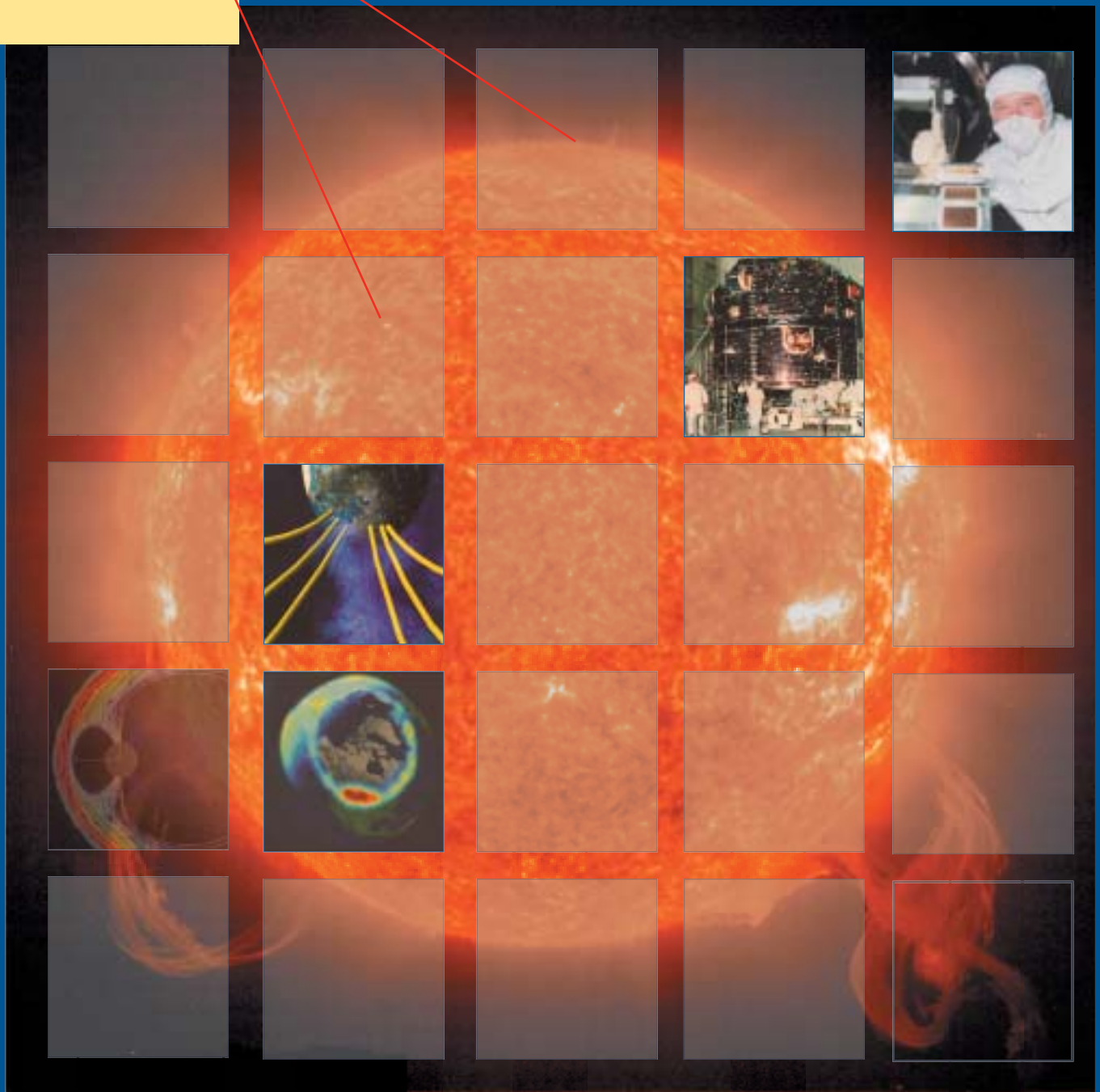
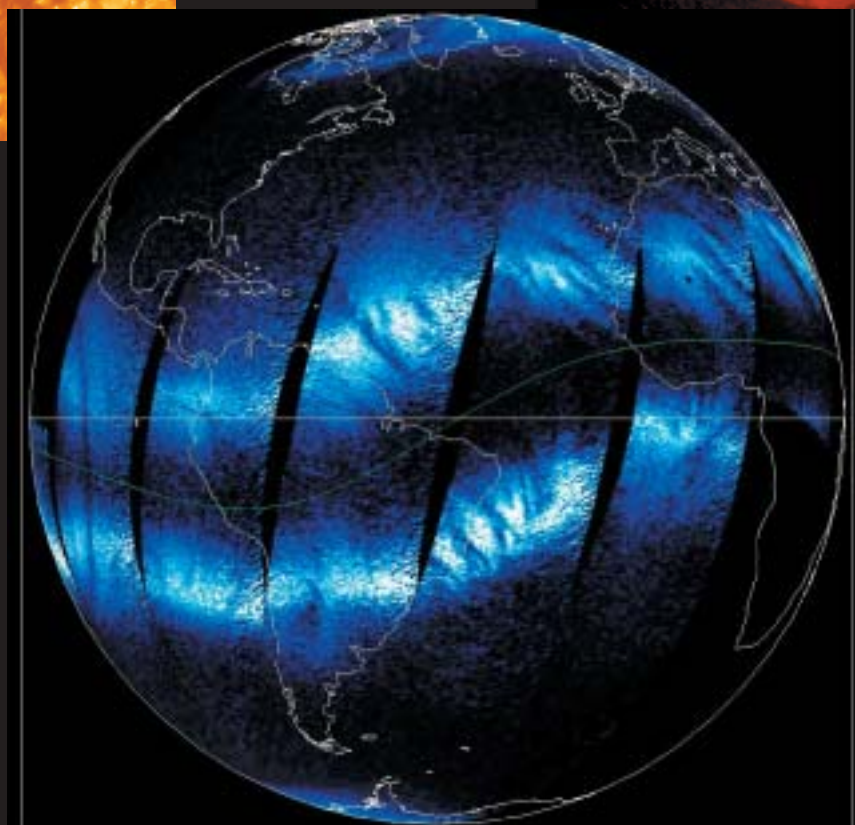
