Chapter 7

Report from Space Plasma Science

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7.1 Introduction

The solar-terrestrial environment exhibits many complex charged particle and plasma phenomena. The energy and particles released in solar flares, the dynamic structure of the magnetosphere, the fluctuating terrestrial aurorae, and the convective motions of the ionosphere are different examples of the pervasive influence of plasma processes. Knowledge of the constitutive physical processes underlying these phenomena is important in several ways. First, it allows us to understand in quantitative terms the variety of interrelated, complex processes acting to shape and influence our terrestrial environment. Second, these phenomena also pose fundamental scientific questions relating to the behavior of plasmas under conditions which are different from those which can be created and studied in conventional laboratories. As a consequence, their investigation extends the frontiers of human knowledge, enabling broader physical understanding of plasmas within the context of their general behavior.

Previous chapters discussed the need to investigate space plasma phenomena through many different modes of investigation, including: (1) passive remote observation, (2) passive in-situ observation, (3) initiation of experiments involving active perturbation of natural phenomena, and (4) execution of experiments taking advantage of the different ranges of physical parameters and conditions available in space. Observations of plasma density and drift speed, energetic particle fluxes, and magnetic intensity are examples of studies of space plasmas which are directed towards understanding the natural processes linking the atmosphere, ionosphere, magnetosphere, interplanetary medium, and the outer solar atmosphere. Such studies are essential parts of other disciplines devoted to explaining the myriad of complicated processes found in and above the Earth's atmosphere.

7.1.1 Plasma Experiments

Space plasma science, however, involves more than simply observing and understanding the solar and terrestrial plasma environments. The ionosphere, magnetosphere, and interplanetary space present opportunities for conducting basic plasma experiments outside the confines of the vacuum chamber walls necessary for ground-based investigations. Plasma experiments in space open the way to increasing knowledge of plasma phenomena on new scales of time, space, and frequency and wavelength. In addition, the natural environment offers a variety of ambient conditions that are difficult to replicate in laboratories. Naturally occurring variations in density, flow velocity, magnetic field intensity, temperature, and ion composition can be exploited to conduct fundamental experiments which are essentially impossible to undertake in the confines of the laboratory. These experiments can involve injection of electromagnetic waves, foreign plasma, charged particle beams or other perturbations, and subsequent observation of responses, often at distances of thousands of kilometers. The interpretation of these results in terms of basic plasma processes provides a means of adding to and improving our knowledge of fundamental plasma physics.

7.1.2 Computational Simulations

Owing to the complexity of phenomena, it is prudent to discuss the important role of computational models in space plasma science. Over the past two decades our capability to numerically investigate the behavior of space plasmas has steadily improved. Models and simulations of the 1960s and 1970s evolved as a consequence of attempts to understand particular features of the solar-terrestrial environment; e.g., the composition and thermal structure of the atmosphere and ionosphere, the dynamics of interhemispheric plasma interchange, the coupled dynamics of energetic plasma in the magnetosphere and electric fields and currents in the magnetosphere and ionosphere, the interaction of the solar wind with the geomagnetic field, the formation of shocks in the solar wind, the propagation of solar and galactic cosmic rays in the solar wind, and the dynamics of magnetic reconnection, among others. More recently, the ability to study plasmas on a microscopic scale has evolved through the use of various simulation techniques with supercomputers. These codes permit the investigation of various modes of plasma dynamics associated with internal energy and momentum transfer between the plasma constituents and plasma waves. Unfortunately, owing to limitations of computer resources, these studies are often limited in terms of their spatial and temporal resolution. Examples of current codes include computations of two stream instabilities associated with plasma currents, the interactions of high energy radiation belt particles with VLF waves, and the generation of electrostatic waves and plasma turbulence.

Great progress has also been made in computing the conditions associated with plasma experiments conducted in space. Our ability to understand striations in ionized barium clouds has been enormously enhanced by application of computer models. Simulations of the dynamics of electron beams injected into dilute plasma from a space platform have expanded our knowledge of the dynamics of electron beam-natural plasma interactions. Models of the AMPTE gas and plasma comets have enabled us to interpret and guide complicated space experiments towards identification of new processes. For the future, it is clear that experiments in space plasma must involve synergistic participation of experimentalists with theoreticians capable of modeling the anticipated interactions. For such support, a community of theoretical plasma scientists must be present and supported with adequate computer resources and contact with experimental programs.

