nature of the cusp, polar cap, auroral oval, and sub-auroral and mid-latitude regions.

The auroral oval is typically located between 65 and 75 degrees geomagnetic latitude. To date, the primary focus of CANOPUS has been on auroral and substorm physics, and this is reflected in the location of the bulk of the CANOPUS sites. In fact, one of the standard "products" of CANOPUS is an inferred auroral oval (see Figure 1), based on data from the Churchill line of magnetometers. More recently however, there has been a dramatic increase in interest in the physics of the cusp and polar cap regions, which are poleward of the auroral oval and encompass the geomagnetic pole.

Our unique geographical advantage puts us also in an excellent position to carry out observations that will be of fundamental importance in studies of the polar cap and cusp regions. To this end, we anticipate fielding CADIs and new magnetometers in more polar regions, and integrating our efforts with those of the Canadian SuperDARN and NORSTAR teams.

3.1.3 Global and intermediate scales

In order to allow an interpretation of the optical data from CANOPUS-2000 in evaluating global and intermediate scale processes, a template of the plasma regimes in the magnetotail is given in Figure 2. In the figure, the regions of the low altitude plasma sheet boundary layer (LAPSBL) and the low altitude plasma sheet (LAPS) correspond to the single region commonly called the boundary plasma sheet (BPS). The BPS is the region of structured electron precipitation and auroral arcs. The region called the inner plasma sheet (IPS) in Figure 2 corresponds to the central plasma sheet (CPS) in the earlier terminology for low altitude . Galperin and Feldstein [1991] named the IPS the remnant layer. The term IPS is used to indicate a connection along magnetic field lines between this region and the near-Earth plasma sheet (PS). This connection has been inferred on the basis of in situ measurements of isotropic precipitation of $\sim$10 KeV ions [Samson, 1994]. The

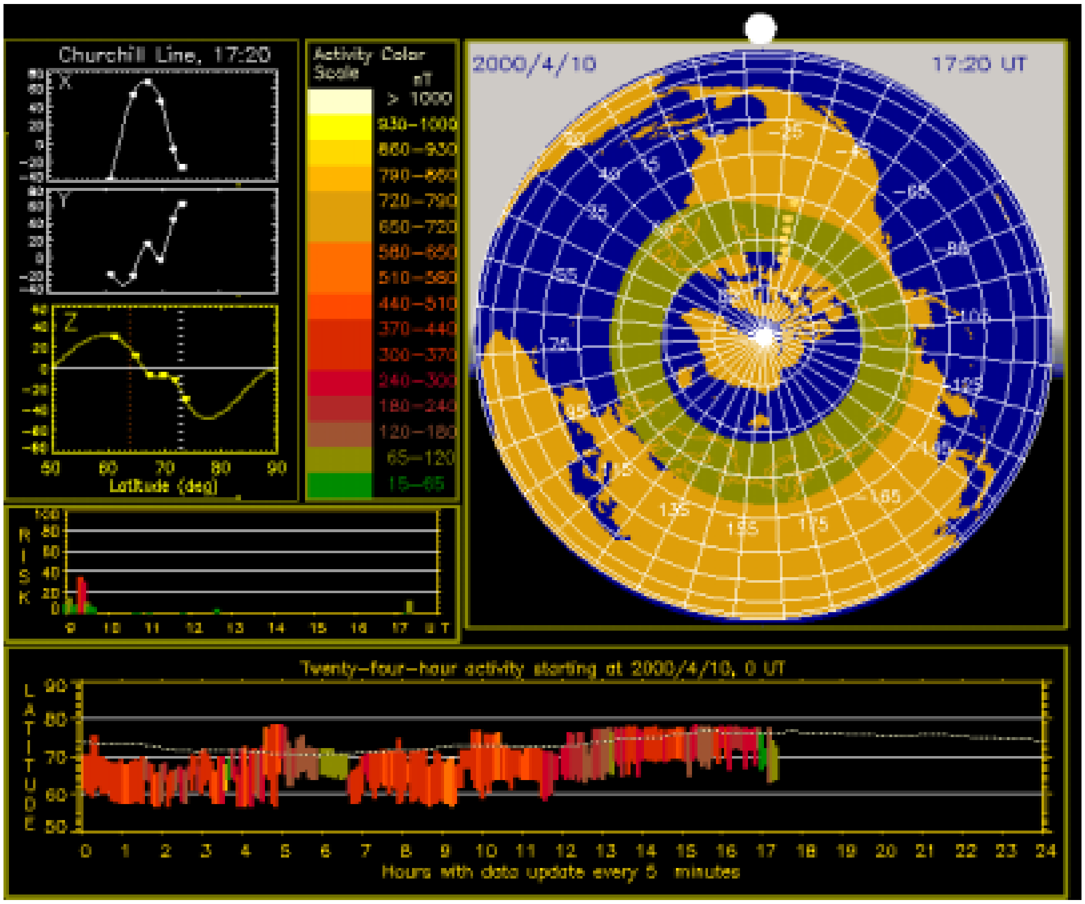

Figure 1: The auroral oval as estimated from CANOPUS magnetometer data (top right). Latitude profiles of the CANOPUS magnetometer data are presented in the top left pannel. The bottom panel shows a time sequence of the location of the aurora oval in the vicinity of the Churchill line of CANOPUS.

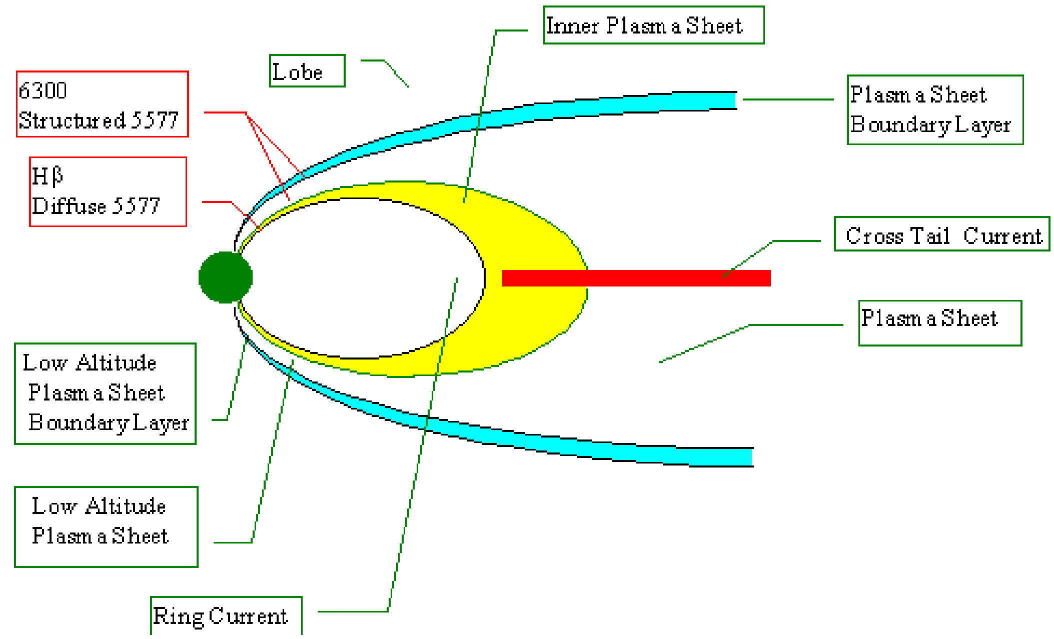

Figure 2: Plasma regimes and auroral particle precipitation in the nightside magnetosphere.

arc that breaks up at substorm onset forms within the IPS, and so this region is coincident with the equatorward part of the auroral oval. The LAPSBL, which most likely maps along field lines to the PSBL, is often a region of spatially structured electron precipitation, sometimes with inverted V signatures, with a variety of energies ranging from hundreds of eV to a number of keV .

Global or magnetospheric scale sizes generally involve magnetospheric convection driven by the solar wind, and changes in the topology of the magnetosphere due to energy storage within the plasmas of the magnetosphere [McPherron, 1991]. During intervals in which the interplanetary magnetic field (IMF) has a southward component, increased merging on the dayside and reconnection in the magnetotail drives enhanced convection within the magnetosphere. The merging process can be transient and localized, giving smaller scale structures in the vicinity of the cusp that are called flux transfer events (FTEs). Many of the features of these processes, occurring near the ionospheric footprint of the cusp, are easily observed in the auroral ionosphere using the SuperDARN radars and the CANOPUS magnetometers [Prikryl et al., 1998]. While it is clear that MHD waves are important in transferring energy from the merging site, the complete physics of FTEs remains to be explained. CANOPUS-2000 will provide data essential to the ultimate understanding of this energy coupling between the solar wind and the magnetosphere.

On the night side, enhanced reconnection and merging leads to the slow (tens of minutes) changes in magnetospheric topology and convection associated with the substorm growth phase [McPherron, 1991]. The growth phase leads to the stretching and thinning of the plasma sheet and eventually the near Earth magnetosphere becomes unstable to MHD instabilities [Samson, 1994]. These growth phase processes can be monitored in the auroral ionosphere using the CANOPUS-1 optical instruments and magnetometers, and the SuperDARN radars [Voronkov et al., 1999]. Field aligned currents near the ionosphere that are associated with large scale or global convection can be determined from SuperDARN [Sofko et al., 1998], ionosonde, and magnetometer data [Kamide et al., 1981]. The optical instruments give the boundaries of the field lines mapping to the plasma sheet and are a good template for mapping convection patterns (measured with SuperDARN) and electrojets (determined from magnetometers) to the magnetospheric regions. While great progress has been made towards understanding nightside magnetotail dynamic processes, a complete picture has not emerged. Integrated satellite and ground based observations are essential in producing that picture. One of the prime research thrusts of CANOPUS-2000 will be to provide valuable input to these coordinated studies.

Figure 3, showing merged MPA data from the Rankin Inlet (RANK) and Gillam (GILL) photometers of the existing CANOPUS-1 array, illustrates some of the points mentioned above using an example event observed on February 9, 1995. The equatorward motion of the equatorward border of the 630.0 nm emissions, marking the Earthward edge of the plasmasheet, and the equatorward motion of the 557.7 and 486.1 nm emissions between about 0300 and 0430 UT indicate a substorm growth phase with energy being stored in a gradually stretching magnetotail. At 0434, a substorm intensification is evident in the optical data with sudden brightenings and poleward motion.

3.1.4 Intermediate scales

There are many intermediate scale processes that are frequently observed in the high-latitude magnetosphere-ionosphere system. These include processes with relevant scales of tens of thousands of kilometers in the magnetosphere and tens to hundreds of kilometers in the ionosphere.

The most dynamic and widely studied of these is the substorm intensification and expansion. Numerous scenarios have been proposed in order to explain the substorm phenomenology. One of these is the Near Earth Neutral Line (NENL) model [Baker et al., 1996], which predicts that the first manifestation of the substorm expansive phase at about 20-40 Earth radii (R_E). The NENL model has not been able to adequately explain ionospheric observations of the substorm intensification and expansive phase, including the brightening of the preexisting auroral arc. For example, the model requires that the NENL form prior to any further activity near the Earth and postulates that energy is supposedly coupled to the near Earth magnetosphere (6-10 R_E) by bursty bulk flows.