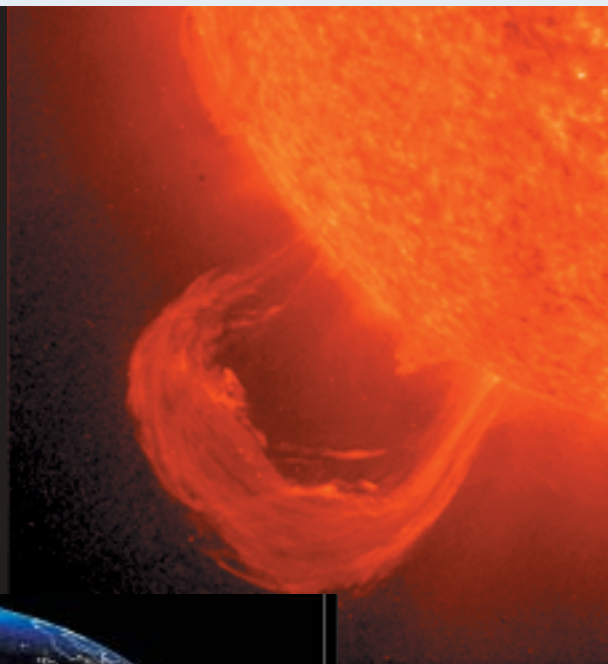
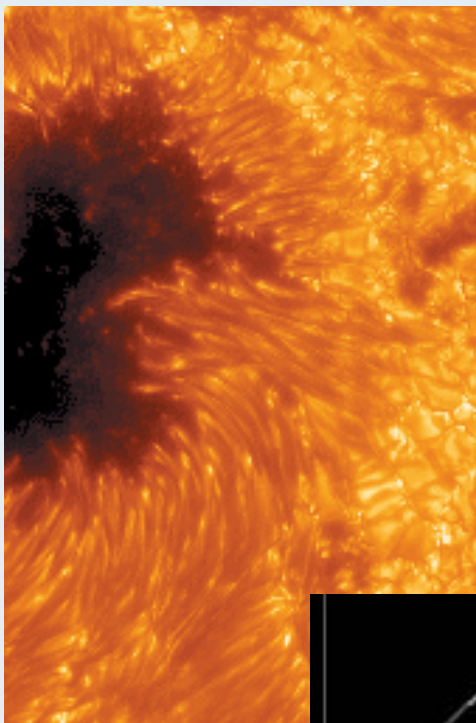