With this background, we now present the general areas of investigation for space plasma science. These brief discussions complement the active space experiments which have already been suggested in previous chapters to expand knowledge of processes involved in solar-terrestrial science.

7.2 Basic Processes of Space Plasma Science

7.2.1 Wave Generation and Propagation

Waves are a ubiquitous feature of plasma and their study in a broad range of physical conditions is an important goal of plasma science. Indeed, one of the goals of the ground-based plasma fusion research is to eliminate waves, since they are often unstable, unpredictable, and can steal energy otherwise destined to heat the plasma. Waves also carry information through plasmas and knowledge about their means of generation and modes of propagation provides new insight to the various internal processes affecting the overall plasma state. Waves can also transfer energy from one part of a physical system to another.

Understanding the generation and propagation of waves, including electromagnetic and electrostatic modes, in space plasmas is important as a general goal of plasma physics. The ability to make measurements over a variety of scale lengths with differing plasma parameters extends conventional laboratory studies. In the past, space studies have concentrated on explaining in-situ observations of waves in terms of various sources of free energy; i.e., plasma currents, density gradients, the presence of energetic particles, dc electric fields, plasma flow, etc. In the future, it is clear that more detailed investigations should be undertaken, including the direct injection of electromagnetic waves from space platforms, and the use of modulated charged particle beams and plasmas.

7.2.2 Wave Particle Interactions

Wave-charged particle interactions include the microscopic electromagnetic interactions between waves in plasmas and the charged particles which make up the plasma. Wave-particle interactions are one process by which energy and momentum are transported between different regions of plasma systems. Wave-particle interactions are exceptionally rich in their diversity, even for the simplest plasmas. When the added degrees of freedom connected with imbedded magnetic fields and multi-component plasmas are considered, wave-particle interactions are found to be among the most complicated physical processes occurring in any plasma environment.

Studies of wave-particle interactions in space involve observations of the nonlinear evolution of the particle and wave distribution functions arising from the interaction. The knowledge gained from such studies is valuable both for understanding basic plasma physics and, if the conditions are chosen correctly, it will also help in understanding specific processes, for example, those occurring in the magnetosphere and the solar atmosphere.

7.2.3 Charged Particle and Plasma Energization

Charged particles in plasma can be accelerated to high energies through a variety of mechanisms, some of which occur in nature or can be induced in suitably arranged space experiments. These include:

- Particle acceleration through resonance with a quasi-monochromatic wave
- Stochastic acceleration resulting from resonance overlap due to large wave amplitudes or the presence of a finite spectrum of waves
- Acceleration by electric fields which results from changes in macroscopic plasma morphology
- Acceleration by parametric processes, such as beat waves, Brillouin, and Raman scattering. These phenomena are fundamentally nonlinear and extremely complicated.

The understanding of all of these critical phenomena is an important goal for space-plasma science in the next decade.

7.2.4 Chemistry and Active Experiments

The natural space environment can be modified with the introduction of foreign gases and plasma to induce or enhance local processes. This includes changes of the local ion composition, reduction of the local electron density, changes in the charge state of ions, changes in the average energy of the local plasma, its chemical nature, and so forth.

Another possibility is the opportunity to change the energy state of the atmosphere by electromagnetic radiation or by particle beams. The first category includes laser-pumped or radiation-heated local regions which may have been chemically altered through release of suitable materials. Electron beam heating has been done in artificial aurora experiments, and will be attempted in equatorial electron beam experiments. These experiments are valuable in that they allow comparison of theory with experiment and permit identification of new or unexpected interactions.

Chemical releases are often used to modify the charge state of the ionosphere. This permits study of various processes occurring within ionospheric plasma, including production, loss, and transport. It is also a way of creating unstable environments which evolve in interesting and new ways not normally found in the natural environment. The possibility of creating large-scale ionic plasma (positive and negative ions dominate the overall composition) is both interesting and important in that it allows new processes to become dominant in plasma behavior. Such experiments are difficult, if not impossible, to make in terrestrial laboratories.

7.2.5 Particle-Particle Interactions

These processes are generally those that involve collisions. The important consequences are:

- Excitation, ionization, and dissociation of atoms and molecules with consequent radiation and change of plasma density
- Recombination leading to decreased plasma density
- Heat conduction
- Electrical current conduction normal to the magnetic field
- Forcing of winds in the neutral atmosphere through collisional interactions

- Creation of unstable ion velocity distribution functions through charge exchange with energetic neutral particles
- Initiation of unusual ion-neutral reactions through high speed interactions.