In the 1980s, Rostoker (see [Rostoker, 1990] and references therein) began to promote the idea that a successful substorm theory must be consistent with ground

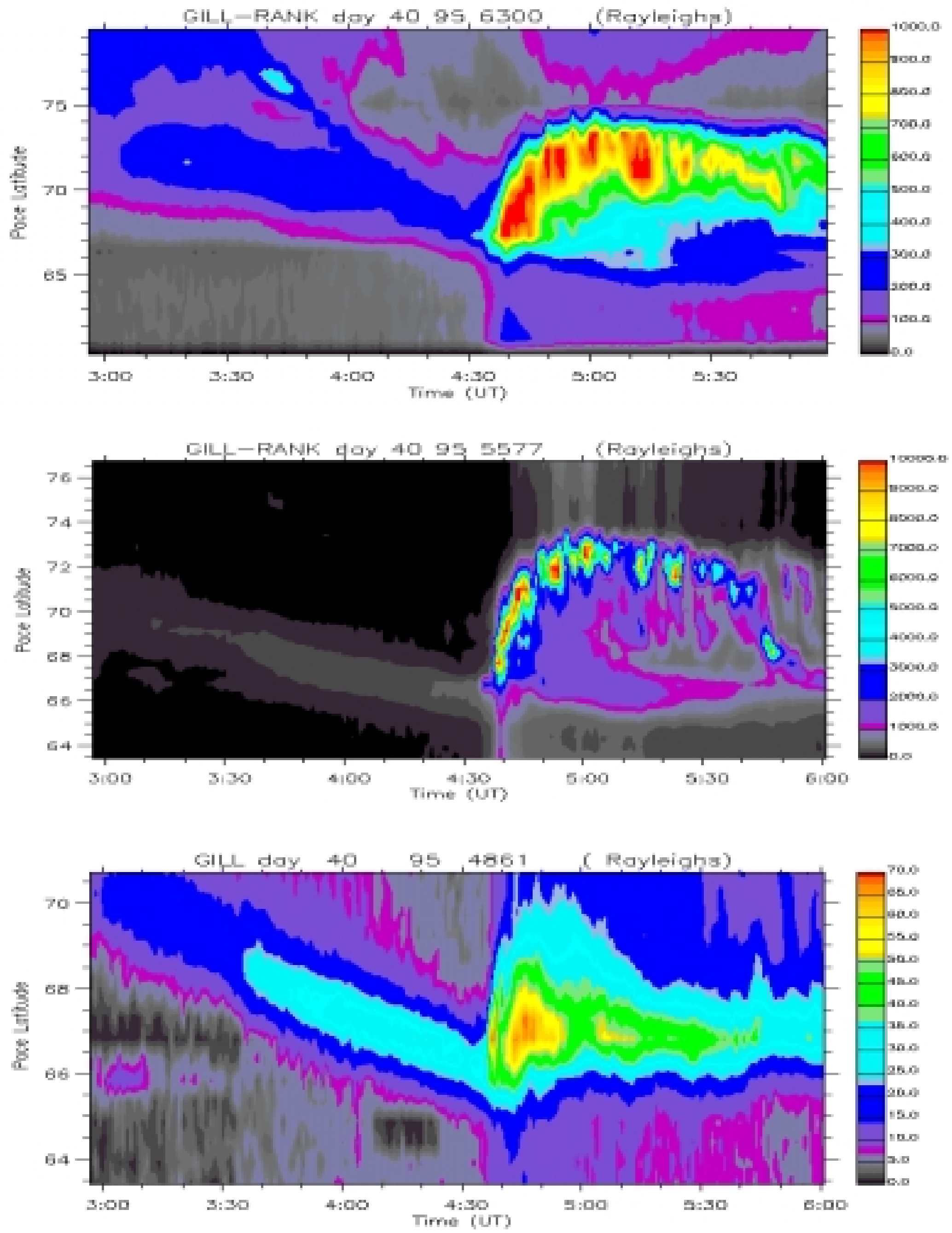

Figure 3: Merged MPA data from the CANOPUS.

based observations of precipitation and magnetic fluctuations. Following this idea, CANOPUS data from numerous substorm events was scrutinized. One crucial result from this body of work is that no manifestions of this early formation of NENL have yet been seen in CANOPUS data. As discussed below, the first event is always the brightening of an auroral arc that maps to the inner Earthward edge of the plasma sheet. This is followed by the formation of large scale auroral vortices (hundreds of kilometers) and the auroral surge. Hβ data has allowed Canadian researchers to determine that the region of near Earth onset is at the Earthward edge of the plasma sheet, much closer to the Earth (6-12 R_E) than the probable position of the NENL (thirty or more R_E). Using a technique proposed by Blanchard et al. [1997] and the CANOPUS-1 optical data, the 630.0 nm emissions have allowed us to determine the regions of the field lines that map to the plasmasheet, and to determine the time when lobe flux reconnection occurs. Lobe flux reconnection seems to always occur after arc brightening, but the process is very explosive (in an Alfvén wave transit time scale) taking only two or three minutes from arc brightening to lobe flux reconnection, at possibly 20-30 earth radii down the magnetotail [Samson, 1997].

On the basis of these observations, the following five stage process for the substorm has been proposed by Canadian scientists:

- Stage 1: The growth phase (see Figure 3, 0300-0430 UT) (duration: 10s of minutes) Merging and reconnection lead to slow adiabatic storage of energy in the magnetosphere. Strong plasma pressure gradients develop near the Earthward edge of the plasmasheet. During this slow growth, the magnetotail remains near equilibrium and essentially stable.

- Stage 2: The precursor phase (duration: minutes) Periodic vortex structures with an azimuthal wavelength of 100-200 km form on a pre-existing auroral arc that is located on field lines threading the inner edge of the plasma sheet (see examples in CANOPUS ASI images in [Samson et al., 1996] and [Voronkov et al., 2000], and Figures 4 and 5 of this document). Ballooning and shear flow ballooning modes might play an important role in the formation of these vortices [Voronkov et. al., 1997]. This instability can "trigger" the substorm intensification.

- Stage 3: Intensification phase (duration: 10s of seconds) Following the precursor phase, the large scale vortex expands poleward, forming the "auroral surge", and there is an enhancement of the electrojet currents. This process is also likely to be connected with the "explosive growth phase" in the near Earth cross tail current [Ohtani et al., 1992] and [Liu, 1997]. The time scales (10s of seconds) of the surge formation and explosive cross tail current growth are comparable to Alfvénic time scales, L/V_A, in the near Earth magnetotail, where L is the characteristic scale size, and V_A is the Alfvén speed, indicating an explosive and nonlinear instability, possibly ballooning.

- Stage 4: The expansion phase (see Figure 3 at 0434 UT) (duration: 10s to 100s of seconds). Nonlinear ballooning may lead to a highly stretched tail magnetic field topology near the Earth, with enhanced cross tail currents. Increased effective resistivity of the plasma initiates a hybrid ballooning-tearing mode or a region of localized reconnection, and the beginning of the dipolarization of magnetic field lines in the near Earth region. Instabilities such as the cross field current instability [Lui, 1991] might enhance the effective resistivity at this time. The tearing or reconnection region evolves in the tailward direction. Only a small amount of work has been done on these hybrid instabilities which might occur in the magnetosphere and consequently this is the most speculative part of the scenario presented here.

- Stage 5: Lobe flux reconnection and recovery phase (minutes). When the region of localized tearing or reconnection reaches lobe field lines, closure of open field flux begins. This phase is compatible with the near Earth neutral line (NENL) model of substorm expansion [Baker et al., 1996]. CANOPUS optical data indicate that this might occur at about 20-40 R_E down the magnetotail. This is followed by the recovery phase, during which the entire system relaxes to a quasi-stable state.

Even though this proposed substorm scenario is consistent with existing CANOPUS data, and supported by three dimensional nonlinear MHD simulations, there is much more to be done. For instance, the timing of the substorm onset, a process which happens on a time scale of seconds, is based on data that is obtained at intervals of tens of seconds. The substorm surge evolves in a structure that expands beyond the single CANOPUS ASI field of view. All of the crucial Hβ observations are from the photometers, which provide only a one dimensional view of a clearly three dimensional process. The instrument compliment of CANOPUS-2000 that will include an array of ASIs, certainly capable of much higher time resolution than the original CANOPUS ASI, will possibly provide two dimensional images of Hβ emissions, and will have an effective field of view comparable in size to the entire surge. This increased capability will give us an opportunity to critically assess the validity of the CANOPUS-1 based model.

While we have focused on the substorm problem here, there are of course numerous other scientifically interesting mesoscale space physical processes. These include:

- large-scale auroral vortices that evolve from mesoscale auroral arcs as a result of unstable MHD modes and are associated with breakups (see above) and pseudo-breakups [Voronkov et al., 2000], and north-south oriented auroral structures [Liu and Rostoker, 1993] and [Donovan et al., 2000].

- Convection mesoscale homogeneity observed as F-region patches and blobs observed travel across the polar cap from the day to the night side [Prikryl et al., 1999].

- sun-aligned arcs observed during primarily northward IMF conditions, and that drift from dawn to dusk, or vice versa, depending on the sign of By [Carlson, 1994].

- rapid plasma flows in the CPS [Baumjohann et al., 1990] and associated ionospheric signatures in the form of poleward boundary intensifactions [Lyons et al., 1999], north-south aligned auroral arcs [Henderson et al., 1998], and auroral streamers [Sergeev et al., 1999].

- Joule and plasma wave heating of ionospheric plasmas in auroral regions

- gravity waves observed with HF radars [Samson et al., 1989] and digital ionosondes [e.g., Hall et al., 1999].

As in the case of the substorm problem, considerable progress has been achieved in research on all of these processes and our ability to gain a more comprehensive understanding of them is hindered by the temporal and spatial limitations of our existing data. CANOPUS-2000 will include several new magnetometers, two new ASIs, and an array of CADIs. In addition, the new SuperDARN Prince George/Kodiak radar pair is now operational, and three additional NORSTAR imagers will be fielded by September of 2000. The ground based capabilities provided by these three Canadian led projects will enable us to make significant advances in our understanding of all the processes listed here.

To summarize, the higher spatial and temporal resolution, and larger geographical coverage that will be afforded by CANOPUS-2000 will allow us to construct a dynamical picture of mesoscale processes and to address questons relating to cross scale coupling in the entire magnetosphere-ionosphere system.

3.1.5 Small scale

Small scale processes in the magnetosphere occur on scale sizes of of tens to hundreds of kilometers, and reach into the kinetic regime (including electron inertia and ion gyroradius effects). Small scale ionospheric processes of interest in the ionosphere include tens of meter scale irregularities, kilometer scale discrete arcs and tens of kilometer scale inverted V's. In this section, we discuss several small scale processes that we will study using the CANOPUS-2000 array.