Fill all these squares with pictures representing the SCIENCE program ...



## Section 1: Science Objectives



Add more images of fine-scale structure ...

# Objective 1

## Opening the frontier of space environment prediction

We will understand the fundamental physical processes important in space -- from the Sun to Earth, to other planets, and beyond to the instellar medium.

The sun, our solar system and the universe consist primarily of plasma, which results in a rich, complex and interacting set of key fundamental physical processes. To predict the behavior of the complex systems that control the environments we will encounter on our return to the moon and journeys to Mars necessitates the development of a complete understanding of these processes. These key processes occur in many locations often with very different parameter regimes and boundary conditions. Our ability to quantitatively examine the same process in different regimes both tests our developing knowledge and enhances our understanding. There are universal themes that are part of all four RFAs, including energy conversion and transfer, cross-scale coupling, turbulence and nonlinear physics. Objective 1 is designed to provide the fundamental physics underpinnings that will enable the predictive capabilities to be developed as part of Objectives 2 and 3.

For each objective ... introductory text should place the objective within the context of the overall road-map approach ... each should connect firmly with the others as a seamless story ...

Add a paragraph or two for each RFA ... what they are, scope, what needs to be addressed... make clear why are these are our priorities ... why these are the most urgent and vital ...

more text ...

### Priority Research Focus Areas

Understand magnetic reconnection to reveal the causes of solar flares, coronal mass ejections, and geospace storms.

Understand the plasma processes that accelerate and transport particles

Delineate how planetary upper atmospheres are affected by energy inputs.

Determine how solar and planetary magnetic dynamos are created and why they vary.

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more text ... and figures

more text ... and figures

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more text ... and figures

more text ... and figures

### RFA 1.1. Understand magnetic reconnection to reveal the causes of solar flares, coronal mass ejections, and geospace storms.

Reconnection is the rapid conversion of magnetic energy to particle energy, which has long been recognized as an important process in regimes ranging from the very low density magnetotail of the Earth, to solar flares to laboratory fusion machines. Solar flares, coronal mass ejections and geospace storms are all initiated and energized by reconnection with often potentially devastating effects to space systems. Although satellite measurements, laboratory experiments and simulations have provided good evidence for consequences of this process as well as a strong indication where the process is initiated, the detailed physical processes are not well-understood.

The explosive conversion of magnetic energy originates in a region known as the diffusion region, which is very small in comparison to the large scales in space. For example, the initiation of magnetic reconnection on the Earth's magnetopause (the boundary separating solar wind magnetic fields from the Earth's magnetic field) occurs in a region with an area of the order of 100's of square kilometers on a surface that has a total area of approximately 60 billion square kilometers. Because of this tiny initiation region on such a large surface, the physical processes that initiate and control reconnection are still poorly understood. Reconnection is, therefore, a process in which cross-scale coupling is of paramount importance. It is also a process that accelerates particles to very high energies and, because it changes the magnetic field topology, it can dramatically alter the regions of space that are accessible to those particles. Reconnection can also sever large

'clouds' of hot plasma from the magnetic fields that anchored them.

Investigation 1. What are the fundamental physical processes of reconnection on the small-scales where particles decouple from the magnetic field?