Future studies linked to careful measurements of these processes offer a rich reward leading to accurate, detailed models of plasma interactions.

7.2.6 Radiation Processes

This topic is relatively new and involves the detailed study of the production, transport, and absorption of microwave, infrared, and shorter wavelength radiation in dense plasma. The interaction of such radiation with matter involves individual molecules, atoms/ions, or electrons, not collective plasma processes. (Interaction of longer wavelength radiation with plasma is discussed in Section 7.2.1.) Clearly, radiation processes are of fundamental importance in transporting energy through portions of the sun and of the earth's atmosphere. In addition, radiation propagating freely from its source and from optically thick regions is the primary means by which remote sensing is accomplished. The opportunity to study fully coupled electromagnetic radiation with plasma dynamics in the space environment supplements the extensive work done in laboratory plasma on similar problems.

7.2.7 Macroscopic Flow of Plasma

Macroscopic flow of plasma is one of the fundamental processes behind the transport of energy, momentum, magnetic, and electric fields across the magnetopause and through the magnetosphere and ionosphere. The transport of plasmas and particles in space is one of the key processes underlying the behavior of the boundary region between any two regions of contracting plasma. Specific examples are the magnetosphere/ionosphere boundary, as well as the boundary between the artificial environment around a space structure and the ambient space environment. This transport is most likely mediated by instabilities which cause particle scattering in a manner akin to classical particle collisions. This wave-induced transport is still one of the fundamental areas for research in basic plasma physics.

7.2.8 Plasma-Magnetic Field Interactions

Studies of interactions between energetic plasma and magnetic fields are an important direction for the future. Previous work with high-speed barium releases in magnetized space plasma has demonstrated a wealth of complex interactions, including the formation of a diamagnetic cavity, a larger region of electrostatically polarized plasma moving with the source, and an even larger coma of disturbed flow. Similar observations exist in laser plasma experiments.

Using space platforms with suitable resources, investigations of steady-state diamagnetic cavities should be possible. In this situation, the plasma effusion speed from its source can be made larger than the diffusion speed of magnetic field. In this situation, a complex region of low magnetic field is maintained by plasma pressure against the flowing ambient plasma and ambient magnetic field. This is an unstable situation which opens the way to investigation of various types of instabilities. It is likely that these will reveal the presence of many new high beta plasma-magnetic field interactions which depend on various plasma and magnetic field parameters.

Magnetic field interactions, analogous to the solar wind-geomagnetic field coupling, can also be anticipated as the capability to construct and operate large magnets in space evolves. These experiments, involving a variety of plasmas and magnetic field configurations, will have relevance to a wide range of astrophysical situations.

It is also important to note that investigations of the phenomenon of the Critical Ionization Velocity effect are an important part of space/plasma science. This process involves the nonclassical ionization of energetic neutral atoms and molecules as they move through a background magnetized plasma. From laboratory studies, and perhaps some space measurements, it is thought that when the center of mass energy of the neutrals rises above their ionization threshold, there will be a rapid ionization of the neutrals. This process apparently involves energization of the ambient electron gas by plasma waves associated initially with the transformation of a few energetic neutrals to ions. The newly born ions have considerable kinetic energy, and through collective plasma processes, this heats the electrons. When sufficient neutrals are converted to ions, such as might happen through charge exchange, the energy density of the electron gas rises to the point where additional ionization of the neutrals ensues, and a flash ionization of most neutrals occurs.

This process has great significance for models of young solar systems, and comprehensive measurements of the processes involved are essential. To do this it will be necessary to achieve the correct physical scale; i.e., the electron gas must be heated over a sufficiently large scale so that its temperature can rise to the point where impact ionization of the neutrals becomes important to the overall system of interacting gases. Such experiments lie in the future and will require much more extensive supporting resources than have been possible with small free-flying satellites or rockets.