Discrete and Homogeneous Auroral Arcs

Explaining the mechanism by which auroral arcs are formed is a fundamental objective in plasma physics. The more homogeneous arcs can have widths of only tens of kilometers in latitude [Knudsen et al., 2000], yet extend over thousands of kilometers in longitude. Kilometer scale, discrete arcs can also have a remarkable regularity, with a number of stable parallel arcs [Trondsen et al., 1997]. How these thin and stable arcs can form in a complicated and dynamic magnetosphere

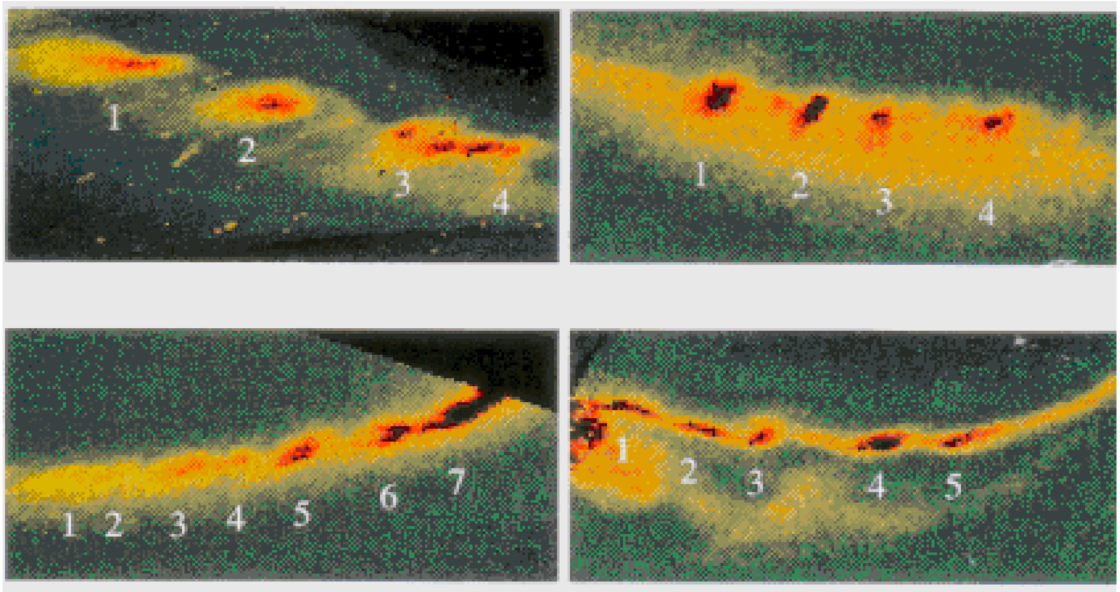

Figure 4: Azimuthally periodic auroral vortices seen by the Freja UV imager [Murphree et al., 1994]. The separation of the vortices are on the scale of 100s of kilometers.

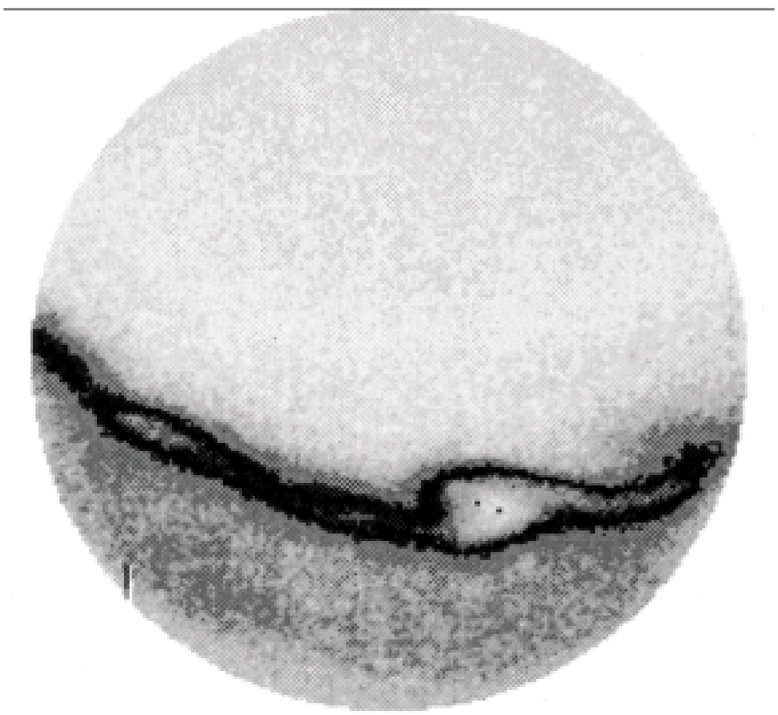

Figure 5: An auroral arc and auroral vortices formed by a ULF field line resonance as seen by the CANOPUS ASI [Samson et al., 1996]. Outside the vortex structures, the arc is about 10 km thick.

is a puzzle. A variety of generator and electron accelerator mechanisms for the formation of auroral arcs have been proposed and some of these are tabulated in the tables below (based in part on Borovsky [1993], Rankin et al. [1999], and Samson et al., [1996]).

Generator Mechanism	**Ionospheric width (km)**
shear in low latitude boundary layer	130
shear in plasma sheet	50
ionospheric conductivity feedback	20
preesure gradients in the near Earth plasma sheet	2-3
MHD field line resonances	10 and <1 subscale

Accelerator Mechanism	**Ionospheric Width (km)**
static magnetosphere ionosphere coupling	300-400
particle anisotropies	1
strong double layers	1-2
electrostatic shocks	2-3
ion acoustic double layers	1-2
kinetic Alfvén waves	1
anomalous resistivity	1-2
nonlocal conductivity in MHD field line resonances	10 and <1 subscale

Recent CANOPUS-1 observations [Samson et al., 1996] and new theories [Rankin et al., 1999] point to field line resonances (see the schematic in Figure 6) and dispersive shear Alfvén waves as the mechanism leading to some auroral arcs. Figure 7 shows an example of 630.0 nm emissions from an auroral arc system produced by a 1.3 mHz field line resonance. The multiple arc system (two arcs are sometimes seen at the same longitude), the 10 km latitudinal scale size of the arcs, and the azimuthal (westward) motion are characteristic of field line resonances. Figure 8 shows an image of CANOPUS-1, MSP measurements of emissions at 630.0 nm from an auroral arc produced by 2.6 mHz field line resonances. Fine scale structuring can be due to both electron inertia and ion gyroradius effects, giving hundreds of meters scales in the auroral ionosphere [Trondsen and meters) vortex structures in discrete arcs might be due to nonlinear tearing modes in the strong field aligned currents associated with the localized Alfvén waves, just above the auroral ionosphere [Seyler, 1990].

The small scales of the auroral processes associated with auroral arcs clearly show that the CANOPUS-2000 optical instruments, particularly the ASIs, will play a dominant role in these studies. HF- radar, magnetometer and CADI observations will prove useful in these studies in characterizing the electrodynamic and plasma environment in which these small-scale instabilities arise.

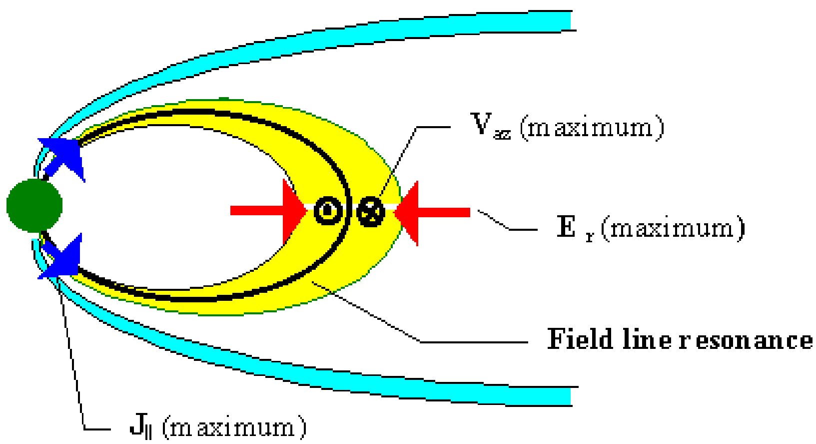

Figure 6: A field line resonance threading the inner plasma sheet (yellow region). The resonance shown here is the fundamental mode with a highly conducting ionosphere. The maximum in the field aligned current, $\mathbf{J}_{||}$, is 90 degrees out of phase with the maximum in the radial electric field, $\mathbf{E}_r$. Typical frequencies of the resonances are 1-4 mHz. Maximum $\mathbf{J}_{||}$ is in the range of many μA/m^2. The maximum in the azimuthal velocity field, V$_{az}$, can be of the order of 100s of km/s. The net perpendicular potential change in the equatorial plane can be of the order of several keV.

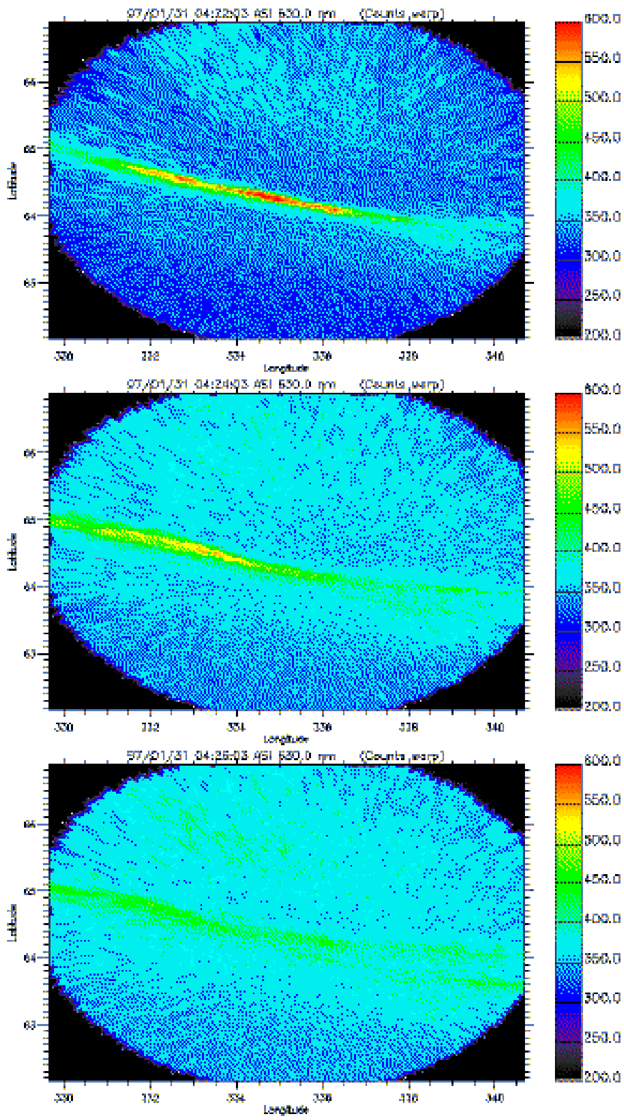

Figure 7: An auroral arc system seen in CANOPUS 630.0 nm ASI data (times are 0422:03, 0424:03, and 0426:03 UT). These auroral arcs were produced by a 1.3 mHz field line resonance.