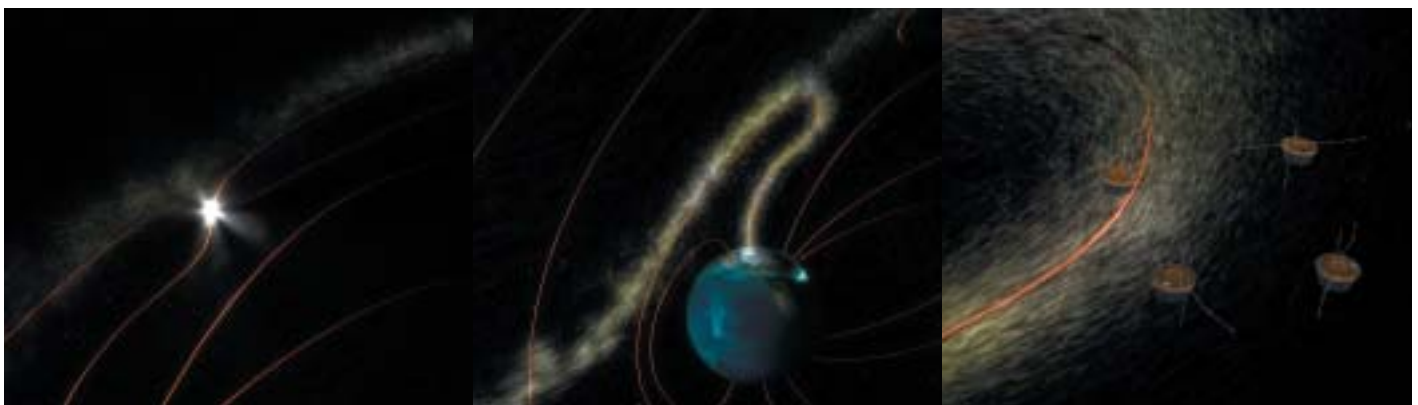
microphysics of mag reconnection [mms]

*Investigation 2.*

solar

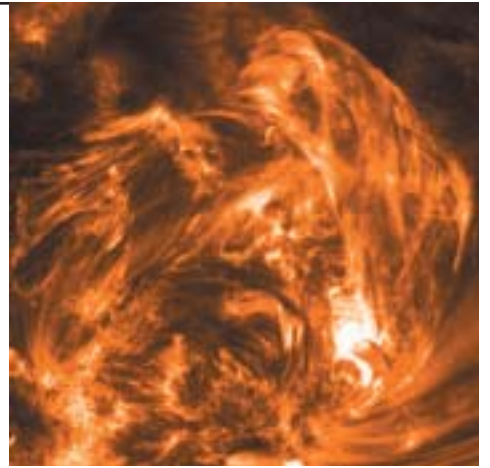
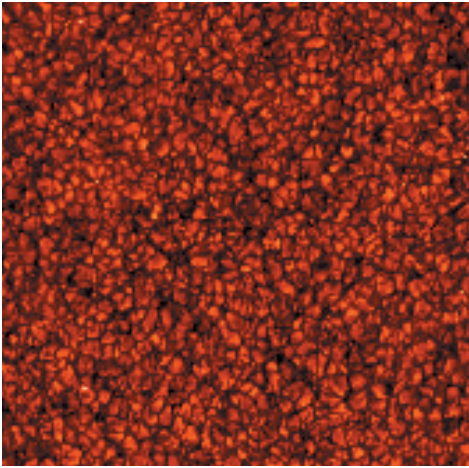
*Investigation 3. What are the mechanisms of particle acceleration in reconnection?*

One of the important components of the reconnection process is the acceleration of particles to high energies. Although some of the acceleration mechanisms are understood, there are many that are not. New instrumentation and multi-spacecraft studies have revealed surprising results. Recent studies of Cluster data have shown that ions can be ballistically accelerated to 10s of kV along the electric field in the region where they are no longer coupled to the magnetic field.