7.2.9 Plasma-Surface Interactions

Processes in the physical contact between plasma and exposed surfaces in space are an important, practical aspect of many advanced scientific and technological space systems. The ability to draw electron current from magnetized space plasma, for example, is an essential feature of plans for power-producing electrodynamic tether systems. Charging of dielectrics in the vicinity of high current beam experiments is similarly an important concern. It is striking to realize that while basic issues of plasma sheaths and current extraction have been known for more than 50 years, we still lack fundamental knowledge of the processes involved, especially at high voltages and currents. Relatively simple experiments, such as measuring the voltage-current collection curves for magnetized plasma, have yet to be done for ranges of parameters when large amplitude plasma waves play an important role.

Much of our present knowledge of plasma sheaths comes from laboratory measurements. In the case of electron current collection, this has imposed severe limitation on the scale of phenomena which can be studied. Because the total number of electrons in a given plasma chamber is limited, measurements of electron current are limited in time and current density to very small values.

In contrast, measurements in space offer a far better situation since it is possible to place the collecting anode in an essentially unbounded medium. This permits application of very high voltages and the formation of very large plasma sheaths; i.e., on the order of 10's of meters or more. The behavior of these sheaths can be carefully documented and, furthermore, they can be perturbed in various ways. For example, waves can be injected, the bias potential of the electrode can be varied, and the neutral gas background can be changed. These and other measurements are an important part of the future of space plasma science in the area of plasma-surface interactions.

7.3 Prospects for Near-Term Plasma Science Experiments in Space

Many of the active experiments performed thus far in space have been intended as either tracers in the magnetosphere or as small-scale perturbations of a local environment. Such experiments have used particle beams, gas and plasma releases, chemical releases, and emission of waves, primarily from the ground. In addition, experiments have been performed that may be viewed as simulations of naturally occurring processes. In many cases these experiments have revealed that the interaction between the perturbing agent and the ambient space environment is more complex than anticipated, and, indeed, requires deeper understanding before active experiments can be used with full confidence as diagnostic techniques. Thus, in recent time the focus of active experiments in space plasmas has shifted somewhat to the investigation of fundamental plasma processes.

In the early 1980s, the space plasma active experiments program was scheduled for flight with a number of NASA missions. Missions which have carried important space plasma experiments included STS-3/OSS-1, Spacelab-1, and Spacelab-2. Prior to the Challenger accident, future programs in space plasma science aboard the space shuttle also included Combined Release and Radiation Effects Satellite (CRRES), Tethered Satellite-1, and several flights of a space plasma laboratory. In the reality of post-Challenger mission scheduling, these flights have been greatly curtailed. The CRRES experiments have been descoped and transferred to an expendable launch vehicle. The Space Plasma Laboratory has been cancelled. Furthermore, it has been explicitly stated that the space shuttle will not be considered for space plasma missions through at least the IOC of the US/International Space Station; i.e., 1997 or later.

As a consequence, during the period 1985-95 progress in space plasma science will certainly be reduced below that planned before the Challenger accident. We foresee that only a limited version of CRRES is likely to fly, that ATLAS will carry a reflight of a Spacelab-1 electron accelerator without the possibility of having remote diagnostics, and that only the TSS-1 mission will attempt a new technology. This is certainly a discouraging prospect to the space-plasma science community and leaves open the possibility that expertise now established in this discipline will be greatly eroded by 1995.

In fact, it is clear that the forthcoming Soviet Active and Apex dual satellite missions will enable the Soviets to undertake a wide variety of important space plasma experiments and to make significant strides in this area of space research. While there is an agreement between NASA and IKI to permit US co-investigators to participate in these Soviet activities, this is not likely to lead to significant US involvement in the development of either the basic instruments of space plasma experiments or in the planning of the actual flight operations unless great efforts are made in the near future.

The NASA suborbital program will continue to support experiments with charged particle beams and VLF wave injection. However, with such platforms there is little opportunity to attempt new experiments such as dusty plasmas, or artificial magnetospheres (terrellas) that require larger platforms and significant energy.

It is clearly the case that the loss of the space shuttle as a supportive platform for space plasma science will put aside the possibility of conducting a wide variety of important, innovative experiments in the forthcoming decade.

As a consequence of these factors, it is important for NASA to adopt a near-term strategy which attempts to extract the maximum possible value from space plasma science experiments currently planned. These include those aboard Atlas-1, TSS-1, and CRRES. Increases of support for these missions, and making adequate provision for satisfactory analysis of the data acquired from these missions, will be essential.