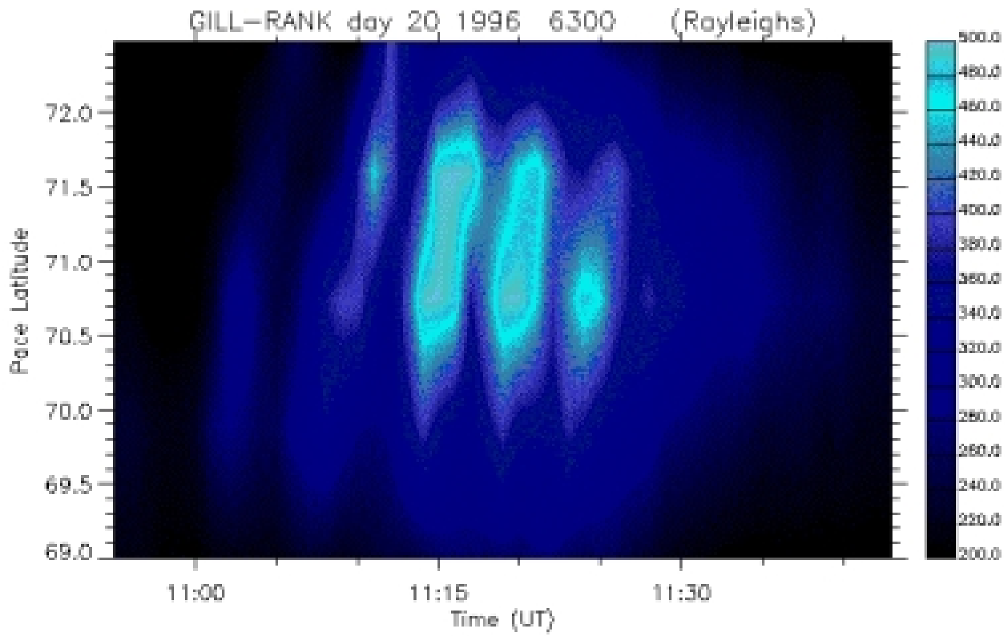

Figure 8: MSP observations of periodic poleward moving bands of 630.0 nm emissions associated with an auroral arc formed by a 2.6 mHz field line resonance.

Small scale ionospheric irregularities

E and F-region irregularities are a common feature of the high latitude auroral ionosphere [Hanuise, 1983]. These meter scale plasma irregularities are associated with ionospheric sources of free energy, including strong electrostatic fields, as well as gradients in electron density and plasma convection. Recent comparisons of SuperDARN backscatter with CANOPUS optical data indicate that irregularities are commonly found at the equatorward border of low energy (100s of eV) electron precipitation from the plasma sheet on the nightside. These irregularities may significantly modify the ionospheric conductivity and therefore affect the larger scale magnetosphere and ionosphere coupling.

3.2 Science implementation

3.2.1 Scientific specifications for instrumentation

In this proposal we have recommended an expanded array of optical instruments, magnetometers, and digital ionosondes. The use of these instruments for meeting our scientific objectives is outlined below.

CADI

The difference between the new Canadian digital ionosondes (CADI) and the "classic" ionosondes is that the older ionosondes were not phase coherent and thus could only measure the electron density along the beam path. Unfortunately many researchers are still not aware of the much expanded capabilities of these new ionosondes, and still regard an ionosonde as an instrument that measures only electron densities. The CADI instrument will allow the measurement of both ionospheric electron density profiles and ionospheric drifts. The drift measurements allow a reliable and independent method to determine local plasma convection velocities. In the future an expanded array of these instruments within CANOPUS-2000 might allow measurement of the cross polar cap potential which is an important indicator of the energy input into the magnetosphere. Typically, this input occurs well in advance of magnetic storms and substorms and therefore the polar cap potential growth is a very first warning indicating that explosive processes are coming.

The combination of plasma drift and density measurements using new ionosondes gives researchers an opportunity to monitor the electrodynamics of the ionosphere, including the spatial and temporal dynamics of conductivity layers, electric fields, and ionospheric currents. In combination with magnetometer and optical data, this should help to identify high latitude current systems and corresponding regions of the magnetosphere where these currents originate.

ASIs and Meridian Scanning Photometers

The selection of the wavelengths for the ASIs is motivated by the scientific objectives mentioned above but limited by the brightness of the auroral emissions and the efficiency of the imagers, and the number of filter positions available in that imager (our present selection has five slots). Currently, our intention is to operate the ASIs at five wavelengths. The combination that we envisage using these wavelengths will allow for high time resolution imaging of large scale auroral features, some understanding of the precipitating electron distribution, average incident energy flux and the identification of magnetospheric boundaries (see below).

- **427.8 nm**: Emission from this N_2^+ band originates primarily in the lower E-region and is weaker than the 557.7 nm emission, typically by a factor of $\sim$5. The intensity of this virtually instantanious decay emission can be related to the incident energy flux of precipitating particles. Note: we may choose to operate at the less bright ${N_2}^+$ band at 470 nm due to the fact that the imaging system will be significantly more optically efficient at that wavelength.

- **486.1 nm**: The Hβ emission is due entirely to proton precipitation. Emissions at other commonly used wavelengths, particularly in faint auroral features, are often due to a mixture of proton and electron precipitation. Hβ provides unambiguous information about proton precipitation and, therefore, a means by which one can determine the relative contribution due to protons at other wavelengths. Emission intensities in proton aurora are commonly greater than 50 R and extremely rarely in excess of 200 R.

- **557.7 nm**: This is a very bright feature present in all discrete electron auroras and diffuse auroras. The emission arises primarily from the lower to middle E-region. Though quantitatively less useful than the other three wavelengths listed here, this line provides important morphological information with high time resolution. The excitation lifetime for this emission is 0.74 seconds and brightnesses in excess of 500 R are commonplace.

- **630.0 nm**: This bright emission arises primarily in the F-region. These emisssions are due to low energy (100s of eV) electron precipitation and can be used to identify the polar cap boundary and the Earthward boundary of the electron plasmasheet. In combination with CADI and magnetometer data, this emission can monitor the large scale dynamics of the magnetosphere.

We do not anticipate any changes to the MSPs, and these instruments might be decommissioned if the ASIs prove to be adequately sensitive to Hβ emissions, and can be accurately calibrated.

Magnetometers

The MARIA magnetometer data has been extensively used by the international community over the past decade. With one exception, the scientific specifications for these instruments will be the same as those given in the CANOPUS-1 project plan. We will use higher standard sample rate (8 Hz) to allow studies of higher frequency plasma waves associated with auroral processes.

Riometers

The present CANOPUS MARIA sites all have functioning 30 MHz zenith type riometers. Riometer data monitor high energy particle deposition in the lower ionospheric D and E regions, and are useful as an indicator of highly disturbed periods. To date, data from the CANOPUS riometers has not been widely used by the scientific community. We expect that in the future, however, this data may prove to be valuable in coordinated studies involving GPS systems and for high latitude radio wave propagation problems. Furthermore, the relatively low cost of continuing their operation and the often unexpected benefits of long term data sets of this type in space science (for example, consider the incredible value of the ongoing Penticton F10.7 cm flux measurements), we intend to continue operating the existing riometers in the next phase of CANOPUS.

Integration

Recent developments in computational hardware and methods promise to dramatically enhance the benefits of observations obtained by large numbers of different kinds of instruments. A central theme in the CANOPUS-2000 program will be the development of sophisticated tools for the integration of data from the four above mentioned instrument arrays and data from partner observational programs (i.e., SuperDARN and NORSTAR). This integrated data will be used as input for state of the art computer simulations and models. This integration effort will also involve the coordinated analysis of both data and computational results. An essential part of integration will be to highlight the role of CANOPUS-2000 in the international space science effort and to provide the CANOPUS-2000 team with access to the latest achievements in our field. The CANOPUS-2000 integration effort will be intimately tied to the Facility for Data Analysis and Modelling.

3.2.2 Measurements for Scientific Studies

CANOPUS-2000 measurements will facilitate scientific research by a significant fraction of the Canadian space science community and numerous international researchers. In this section, we describe how CANOPUS-2000 measurements will be used in several key areas of research that are active thrusts of the Canadian community.

Magnetospheric convection

The measurement and interpretation of global scale convection processes requires the use of all the CANOPUS-2000 instruments plus data from the CANOPUS-2000 partners, NORSTAR and SuperDARN. CADI and SuperDARN give direct measurements of plasma convection velocities, providing ionospheric irregularities are present. Magnetometer data allow measurement of ionospheric electrojet strengths and an estimation of ionospheric electric fields, provided the ionosphere conductivity can be estimated using a model or inferred from CADI data. On the nightside, the measured convection fields can be compared to the optical data to determine the mapping of the ionospheric convection regimes to the regions of the magnetosphere [Voronkov et al., 1999].

Magnetospheric topology, energy storage, and plasma regimes

Plasma densities in the dayside magnetosphere can be determined by using magnetometers for measuring the ULF (1-10 mHz) shear Alfvén field line continuum frequencies [Waters et al., 1996] in the CANOPUS data. An optimal spacing of station requires a separation of less than 200 km, and this is the reason we are requesting two further stations on the Churchill line.

The use of the optical data to determine plasma regimes in the magnetotail was outlined in the discussion of Figure 2.

Energy storage in the magnetosphere is largely concentrated in the Earth's magnetotail and the ring current. During intervals with enhanced reconnection and merging that are primarily associated with southward interplanetary magnetic field periods, tail field lines stretch and strong pressure gradients develop near the Earthward edge of the plasma sheet. The expansion of the region of open field lines on the nightside can be monitored by following the equatorward motion of the poleward boundary of red emissions (see Figures 2 and 3). The region of open field lines can also be estimated from magnetometer data (Figure 1), but this technique incorporates uncertainties in the baseline determination and requires careful comparison with the more robust optical measurements.

Stretching of field lines in the near Earth magnetotail can be monitored by following the equatorward motion of the equatorward band of Hβ emissions (see Figure 3). In fact, the latitude of the Hβ emission gives a simple qualitative measure of energy storage in the magnetosphere, and an indication of the likelihood quantitative models will have to wait for a comparison of the optical data with global MHD computational models developed within FDAM as part of the Canadian space weather program.

Intermediate scale processes

High time resolution (10 seconds or better) and two dimensional images are strict requirements for studies of the explosive or expansive phase of the substorm.

As such, the ASIs will play a central role in studies of the substorm intensification and expansive phase. As well, the magnetometer data will give very accurate estimates of the time of substorm intensification onset as well as in mapping of the dynamic evolution of the substorm electrojets.

The optical emissions from precipitating electrons and protons, and the frequencies of field line resonances (that are currently measured by magnetometers) associated with the substorm indicate that the intensification starts at the Earthward edge of the plasmasheet and near the ring current (at a distance of no more than 8-10 R_E). The electron arc which brightens to initiate the intensification is embedded in the poleward side of a region of diffuse 557.7 nm and Hβ emissions caused by energetic (tens of keV) proton precipitation. These protons have been energized as they convect earthward from the magnetotail into the more dipolar region of the magnetosphere (see Figure 2). The precipitation of these protons, which are on field lines mapping to 6-10 R_E, forms the midnight and pre-midnight diffuse 557.7 nm and Hβ emissions at the equatorward edge of the auroral oval. The red line emissions which map along field lines to the plasma sheet (see Figure 2), indicate that the region of open field lines is often 4-6 degrees poleward of the arc which initiates the substorm. However, the detailed picture of the proton band formation is still unclear and requires further experimental and theoretical studies.

Small scale processes

Scale sizes in mesoscale arc systems range from ∼20 km down to ∼1 km and an instrument of choice for their investgation is the ASI. Although these scale sizes cannot be succesfully resolved by CADI and SuperDARN, these instrumements will be useful in characterizing the eletromagnetic conditions in the region containing the arcs. As well, they might find use in studying the spectra of irregularities produced by the arcs.