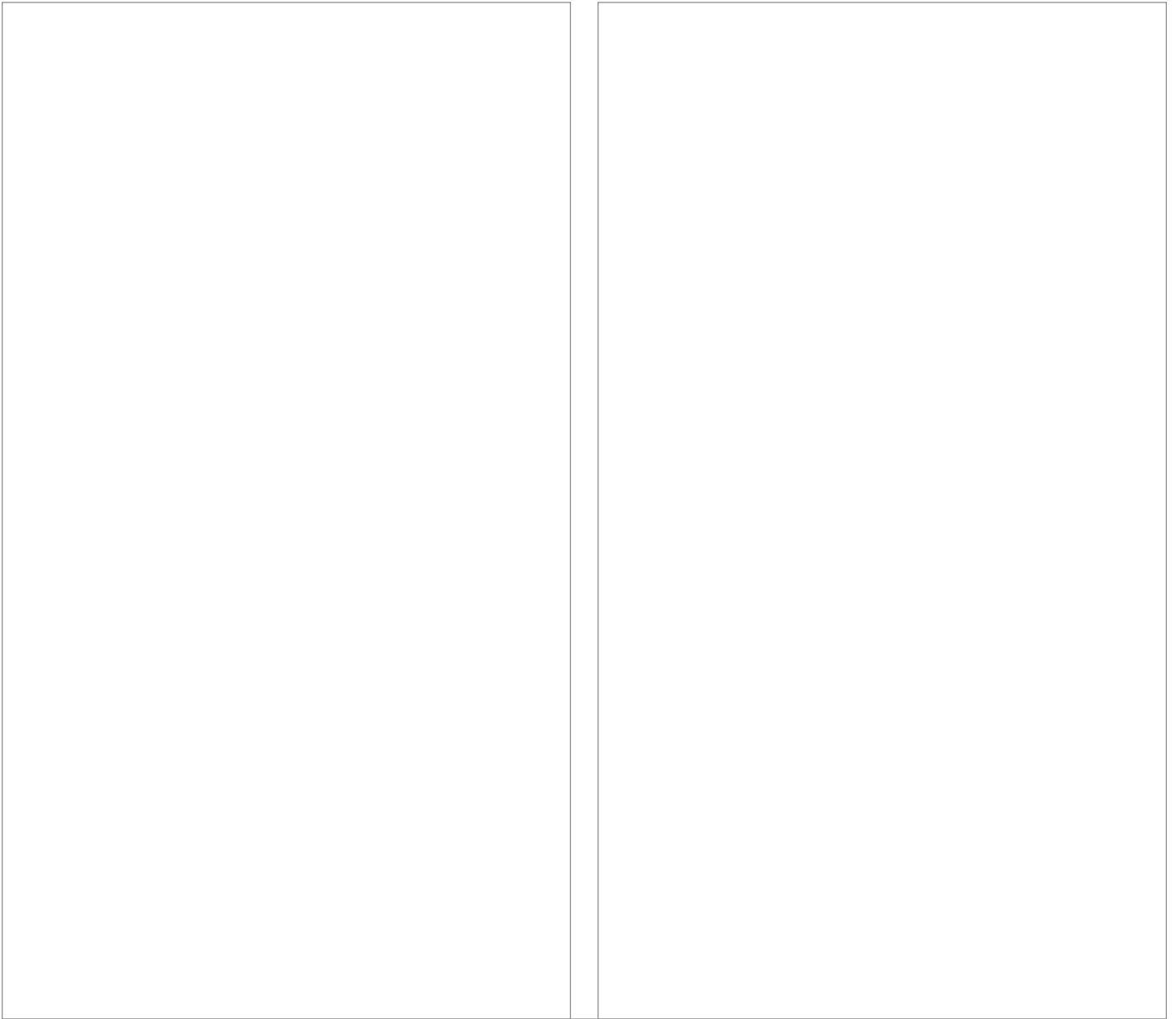


Show some reconnection sequence ... either at magnetopause, magnetotail, or on the sun ... make the “why this is important” point ... transfer of energy, mass ? site of explosive release?





Does something like this make a good sequence?? what would be in the middle? a big sunspot, and then a big sunspot with nasty polarity signatures? .... understanding how you get from such a pretty surface to a massive eruption is part of what section?? maybe we need something more specific to reconnection here and use these figures in another place ....