In the same vein, NASA should ensure that the data already collected on its space plasma science experiments are adequately studied. Extensive data obtained on STS-3, SL-1 and SL-2 have remained unanalyzed owing to lack of data analysis funds. Data from various rocket flights are likewise under-analyzed. This situation should be rectified, perhaps by identifying these basic data sets as being among those which should be part of the "missions to data" concept described elsewhere in this report.

7.4 Future Plans

It is convenient to arrange the possible active experiments into the various categories given below.

7.4.1 Large-Scale or Global Modifications of Terrestrial Plasma

This category includes such experiments as alteration of the trapped radiation flux by wave injection to induce precipitation, additions of energetic tracer species to the natural trapped flux, alteration of the ionosphere by dumping electronegative species to produce negative ions, and perturbation of the natural current paths. The Workshop agreed that these experiments would be discussed by the other, relevant panels.

7.4.2 Large-Scale Active Imaging and Tracing

This class of experiments includes radar and laser sounding and chemical releases for tracer purposes. Again, these topics are discussed in other sections of this report.

A special experiment discussed by the space plasma science panel is that of active tomography to make observations of plasma density in the ionosphere and magnetosphere. Active tomography is a multiple satellite experiment in which one satellite, the transmitter, transmits electromagnetic waves and the other satellite, the receiver, receives it with the objective of monitoring the region between the two. In the case of radio waves, this technique can be used to monitor the total plasma content. A radio-transmitting satellite would emit phase correlated signals and the receiver would measure the phase shift and Faraday rotation of the signal. From the signal measurement, the total electron (plasma) content and the magnetic field direction of the spatial region between the two would be detected. In the simplest form, two satellites would be orbiting at some moderate distance (few Earth radii) from the other and make tomographic measurements of magnetospheric regions.

In more complex situations, a cluster of receivers would fly and one common transmitter would be used to produce the signal.

The same principle could be used for electromagnetic waves in the optical domain. A tunable light source—perhaps a laser—would be flown on the satellite and the receiver would observe the optical absorption of the space region between the two satellites.

7.4.3 Three-Dimensional Plasma Experiments

Space vehicles offer the promise of performing three-dimensional experiments in unbounded plasma with varying mixtures of neutral gas. These could be done on a scale size that should make the instrumentation easy to build. In addition, the relevant time scales are microseconds or longer, which are easily measured and recorded. In spite of these advantages, plasma experiments in space have not been easy to perform. The principal reasons for this are that diagnostic instruments are difficult to place accurately, and the space platforms that carry them may be big enough to interfere with the experiment.

Examples of three-dimensional plasma experiments are:

- Wave injection
- Particle beam injection
- Plasma injection
- Dust injection
- Production of wakes
- Terrellas/artificial magnetospheres.

These techniques relate to the processes detailed above.

The general requirement for performing these experiments is to provide one space platform that perturbs or alters the natural plasma and diagnostic detectors that can either be maneuvered into the correct positions or that are deployed in a large array. Furthermore, the diagnostics must be small to minimize perturbations and able to telemeter data at a rapid rate, often high for short periods. The proper positions usually are in relation to the local magnetic field and/or the plasma streaming velocity (negative of orbital velocity). For example, to perform particle beam experiments the diagnostics must be maneuvered along the injected beam, which is along the magnetic field, from a few meters to a few kilometers or more. The positioning accuracy in scanning across the beam must be to a few meters or tens of meters, with measurements to be made out to hundreds of meters away from the beam.

As another example, naturally occurring fast-moving bodies which are in a neutral or a plasma medium create wakes. The phenomena associated with these wakes are rather complex and their modeling is particularly difficult. However, relatively simple experiments can be performed on orbiting bodies which simulate the action of the naturally occurring phenomena. Such simulation experiments can be performed in low-Earth orbit. A larger body which creates the wake should be used, and at least one diagnostic spacecraft which has accurate positioning should be used for diagnostic three-dimensional mapping. It is possible to use parts of already planned spacecraft to act as the solid body. Another possibility, conceived more than a decade ago, would be to attach an electrically active tether from the shuttle to a large, conducting echo-like (early US passive communications satellite) balloon.

Comparable requirements must be met in performing other types of experiments. Some experiments of this sort can be done with separating payloads on sounding rockets, and these have the great advantages of ready access to space and low cost. With small satellites it appears difficult to perform experiments that require relative positioning of two bodies over an extended period of time. Some terrella experiments can probably be performed with a single orbiting body having sensors attached.