ASI data will be valuable in determining the widths of arcs, spatial distributions of energy deposition, for identifying low frequency oscillations, and for measuring the wavelengths and propagation characteristics of periodic longitudinal structures.

Placing Campaign-style Observations Within a Larger Context

Due to the scale sizes of these processes, they are most often studied using high time and spatial resolution instruments operated in campaign modes on the ground or on satellites and rockets. Nevertheless, large scale ground based observations provided by instrument arrays such as CANOPUS play a crucial role in studies of small-scale processes in characterizing the electrodynamic and mesoscale plasma environment conducive to the generation of these instabilities. There are numerous examples in the literature of this very important role of these larger scale ground based observations. Four examples of such work are

- Hall et al. [1990] used CANOPUS ASI data to show that the presence of an auroral arc between the BARS radar transmitter/receiver and the radio auroral scattering region greatly enhanced the likelihood of strong VHF echoes, thus explaining the existence of VHF radar echoes at anomolously large aspect angle angles.

- Sedgemore-Schulthess et al. [1999] used meridian scanning photometer data to demonstrate that enhanced incoherent scatter radar spectra obtained with EISCAT occur within sharp conductivity gradients in the cusp-cleft region and are associated with field-aligned currents.

- Olsson et al. [1998] used Freja electron spectrometer data to perform the first-ever observational test of the Knight-Lyons current voltage relationship during magnetically active times. In this study, CANOPUS magnetometer data was used to identify the substorm onset timing and location.

- In deciding when to launch the GEODESIC sounding rocket from Poker Flat, D. Knudsen (private communication) used a host of ground-based and space based instruments in order to correctly predict the formation of a large auroral surge over northern Alaska.

There is ongoing Canadian work aimed specifically at coupling measurements of small scale processes with CANOPUS, SuperDARN, and NORSTAR observations. For example, D. Knudsen has begun a project to construct a photometer capable of $\sim$500 Hz monochromatic measurements, which will be mounted on the side of one of the new NORSTAR imagers and will be used to identify occurrences of flickering aurora. As well, M. Lessard (Dartmouth Colledge) and D. Knudsen are developing an induction coil magnetometer that they hope to deploy at CANOPUS sites.

In implementing CANOPUS-2000, we will make every effort to ensure that our observational program provides scientifically meaningful context for experiments aimed at understanding small scale plasma processes. This applies equally to large international satellite missions (such as Cluster, FAST, and IMAGE) as well as small ground-based campaigns (such as Trondsen's use of the UofC's Portable Auroral Imager).

3.3 Connection to International Programs

One of the great benefits of CANOPUS-1 has been to allow Canadian scientists to enter into collaborations with scientists in the international community. CANOPUS-2000 will enhance our ability to do so. Below, we briefly discuss some of the international observational programs that are directly related to CANOPUS scientific goals and capabilities.

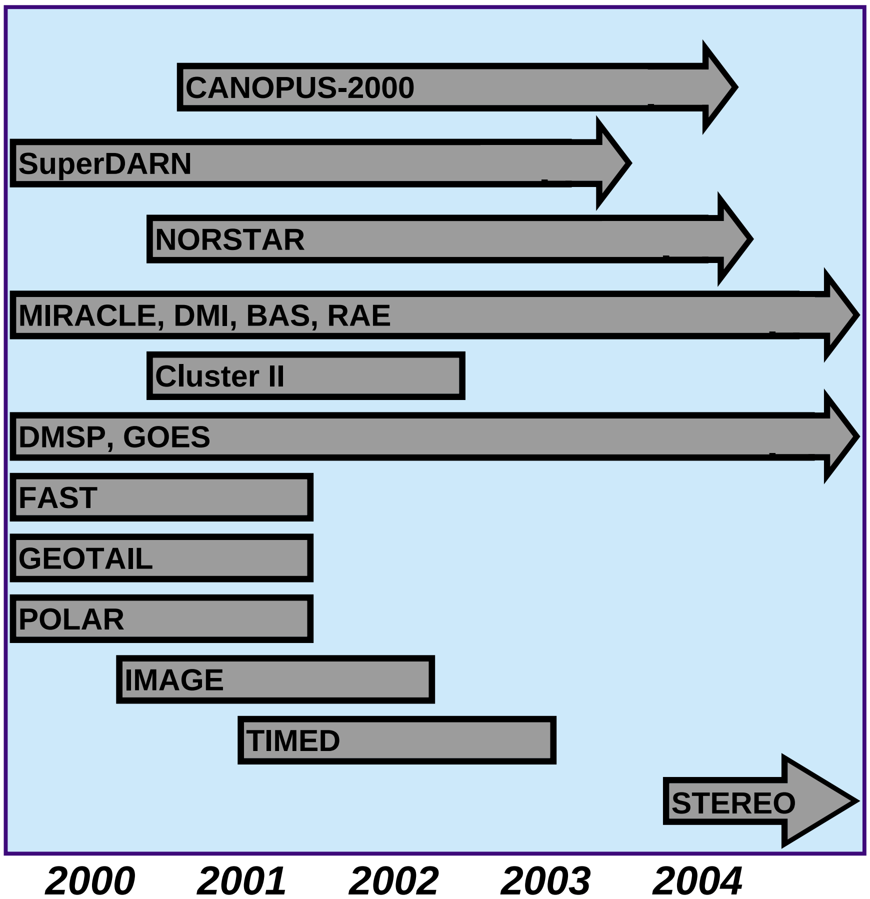

Figure 9: Schematic showing periods of operation of some ground based and spacecraft programs relevant to CANOPUS-2000.

Relevant Ground Based Programs

CANOPUS-2000 will be one of a number of large ground based instrument arrays that operate worldwide. Together with MIRACLE (Scandinavia/Svalbard), MACCS (Eastern Canada), the DMI Greenland Chain, the Alaska Geophysical Institute instruments at and around Poker Flat, the British Antarctic Survey (BAS) and Russian Antarctic Expedition (RAE) programs for operations in Antarctica, and the worldwide SuperDARN radar array, we provide a global picture of the electrodynamics of near-Earth space. These instrument arrays all offer a variety of distinct advantages, and suffer from specific disadvantages. The distinctly Canadian advantages are excellent access to a large portion of the auroral and polar regions and a long history of cutting edge ground based science. In recent years, advances in computer technology and more cost effective data storage media have facilitated the use of ground based data obtained on a truly global scale. Through CANOPUS-2000, we are fulfilling our responsibility to the international space science commuity.

Relevant Spacecraft Programs

The United States, Japan, and the European Community operate a number scientific satellite programs. In situ particle and field measurements will be obtained by most or all of the following spacecraft over the next several years. The ESA Cluster II mission was successfully launched in August 2000. This cluster of 4 spacecraft will be injected into a 4x19 R_E inertially fixed orbit and will provide the first ever direct measurements of plasma pressure gradients, magnetospheric currents, and field line curvatures. The Cluster community has specifically focused an enormous effort on coordination with ground based observational programs including CANOPUS. Through CANOPUS, SuperDARN, and NORSTAR, Canadian scientists will have high-level access to the Cluster data set.

The FAST satellite, and the fleet of up to five DMSP spacecraft are in orbits below 4000 km. POLAR is in a 2x8 R_E orbit and Geotail operates at radial distances of up to 30 R_E in the nightside magnetosphere. As well, the GOES measurements from geostationary orbit. The newly launched IMAGE spacecraft is devoted to remote sensing of magnetospheric processes, including the proton aurora.

These seven missions provide the capability of important in the processes that we have identified in our science objectives. We anticipate using data from all seven missions, in conjunction with the complementary ground based programs discussed above, in achieving our science goals.

From a more long term perspective, there will be five more STP missions over the next decade. All of these five (TIMED, STEREO, Magnetosphere Multiscale, GEC, and Magnetosphere Constellation) will provide new and unique opportunities for collaborations involving ground based observational work. Magnetosphere Multiscale (MMS), for example, is a five satellite "cluster"-type mission scheduled for launch in 2006. The mission objectives of MMS focus on smaller scale, and higher frequency processes than the ESA's CLUSTER II. Lessons learned from collaborative work involving NORSTAR, SuperDARN, CANOPUS-2000 and CLUSTER II, as well as our demonstrated expertise in dealing with magnetospheric plasma physics questions will put us in an excellent position to exploit the opportunity that MMS presents.

It is very likely that sometime over the next decade, a mission involving a number of orbitally phased low altitude spaceraft will be undertaken by NASA. Such a mission would be aimed at resolving unanswered questions in auroral physics: as in the case of Cluster, the $\sim$4 spacecraft would allow for the separation of temporal and spatial variations. In previous nearly funded missions, ground based support has been central in the design and expected scientific yield.

4 Program Design

4.1 Overview

For CANOPUS-2000, we are requesting the acquisition and installation of four new magnetometers, two new ASIs with Hβ imaging capacity, two digital ionosondes, a modernized data acquisition network, and a new data archiving and retrieval system with a web-based interface. All four magnetometers will be at new sites. The ASIs and digital ionosondes will be placed at existing sites.

4.1.1 CANOPUS-2000 deliverables

All the data mentioned below (except the high time resolution ASI data) will be available from the Ottawa archiving site and a mirror site at Edmonton. High time resolution ASI data will be available from data archives at Calgary. CANOPUS standard indices will be provided automatically to a number of international ogranizations and will be available on request.

Scientific data

1. 3-component fluxgate magnetometer data from 17 sites sampled at 8 Hz.
2. 30 sec, high resolution data from the existing MPA array (3 instruments) at existing mavelengths.
3. 1 min, high resolution (512x512) ASI data at selected emission wavelengths (see the discussion of instrumentation).
4. 10 sec or less, high resolution ASI data for selected intervals (i.e., the ASIs will be operated on a "campaign mode" basis).
5. 1 min ionospheric density profile measurements from digital ionosondes.
6. 1 min ionospheric plasma convection velocities from digital ionosondes.

CANOPUS-2000 standard indices

1. ionospheric electrojet strengths and locations (magnetometer and CADI data).
2. auroral activity index, including energy deposition in the ionosphere (magnetometer and optical data).
3. magnetic activity indices (magnetometer data).
4. an index of energy storage in the magnetosphere, including cross polar cap potential, (from magnetometers, optical data, and digital ionosondes).