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## RFA 1.2. Understand the plasma processes that accelerate and transport particles

The existence of very high energy particles within the solar system is a impediment to the exploration of the solar system, particularly by humans. To mitigate the effects of these energetic particles, we must understand how and where they are accelerated and how they are transported throughout the heliosphere. Gaining this understanding is the focus of RFA 1.2. Although the particles are accelerated in many different locations within and outside the solar system, there are only a handful of processes that operate to accelerate particles to high energies. These include quasi-static electric fields to the background magnetic field, wave parallel electric fields, stochastic (Fermi) acceleration and drift of particles along a component of the electric field.

Energetic charge particles (ions and electrons) are accelerated both at localized sites (solar flares, magnetotail reconnection sites, auroral double layers), and globally (coronal and interplanetary shocks, CIRs, GMIRs, termination shock). The particles then undergo complicated transport that distributes them through the global system. For example, the initial intensity of prompt solar energetic particles (SEPs) depends initially on the directness of their magnetic connection into the solar corona, while the total fluence (dose) of energetic particle radiation depends on the transient magnetic disturbances that CMEs have produced on field lines beyond the exposure location

Consequently, if we are to characterize the distribution of these particles (in energy, time, and space) sufficiently so that we can design Exploration missions that are reliable and economical, we must understand both the dynamics of acceleration sites and the transport throughout the spatial structure of the system.

*Investigation 1. How are energetic particles accelerated in regions coupling very different plasma regimes?*

Understanding the role of boundary conditions and drivers that control the size and development of the electric fields field that accelerate particles to high energies is critical to obtaining the complete understanding of acceleration in astrophysical plas-

mas. The myriad scales and types of structures in which such fields can occur result in a complex phenomenology that occurs almost universally within space plasmas. Examples include parallel electric fields in kinetic Alfvén waves and in solitary waves. A complete understanding is necessary to provide predictive capability for such phenomena as solar energetic particles.

The Earth's aurora provides a unique opportunity to elucidate the mechanisms of energetic particle acceleration by parallel electric fields and waves. Previous rocket and satellite missions have provided evidence that energetic electrons and ions are produced by a wide range of processes, including large amplitude quasi-static parallel electric fields occurring in microphysical structures ('double layers'), wave parallel electric fields (KAW, electron holes, etc), and large perpendicular wave fields. The occurrence of these fields and the size of the acceleration are dependent both on the ionospheric and atmospheric boundaries and on the drivers in the magnetosphere. The aurora is, thus, an excellent laboratory for studying coupled systems and the interaction of large and small scales. Making progress in this study requires extremely high time resolution measurements on multiple satellites.

*Investigation 2. How are energetic particles accelerated and modulated by very large-scale structures such as the heliosphere?*

The heliosphere is a huge structure ~100 AU in radius, and its interface region (heliosheath) with the VLISM (Very Local Interstellar Medium) extends outward for yet another several hundred AU. It is through this interface that galactic cosmic rays enter the solar system, while it is the details of the structure and dynamics of disturbances within the heliosphere (solar wind) that determine the solar-cycle modulations of GCRs. Recent energetic ion and electron measurements from Voyager-1 at 85-95 AU have also revealed highly efficient particle acceleration in the vicinity of the expected termination shock.

*Investigation 3. How are particles accelerated in solar flares and CMEs?*



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**\*\*need a process related statement of this investigation. maybe needs to be 2. one for shock acceleration and one for reconnection?\*\***

[reconnection investigation, under particle acceleration include-ballistic acceleration in electric fields in ion diffusion region; wave acceleration; etc]

Observations of photon emission (x-rays and gamma-rays) prove that particles are explosively accelerated to relativistic energies in the chromosphere and lower corona. Subsequent acceleration by shocks (CME-driven) in the solar corona and solar wind (ICMEs) is a comparably important mechanism. The initial intensity of prompt solar energetic particles (SEPs), however, depends initially on the directness of their magnetic connection into the solar corona, while the total fluence (dose) of energetic particle radiation depends on the transient magnetic disturbances that CMEs have produced on field lines beyond the exposure location

[shock acceleration, under particle acceleration]

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### RFA 1.3. Delineate how planetary upper atmospheres are affected by energy inputs.