However, if NASA is going to pursue active plasma and other experiments, a significant investment in facilities is required. Much of this has been recognized for some time and studied before, but is perhaps worth restating in terms of the space station or astronaut-tended platform. The perturbing mechanism should be on the major platform, which can provide significant power when needed. Specially designed diagnostic instruments should be operated on:

- Carefully designed fixed positions on the main platform. Remote sensing at close range may be carefully considered.
- The servicing crane or equivalent. [This is the decendent of the remote manipulator system (RMS)]. This will afford accurate positioning within limited range.
- On one or more maneuverable subsatellites such as the OMV, as suggested by MSFC. This was once studied by GSFC as the Solar-Terrestrial Subsatellite.
- There may be use for multiprobes or the equivalent. The geometry of the perturber is critical. For example, if one is studying wakes or surface interactions, a simple shape is important to make analysis tractable. Particle and injection depends critically on the magnetic field.

Active experiments, balanced with computer models and simulations, can also provide information on plasma transport mechanisms. The first class of experiments includes pulsed plasma beam or contactor experiments where a dense plasma cloud is released into the ambient medium. The plasma cloud expands and distorts in response to its internal diamagnetic structure as well as the external flow field. This expansion sheds light on the fundamental plasma physics of high beta plasma clouds, such as occur in the magnetotail, as well as the nature of the transport process when the cloud is diluted. Such experiments are conceptually similar to those already underway in ground-based laboratories, with an important exception. By using pulses of sufficient density and duration, it is possible to create steady-state diamagnetic plasma regions near the source. Information about the various processes acting in such an unusual plasma configuration is an important step towards understanding a new regime of plasma physics.

Another class of active experiments includes pulsed particle beam experiments where specific instability wave modes are excited. These can be studied for their influence on the particle transport if the pulsed beam is combined with plasma pulses described above.

Finally, using charged particle beams, it is possible to study the propagation of charged particle bunches in magnetized plasma. Motions across magnetic fields have been studied in the context of laser-ionized channels and there are various results from laboratory and theoretical studies which indicate the need for space experiments. With respect to the motions of electron pulses parallel to magnetic fields, there is an urgent need to understand the collective processes affecting such propagation. In general, such a pulse can propagate only when the injected electron density is less than the ambient ion density. In this situation, it is predicted that a potential well will confine the energetic electrons, permitting the well to propagate away from the source at a speed determined by various ambient plasma and injected electron densities and energies. Experiments of such propagation are difficult to make in the laboratory, but can be done relatively easily in space.

7.5 Conclusions

The use of space as a medium for undertaking space-plasma science offers exciting new possibilities for plasma physics as well as other branches of solar-terrestrial science. This new and innovative work should be explored to the fullest extent possible in the coming years. Nevertheless, the loss of the space shuttle as a platform for conducting exciting, new space plasma experiments is a severe blow and the US space plasma physics community must survive until platforms with sufficient energy, and other resources are again available. In the meantime, the Soviet programs, even with joint participation, will most likely bring about a significant shift of leadership in this field. The Soviets are reaping benefits from 15 years of intensive study and planning undertaken now by US scientists and their associated international collaborators. While it is certainly valuable for the US active space science community to participate with the Soviets, this situation may not be advantageous to maintaining a position of research leadership.

To help overcome these difficulties, it is recommended that NASA make strong efforts to fully study existing data from already completed space plasma science missions and experiments. This may involve further funding of the groups who originally conducted the experiments and might be part of a new initiative related to "missions to data."

For those missions which are now scheduled, examination of their science goals and level of support is warranted. These missions, including Atlas-1, TSS-1 and CRRES, will be the sources of data which must carry the space plasma science community through a most difficult period. Supplementing these experiments, and the experiment teams, will come at far less cost than those expenses which accrue to entirely new missions.

The suborbital (rocket) program is an important means for nurturing progress in the field of space plasma science. To maintain research momentum in this field, it will be necessary to provide more flight opportunities than have been available in the past.

In looking to the period after 1995, it appears that a combination of astronaut-tended vehicles and free-flyers can be used for various important experiments and observations. Astronaut-tended platforms, for example, can be used in many active plasma and charged beam experiments. Likewise, the space station will enable entirely new types of experiments requiring substantial electrical power, remote observation sites, and perhaps even small, tethered payloads.