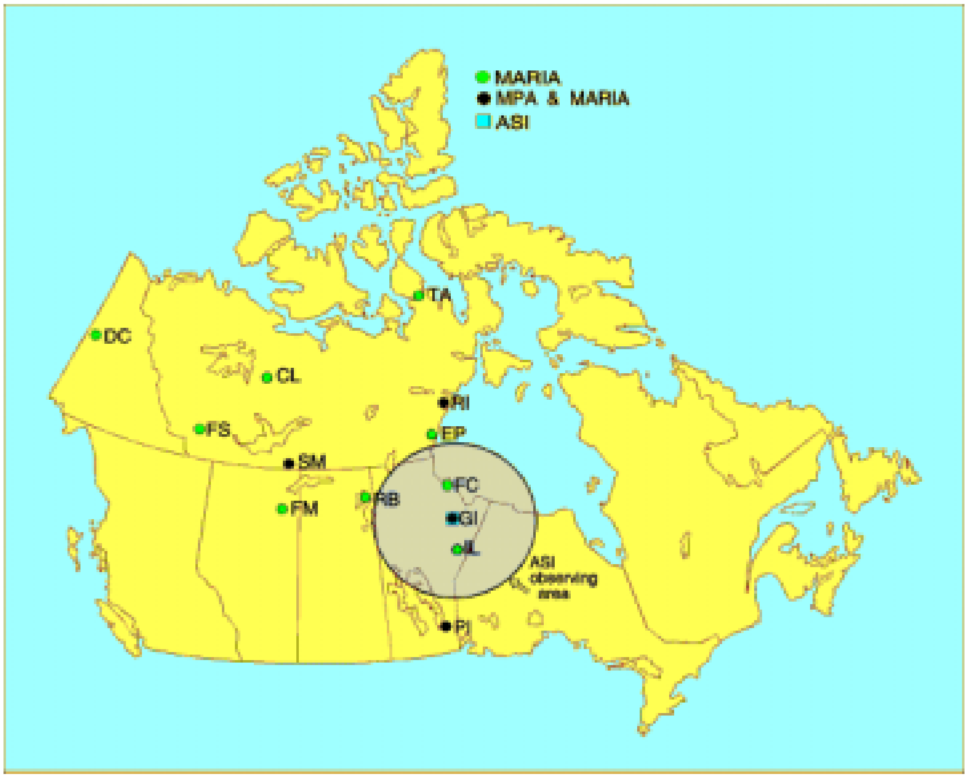

Figure 10: CANOPUS-1.

5. indices for the risk of magnetic storm and substorms (based on the index of energy storage (4)).

6. magnetospheric, equatorial plasma densities (from field line resonances seen in magnetometer data).

7. ionospheric irregularity index, including global positioning system (GPS) risk assessment (from digital ionosondes, SuperDARN (as a CANOPUS-2000 partner), and optical data).

4.2 The CANOPUS-2000 array

The CANOPUS-1 magnetometer array (Figure 10) will be extended by the addition of a minimum of four new sites. The two western sites, potentially at Whitehorse and Inuvik, will extend the CANOPUS-2000 azimuthal coverage and allow further support for the SuperDARN radars at Prince George and in Alaska (Figure 11). The new sites, one between Fort Churchill and Eskimo Point and the other between Island Lake and Pinawa are all for the measurement of magnetospheric plasma densities using the ULF Alfvén wave continuum.

When completed, the ASI array will have Hβ imagers at Rankin Inlet and Gillam, (Figure 12) allowing full latitudinal coverage of the auroral oval and further

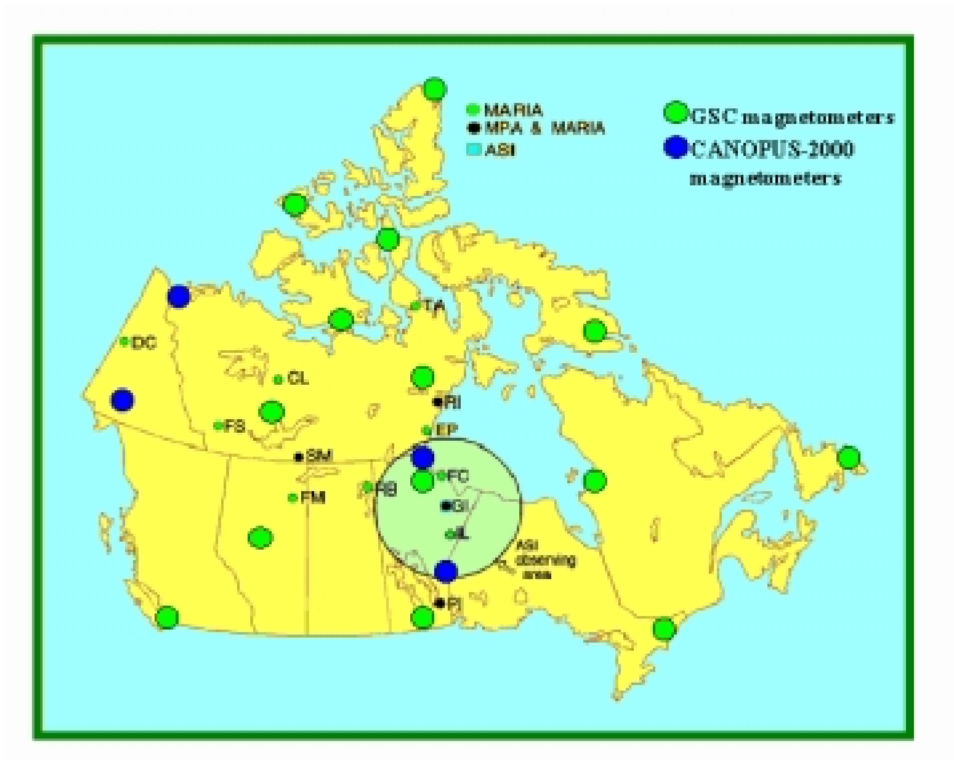

Figure 11: Added magnetometers for CANOPUS-2000.

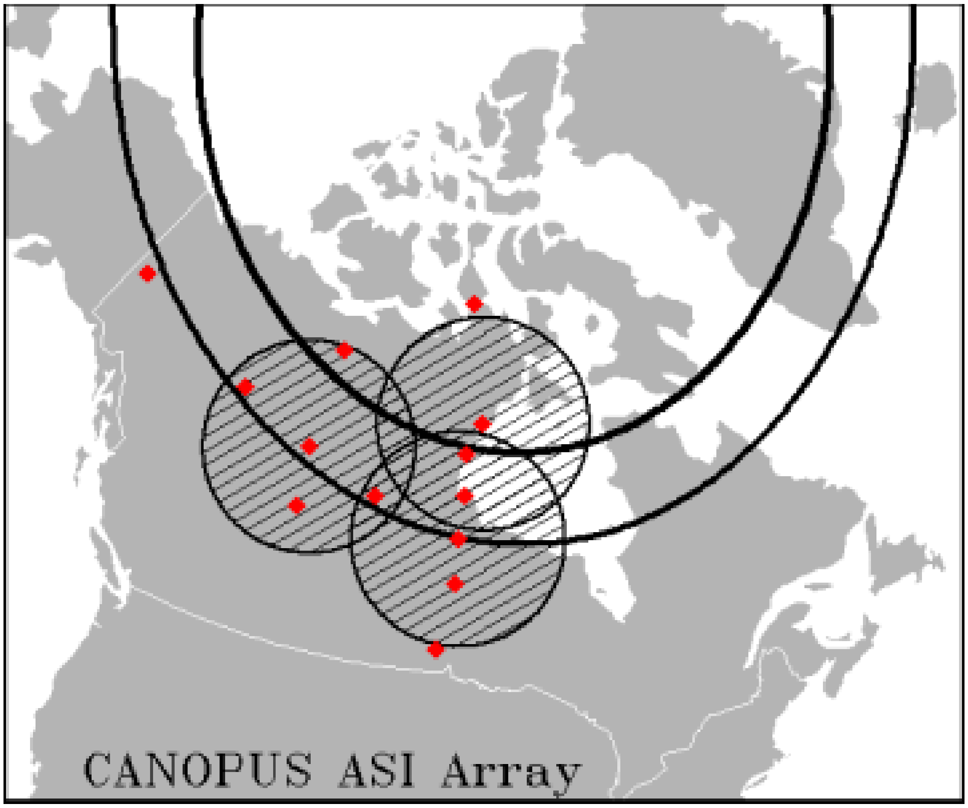

Figure 12: The CANOPUS-2000 ASI array. Circles show the estimated field of view.

coverage under the SuperDARN field of view. The POLARIS imager will be moved to Fort Smith to give enhanced longitudinal coverage. The previously planned site in Rabbit Lake for the POLARIS imager may become a very difficult place for a transportation reason because of the cessation of operations at the uranium mine there.

The plans are to install two CADI instruments, one at Rankin Inlet and one at Taloyoak (Figure 13). The Rankin Inlet station will be particularly useful for monitoring the transition from open to closed field lines in the night side magnetosphere. The 630.0 nm optical emissions indicate that the average position of this boundary is typically at the Rankin Inlet zenith in the midnight sector. This location will also allow us to evaluate the performance of the ionosonde on both open, polar cap field lines and closed auroral field lines, including intervals with substorm expansive phases. The CADI velocity measurements can also be used to complement SuperDARN measurements in this area. The site at Taloyoak will allow monitoring of polar cap and cusp (dayside) phenomena. If performance is acceptable, an extended polar cap array might be considered. The advantage of such an array would be the capacity to measure the cross polar cap potential, ionospheric conditions and local time permitting.

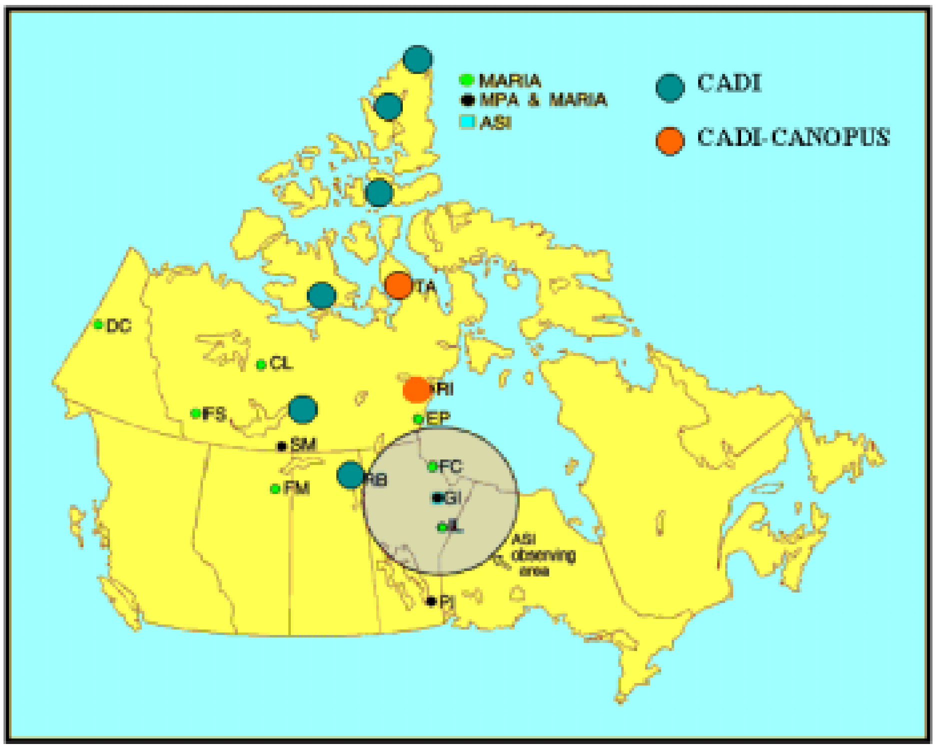

Figure 13: The existing CADI array and the recommended initial CADI instruments for CANOPUS-2000.