The upper atmospheres of planets are dramatically affected by energy inputs, including solar radiation, energetic particles from the aurora and ring/current radiation belts, and winds and other inputs from the lower atmosphere. This RFA is designed to provide a comprehensive understanding of the inter-related roles of these energy inputs. This is needed to enable the quantitative predictions of atmospheric structure needed for operations of satellites in the Martian atmosphere and mitigation of the effects of global change, as well as habitability of planets. The investigations focus on transfer of energy and momentum via gravity waves, energetic particle effects on atmospheric chemistry, and coupling between different plasma regimes. Additional fundamental processes include cross-scale coupling and development of nonlinear waves.

*Investigation 1. Understand the nonlinear dynamics governing transfer of momentum and energy between different spatial and temporal scales.*

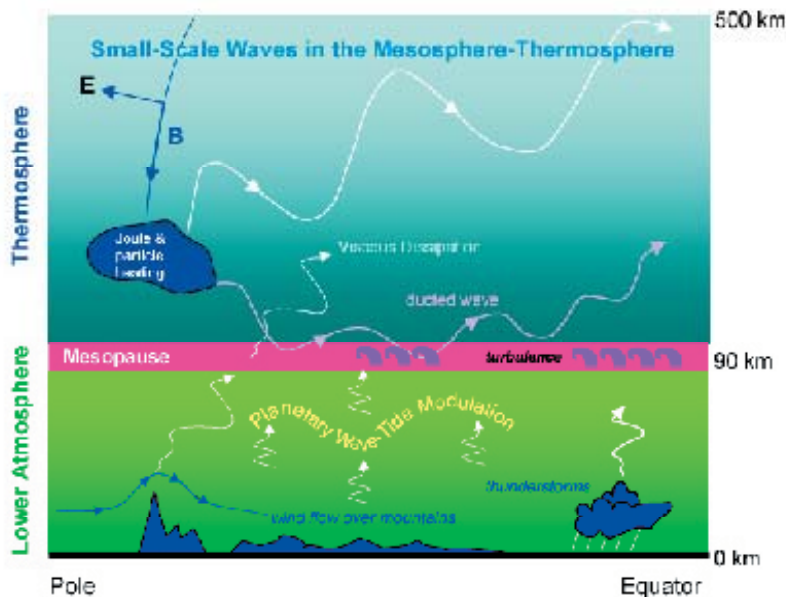
An important mechanism for transferring momentum and energy within the atmosphere is through the generation, propagation and dissipation of gravity waves. Gravity waves are generated by convection and latent heating, geostrophic adjustment, instabilities, and flow over topography in the lower atmosphere. The waves grow exponentially with height, and eventually undergo dissipation at higher altitudes where they deposit net momentum and heat into the atmosphere. Often, dissipation involves convective or dynamic instability and the transition to turbulence. Turbulence is important for the net vertical transport of heat, momentum and constituents. Gravity waves also interact with global-scale atmospheric tides and planetary waves and modify their behavior. In addition, gravity waves are launched from regions of intense auroral heating, and propagate horizontally, carrying energy and momentum to the low-latitude thermosphere and ionosphere. The fundamental physics of how gravity waves are generated, how they interact with other scales of motion, and how they undergo instability, break and create turbulence is poorly known. Sub-

grid parameterizations of gravity wave effects, which are essential for realistic general circulation model simulations of the atmosphere, cannot be developed until these basic physical processes are understood. Advances in this area require development of theory, intensive numerical simulations, high spatial and temporal measurements, and global measurements from space that delineate the sources, sinks and propagation characteristics of the waves throughout the atmosphere.

The theme of cross-scale coupling is also pertinent to outstanding problems in the ionosphere involving the formation of small-scale structures or plasma irregularities. Plasma irregularities interfere with communications and navigation systems. In many cases the ionosphere is preconditioned by large-scale processes in a way that leads to the initiation of instabilities and subsequent irregularity formation. While some understanding exists for the onset of plasma irregularities at equatorial and polar latitudes, the processes relating to the origin and evolution of newly-discovered storm-time mid-latitude ionospheric irregularities have not yet been identified. Our ability to characterize these irregularities and to understand their driving mechanisms suffers from a lack of basic measurements and from limited theory and modeling. In addition, the basic processes governing the onset, spatial extent, temporal evolution, intensities and spectral properties of these irregularities have not been characterized and in some cases never even measured.