4.3 Instrumentation and specifications

4.3.1 Magnetometers

Each station will be equipped with a 3-component fluxgate magnetometer of the ring-core type. These instruments might be supplied by Narod Geophysical of Vancover, British Columbia. Among the specifications met by these magnetometers are:

1. ± 80000 nanoTesla (nT) dynamic range on all axes.
2. resolution of 0.025 nT.
3. temperature coefficient < 0.1 nT/C.
4. drift of < 0.01 nT/day.
5. noise figure of < 0.007 nT at 1 Hz.

4.3.2 Optical Instruments

MPA

We shall maintain the existing array. The array is comprised of four meridian scanning photometers, an eastern line of three instruments close to the 337^o magnetic longitude meridian and one instrument to the west close to the 313^o magnetic longitude meridian.

Each instrument provides the intensities of the four prime auroral emissions (470.9 nm, 486.1 nm, 557.7 nm, and 630.0 nm) along the N-S meridian at a rate of one scan per minute, with readings averaged over 0.5^o latitude intervals (17 data points per wavelength per scan) at the ∼100 km altitude (higher resolution data with 80 points per meridian scan per wavelength, is available on request). Background intensities are also collected by the photometers. The data (corrected for gain non-linearities, dark count and background) is available in near real time at the CANOPUS data center.

Imagers

We are considering two standards in ASI instrumentation. The most sophisticated imager, described below, should provide imaging of Hβ emissions, and might allow us to eventually decommission the MPA array. We shall call these ASIs Hβ imagers, though they measure other emission lines as well. We have also included detailed specifications and cost estimates for the less sophisticated POLARIS ASI. An instrument of this class has been evaluated through tests at the CANOPUS-1 site at Gillam, and performed well. Images from this new ASI are available through the CANOPUS data distribution network.

The Hβ imagers utilize 3" optics, a science grade Photometrix camera with thinned backside illuminated thermoelectrically cooled 512x512 CCD, and a thermoelectrically cooled photocathode, the latter being Gen II with enhanced blue response. These specifications should give a sensitivity of 5 Rayleighs/second/pixel at 486.0 nm and consequently these instruments should be capable of obtaining images of the diffuse proton aurora with an integration time of only one second. We point out that these imagers will be eminently capable of providing high quality images at virtually all traditionally used auroral emission lines. The Hβ imagers come with a five slot filter wheel. As well we plan to use the Hβ imager to obtain images using one of the N_2^+ bands (either 427.8 nm or 470.9 nm) and the O_1 line at 630.0 nm. Images using one background filter, preferably near the Hβ wavelength, are also required. The remaining slot can be used to obtain background intensities at a second wavelength, or to obtain images using the more traditional (though less quantitatively useful) O_1 emissions at 557.7 nm.

The POLARIS imager was tested at the field site at Gillam in the spring of 2000. This all-sky imager (ASI) is an intensified charge coupled device (CCD) based digital camera. The imagers will have the following properties:

- Capable of selecting specific wavelengths with a five-slot filter wheel.
- High sensitivity in the 400 to 630 nm spectral range.
- High signal-to-noise ratio for integration times on the order of seconds.
- Large dynamic range to detect both faint and intense features.
- Filters with passbands centered on 427.8- (or 471-), 557.7-, and 630.0-nm, and one as yet to be chosen wavelength for cloud/starfield detection.

High optical throughput is achieved by using fast lenses (f/1.4) and large-diameter optics with 3-inch diameter, high-transmittance interference filters. The following table provides an overview of the sensitivity of the KEO ASI at four auroral wavelengths. The numbers reflect data provided by KEO, based on actual past experience. The quoted sensitivities are for a 1-s integration time, and it has conservatively been assumed that a signal-to-noise ratio of at least 1:3 is required for acceptable detection.

Wavelength (nm)	Quantum Efficiency (%)	Resp. (mA/W)	Sensitivity (R)
427.8	8	27	80
486.1	11	44	60
557.7	12	54	50
630.0	10	52	60

The following table contains a summary of information pertaining to the amount of data which will be produced by a single imager. It should be noted that these values are preliminary estimates, but should give a reasonable indication of final values. In compiling this information, we have considered two levels of operation (i.e., the present Gillam ASI mode and the desired Hβ imager operating mode (here called "science stream"). The science stream operating mode would be required for meeting our proposed scientific objectives. One should note that we have been optimistic in terms of viewing schedule (i.e., we will not typically operate for 2600 hours). As well, note that in determining telemetry requirements, we should explore the possibility of downloading only some fraction of the data (deemed necessary for space weather and collaboration purposes) and use on site storage media for the complete data set.

	Science Stream	**Current Gillam ASI**
frame size	256 x 256	256 x 256
pixel depth	16 bits	8 bits
frames per minute	12	2
compression	2x	1x
data rate	90 kb/s	8.7 kb/s
data per hour	45 Megabytes	3.8 Megabytes
yearly total (2600 hours)	114 Gigabytes	9.5 Gigabytes

4.3.3 CADI

The Canadian Advanced Digital Ionosonde (CADI) was developed at UWO with funding from the Canadian Network for Space Research and is commercially built and sold by Scientific Instruments Limited of Saskatoon.

CADI is an ionosonde that operates in both vertical and oblique regimes. The range of frequencies is 1-20 MHz and the pulse power of 600 W allows succesfully measure electron densities of all major ionospheric levels. The maximum height of the pulse is ~1000 km with the height resolution of 6 km. CADI operates with a conjunction with an IBM compatible PC. The CADI data development programs are in C and IDL that provides a convenient implementation into the CANOPUS database. The current software allows different representations of data including standard ionograms, temporal behaviour of virtual reflection heights and drift velocities, and others.

The basic measurements that are made by a digital ionosonde are:

1. Ionospheric electron density (derived from ionograms).
2. Ionospheric location of reflectors (derived from angle of arrival of echoes).
3. Ionospheric motion (derived from Doppler shift of echoes combined with location of reflector).

The standard operational sequence to be used at the polar/auroral sites is to record a 95 frequency ionogram once per minute and drift measurements on 2 "fixed" frequencies each 30 seconds. A typical daily data collection at a station is about 5 MB of data.

4.4 A New Data Acquisition Network

The existing CANOPUS/DAN (see the CANOPUS web site) is a distributed data acquisition and analysis network that promotes the scientific investigative process by permitting participating researchers to interact by exchanging graphic images between workstations in quasi real-time mode as though they were in the same room while remaining in their own laboratories. CANOPUS-2000 will look at a new DAN that builds on the strengths of the existing DAN listed below, but with enhanced facilities, software and hardware for data archiving and retrieval. A feasibility study (Task 1 below) will look at features for a new DAN, including web based access, different data retrieval infrastructure (including internet options), changes in the operating system (possibly to LINUX) at the Ottawa site, and implementation of robust disk hardware for storage of large volumes of data. Data rates will be determined when final instrument specifications and data compression techniques have been determined.

Up to 80 MB of data from CANOPUS-1 field instrumentation arrive daily in DAN. Data rates for CANOPUS-2000 are likely to be at least an order of magnitude higher. The data is processed routinely using the CANOPUS-1 developed software, with high priority, to a level appropriate to the instrumentation and stored on disk. Subsequent processing under direct control of the instrument teams further processes the data to useful quantities. In either or both of these stages, extracts of the data are made to generate key parameters and data summaries for inclusion in the database, which are presently transferred to the NSSDCA on a monthly basis.

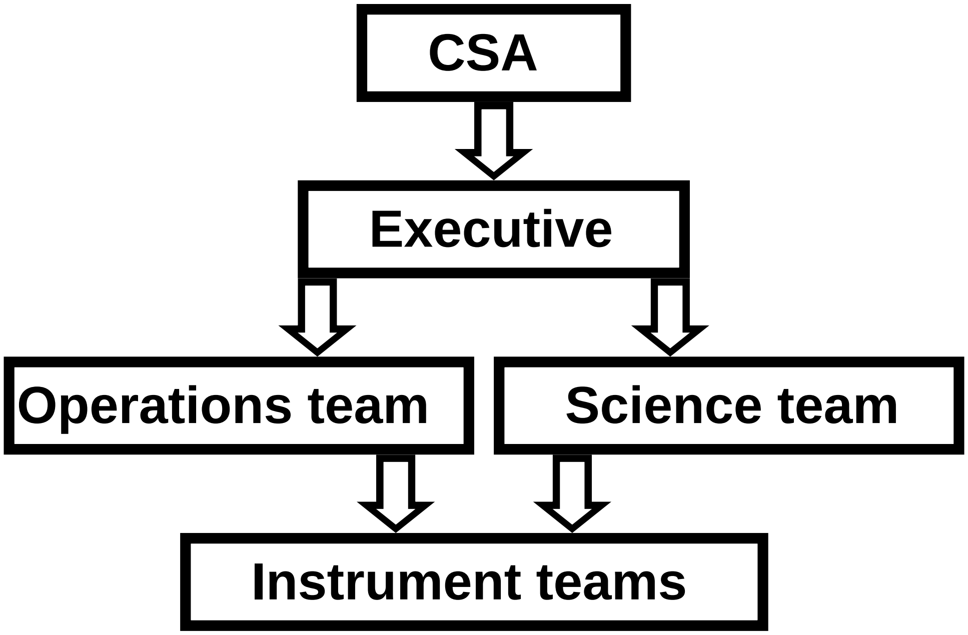

Figure 14: CANOPUS-2000 management.

5 Management

The scientific executive includes the chief mission scientist who reports directly to the Canadian Space Agency. All management decisions will be made by the **executive** (see below). We will form an **operations team** that will be principally responsible for the operation of the cornerstone programs discussed in the introduction, as well as coordinated work involving SuperDARN, NORSTAR, FDAM and the Canadian space weather initiative. As well, we will have a science committee consisting of roughly five members of the Canadian space science community who will assist with the overall direction of the program.

5.1 Executive

Team members will be solicited at the end of the CANOPUS-1 contract.

5.2 Scientific Program Manager

The scientific program manager is responsible for short and long term scientific programs and monitoring of progress under contracts.

5.3 Operations and Instrument Teams

The operations team members are leaders of instrument teams. Suggested instrument teams for the CANOPUS-2000 are:

Optical
Magnetometer/Riometer
CADI
Integration
Radar

The prime consideration in selecting the members of the instrument teams will be to give significant authority to the individuals most directly responsible for producing the data, and to allow those individuals reasonable input and opportunity for collaboration in studies that utilize their data.

5.4 Science Team

Members not selected at this time. The prime consideration here is to provide scientific direction. Members of this team should be representative of the broad range of Canadian space science research and must be willing to invest effort to keep the Canadian CANOPUS based program world class in terms of its scientific relevance.

6 Tasks and Scheduling

6.1 Tasks

1. Feasibility study and design criteria for a new Data Acquisition Network (DAN) (contract).
2. Identification of new sites for magnetometers and CADIs.
3. Implementation of a new DAN with archiving at Ottawa and mirror site at Edmonton.
4. Development of a web-based data archiving and management system to complement DAN.
5. Acquisition and testing of new generation Narod magnetometers.
6. Installation of new magnetometers.
7. Acquisition, installation and testing of 2 CADI systems.
8. Development and refinement of CADI software for intergration of CADI data in to DAN.
9. Acquisition and testing of two new ASI Hβ imagers.
10. Development and refinement of ASI software for data reduction, archiving (DAN), and scientific visualization (Calgary).
11. Installation of Hβ imagers. Begin feasibility test for possible decommissioning of MSPs.
12. Refurbishment of existing MSPs.
13. Decision on decommissioning of MSPs.

6.2 Scheduling

To be determined in consultation with the CSA. Tasks 1, 4, 6, 8 and 11 have the highest priority. We suggest the following time line for installation:

- **magnetometers** : two in the year we will call Start Date plus One Year; 2 in the year called Start Date plus Two Years.
- **CADIs** : two in the summer of 2001.
- **ASIs** : one in the summer of 2001; the second in the summer of 2002.
- establish the **mirror site** in 2001.

- establish **Science Team** at Start Date.
- establish **Rules of the Road** at the first Executive meeting.

7 Costs

The costs of upgrading the CANOPUS network involve the acquisition of new instrumentation, the modification of existing sites, the establishment of new sites, the installation of new equipment at those sites, and modifications to the data aquisition network (i.e., telemtry and so on). Below, we discuss specific instrument costs relevant to the proposed modifications to our array. More detailed cost breakdowns can be obtained via the instrument teams (i.e., through D. Wallis for magnetometers, J. MacDougall for CADIs, and T. Trondsen for the ASIs). We will address building modification, site establishment, installation and telemtery costs. All costs are estimates only, and are in Canadian dollars.

7.1 Instruments

7.1.1 CADI

CADI digital ionosonde including PC computer (purchased from Scientific Instrumentation Ltd.) $15,000. Antennas and cables $3000.

7.1.2 ASIs

The POLARIS imager cost roughly $70,000. Two H$\beta$ imagers purchased by the University of Calgary cost roughly $110,000.

7.1.3 Magnetometers

Narod Geophysics Limited no longer can manufacture the "CANOPUS 5-100" magnetometer, but expect to have a replacement available within a few months at a cost estimated to be $12000. NGL does not provide suitable sensor head packaging (provision for post mounting, addition of tilt meters and a temperature sensor). A crude estimate of the costs of the packaging is $5000 if sufficient numbers are built.

7.2 Installation

Costs to be determined in consultation with SED.

7.3 Data acquisition and archiving

Costs to be determined in consultation with CSA group in Ottawa.

8 References

Baker, D.N., T.I. Pulkkinen, V. Angelopoulos, W. Baumjohann, and R.L. McPherron, The neutral line model of substorms: Past results and present view, *J. Geophys. Res., 101,* 12,975, 1996.

Baumjohann, W., G. Paschmann, and H. Luhr, Characteristics of high-speed ion flows in the plasma sheet, *J. Geophys. Res., 95,* 3801, 1990.

Blanchard, G.T., L.R. Lyons, and J.C. Samson, Accuracy of using 6300 A auroral emission to identify the magnetic separatrix on the nightside of Earth, *J. Geophys. Res., 102,* 9697, 1997.

Borovsky, J. E., Auroral arc thickness as predicted by various theories, *J. Geophys. Res., 98,* 6101, 1993.

Carlson, H. C., The dark polar ionosphere: Progress and future challenges, *Radio Sci., 29,* 157, 1994.

Cowley, S.C., and M. Artun, Explosive instabilities and detonation in magnetohydrodynamics, *Physics Reports, 283,* 185, 1997.

Donovan, E.F., et al., North-south aligned auroral structures observed by an all-sky imager, submitted to *Geophys. Res. Lett.,* 2000

Galperin, Yu.I., and Ya.I. Feldstein, Auroral luminosity and its relation to magnetospheric plasma domains, in *Auroral Physics,* edited by C.-I. Meng, M.J. Rycroft, and L.A. Frank, p. 207, Cambridge University Press, England, 1991.

Hall, G., D.R. Moorcroft, L.L. Cogger, and D. Andre, Spatial relationship between large aspect angle VHF radio aurora and 557.7-nm emissions: Evidence for refraction, *J. Geophys. Res., 95,* 15,281, 1990.

Hall, G., J. W. MacDougall, J.-F. Cecile, D. R. Moorcroft, and J. P. St-Maurice, Finding gravity wave source positions using the Super Dual Auroral Radar Network, *J. Geophys. Res., 104,* 67, 1999.

Hanuise, C., High latitude ionospheric irregularities: A review of recent radar results, *Radio Sci., 18,* 1093, 1983.

Henderson, M.G., G.D. Reeves, and J.S. Murphree, Are north-south aligned auroral structures an ionospheric manifestation of bursty bulk flows?, *Geophys. Res. Lett., 25,* 3737, 1998.

Kamide, Y., A.D. Richmond, and S. Matsushita, Estimation of ionospheric electric fields, ionospheric currents, and field-aligned currents from ground magnetic records, *J. Geophys. Res., 86,* 801, 1981.

Knudsen, D.J., E.F. Donovan, L.L. Cogger, B.J. Width and structure of mesoscale optical auroral arcs, submitted to *Geophys. Res. Lett.,* 2000.

Liu, W.W., Physics of the explosive growth phase: Ballooning instability revisited, *J. Geophys. Res., 102,* 4927, 1997.

Liu, W.W., and G. Rostoker, On the origin of auroal fingers, *J. Geophys. Res., 98,* 17,401, 1993.

Liu, W., and R. Rankin, The Facility for Data Assimilation and Modeling (FDAM), CSA report, September 10, 1999.

Liu, W., R. Rankin, and D. Boteler, Space Weather in Canada, CSA report, 1999.

Lui, A.T.Y., A synthesis of magnetospheric substorm models, *Geophys. Res. Lett., 96,* 849, 1991.

Lyons, L.R., T. Nagai, G.T. Blanchard, J.C. Samson, T. Yammamoto, T. Mukai, A. Nishida, and S. Kokubun, Association between Geotail plasma flows and auroral poleward boundary intensifications observed by CANOPUS photometers,*J. Geophys. Res., 104,* 4485, 1999.

McPherron, R.L., Physical processes producing magnetospheric substorms and magnetic storms, *Geomagnetism, Volume 4,* Ed. J.A. Jacobs, Academic Press, 593, 1991.

Murphree, J.S., M.L. Johnson, L.L. Cogger, and D.J. Hearn, Freja UV imager observations of spatially periodic auroral distortions, *Geophys. Res. Lett., 21,* 1887, 1994.

Ohtani, S., K. Takahashi, L.J. Zanetti, T.A. Potemra, R.W. McEntire, and T. Iijima, Initial signatures of magnetic field and energetic particle fluxes at tail reconfiguration: Explosive growth phase, *J. Geophys. Res., 97,* 19311, 1992.

Olsson, A., L. Andersson, A. I. Eriksson, J. Clemmons, R. E. Erlandsson, G. Reeves, T. Hughes, and J. S. Murphree, Freja studies of the current-voltage relation in substorm-related events, *J. Geophys. Res., 103,* 4825, 1998.

Prikryl, P., R.A. Greenwald, G.J. Sofko, J.P. Villain, C.W.S. Ziesolleck, and E. Friis-Christensen, Solar wind driven magnetic reconnection at the dayside magnetopause, Pc5 compressional oscillations, and field line resonances, *J. Geophys. Res., 103,* 17307, 1998.

Prikryl, P., J.W. MacDougall, I.F. Grant, D.P. Steele, G.J. Sofko, and R.A. Greenwald, Observations of polar patches generated by solar wind Alfvén wave coupling to the dayside magnetosphere, *Ann. Geophys., 17,* 463, 1999.

Rankin, R., J.C. Samson, and V.T. Tikhonchuk, Parallel electric fields in dispersive shear Alfvén waves in the dipolar magnetosphere, *Geophys. Res. Lett., 26,* 3601, 1999.

Rostoker, G., Why do we need ground based, balloon, and sounding rocket measurements in the future? in *Magnetospheric Physics,* edited by B. Hultqvist and C.-G Falthammar, Plenum Press, New York, p. 115, 1990.

Rostoker, G., J.C. Samson, F. Creutzberg, T.J. Hughes, D.R. McDiarmid, A.G. McNamara, A. Vallance Jones, D.D. Wallis, and L.L. Cogger, CANOPUS - A ground based instrument array for remote sensing in the high latitude ionosphere during ISTP/GGs program, *Space Sci. Rev., 71,* 743, 1995.

Samson, J.C., R.A. Greenwald, J.M. Ruohoniemi, and K.B. Baker, High-frequency radar observations of atmospheric gravity waves in the high-latitude ionosphere, *Geophys. Res. Lett., 16,* 875, 1989.

Samson, J.C., Mapping substorm intensifications from the ionosphere to the magnetosphere, in *Proceedings of the International Conference on Substorms 2,* University of Alaska, 1994.

Samson, J.C., L.L. Cogger, and Q. Pao, Observations of field line resonances, auroral arcs, and auroral vortex structures, *J. Geophys. Res., 101,* 17373, 1996.

Samson, J.C., Nonlinear, hybrid, MHD instabilities associated with substorm intensifications, *Proceedings of the International Conference on Substorms-4,* Japan, March, 1997.

Sedgemore-Schultness, K.J.F., M. Lockwood, T.S. Trondsen, B.S. Lanchester, M.H. Rees, D.A. Lorentzen, and J. Moen, Coherent EISCAT Svalbard Radar spectra from the dayside auso/cleft and their implications for transient field-aligned currents, *J. Geophys. Res., 104,* 24,613, 1999.

Sergeev, V.A., K. Liou, C.-I. Meng, P.T. Newell, M. Brittnacher, G. Parks, and G.D. Reeves, Development of auroral streamers in association with localized impulsive injections to the inner magnetotail, *Geophys. Res. Lett., 26,* 417, 1999.

Seyler, C.E., A mathematical model of the structure and evolution of small-scale discrete auroral arcs, *J. Geophys. Res., 95,* 17199, 1990.

Sofko, G.J., A.V. Koustov, K. McWilliams, G.C. Hussey, D. Andre, J. MacDougall, J.P. St. Maurice, D.R. Moorcroft, J.C. Samson, A. Hamza, and P.Prikryl, SuperDARN: The Super Dual Auroral Radar Network, *Phys. In Canada, Nov/Dec,* 371, 1998.

Trondsen, T.S., L.L. Cogger, and J.C. Samson, Observations of asymmetric, multiple auroral arcs, *Geophys. Res. Lett., 24,* 2945, 1997.

Trondsen, T.S., and L.L. Cogger, A survey of small-scale spatially periodic distortions of auroral forms, *J. Geophys. Res., 103,* 9405, 1998.

Vallance Jones, A., An automatic ground based instrumentation array to support space projects, CANOPUS Science Team, 1986.

Voronkov, I., R. Rankin, P. Frycz, V. T. Tikhonchuk, and J.C. Samson, Coupling of shear flow and pressure gradient instabilities, *J. Geophys. Res., 102,* 9639, 1997.

Voronkov, I., E. Friedrich, and J.C. Samson, Dynamics of the substorm growth phase as observed using CANOPUS and SuperDARN instruments, *J. Geophys Res., 104,* 28,491, 1999.

Voronkov, I., E.F. Donovan, B.J. Jackel, and J.C. Samson, Large-scale vortex dynamics in the evening and midnight auroral zone: Observations and simulation, *J. Geophys. Res., 105,* 18,505, 2000.

Waters, C.L., J.C. Samson, and E.F. Donovan, The variation of plasmatrough density derived from magnetospheric field line resonances, *J. Geophys. Res., 101,* 24,737, 1996.