*Investigation 2. Understand how energetic particles chemically modify planetary environments*

Energetic particle precipitation (EPP) perturbs atmospheric composition through dissociation and ionization processes, excitation of atmospheric species, and chemical pathways that are coupled with dynamical transport. EPP is responsible for planetary aurorae and, in Earth's atmosphere, the production of odd hydrogen (HOx) and odd nitrogen (NOx). These constituents play major roles in controlling global distributions of ozone. For example, NOx is created in the mesosphere and thermosphere by EPP, and transported downward in the polar night, in the absence of photo-dissociating solar radia-



tion. Once in the stratosphere, catalytic reactions leading to the destruction of ozone can occur. The largest NO<sub>x</sub> increase in the upper stratosphere ever observed occurred in April 2004 and is attributed to EPP. The major unknown in this problem is the spatial and temporal variability of the energetic particle spectra over time scales ranging from hours to decades. Thus, the physical processes fundamental to auroral precipitation, solar flare production of energetic protons, and electron precipitation from the radiation belts are key to our understanding of this phenomenon.

In addition, the processes controlling the transport of NO<sub>x</sub> downward to the stratosphere, including nonlinear interactions between gravity waves, the mean circulation and turbulence, are not well understood. Finally, the dynamical-chemical feedback mechanisms that are important to determining the final atmospheric response need to be identified and understood.

*Investigation 3. Understand how the magnetosphere and the ionosphere-thermosphere (IT) system interact with each other*

The exchange of energy and momentum between the magnetosphere and the ionosphere-thermosphere (IT) system strongly affects the behavior of both regions. Understanding how this exchange takes place on different space and time scales is

essential for understanding and predicting both quiet- and storm-time behaviors of these geospace regions. The exchange takes place mainly in the IT “boundary layer” between about 100 and 500 km, where ion motions undergo a transition from dominance by collisions with air molecules at lower altitudes to dominance by electromagnetic fields at higher altitudes. It is here that energetic particle precipitation increases ionization levels and enhances the inherent electrical conductivity of the ionosphere, modulating the magnetosphere-ionosphere electrical circuit that transfers the energy. The rate of energy and momentum transfer is also influenced by winds that are set into motion by collisions with rapidly moving ions, creating a time-dependent feedback. The strong heating produces vigorous vertical motions of the air that mix the constituents unevenly and change the ion loss rate, affecting the ion densities and electrical conductivities. The fundamental processes that determine the rates of energy and momentum exchange on different scales, the manner in which the magnetosphere and the IT system respond to this multi-scale exchange, and the character and strength of the various nonlinear feedbacks, are poorly understood.

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**RFA 1.4. Determine how solar and planetary magnetic dynamos are created and why they vary.**

The existence of the magnetic fields of the Sun and planets is a critical element of the Sun-Solar System connection. However, the operation of the dynamos in stellar and planetary interiors is very poorly understood. Because the solar magnetic field is the source of energy for acceleration of solar particles to high energies and controls the structure of the heliosphere and, thus, the entry of galactic cosmic rays into the solar system, it is imperative that we understand the origin and variability of the solar magnetic field. The dynamo in the Earth's interior sustains the geomagnetic field, which provides the shield that enables life to flourish in the otherwise deadly radiation environment of the solar system. It is well-known that the geomagnetic field varies in strength and ultimately reverses, weakening the shield during this change.

Nonlinear coupling and dynamics of flows.

Investigation 1.

- solar dynamo: prediction of solar cycle (long-term planning for lunar/mars colonies),  
prediction of emergence of active regions (short-term warning)  
prediction of Maunder minimum (Ice ages ?, ozone holes?)
- Earth dynamo: prediction of magnetic field flipping

