Sun Solar System Connection

NASA’S VISION

To improve life here,
To extend life to there,
To find life beyond.

NASA’S MISSION

To understand and protect our home planet,
To explore the universe and search for life,
To inspire the next generation of explorers
... As only NASA can.

NASA’S VALUES

Safety, the NASA Family, Excellent, and Integrity

Composite image of our Sun in three wavelengths. Blue-green are the coolest ____ wavelengths and show ____, Red is somewhat hotter and shows ___________ and yellow-white is the hottest part of the solar corona and ___________________ ___

NASA STRATEGIC OBJECTIVE #15

Explore the Sun-Earth system to understand the Sun and its effects on Earth, the solar system, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational systems.

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INTRODUCTION TEXT STARTS HERE ... MAYBE START WITH A NICE QUOTE

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More intro text ....

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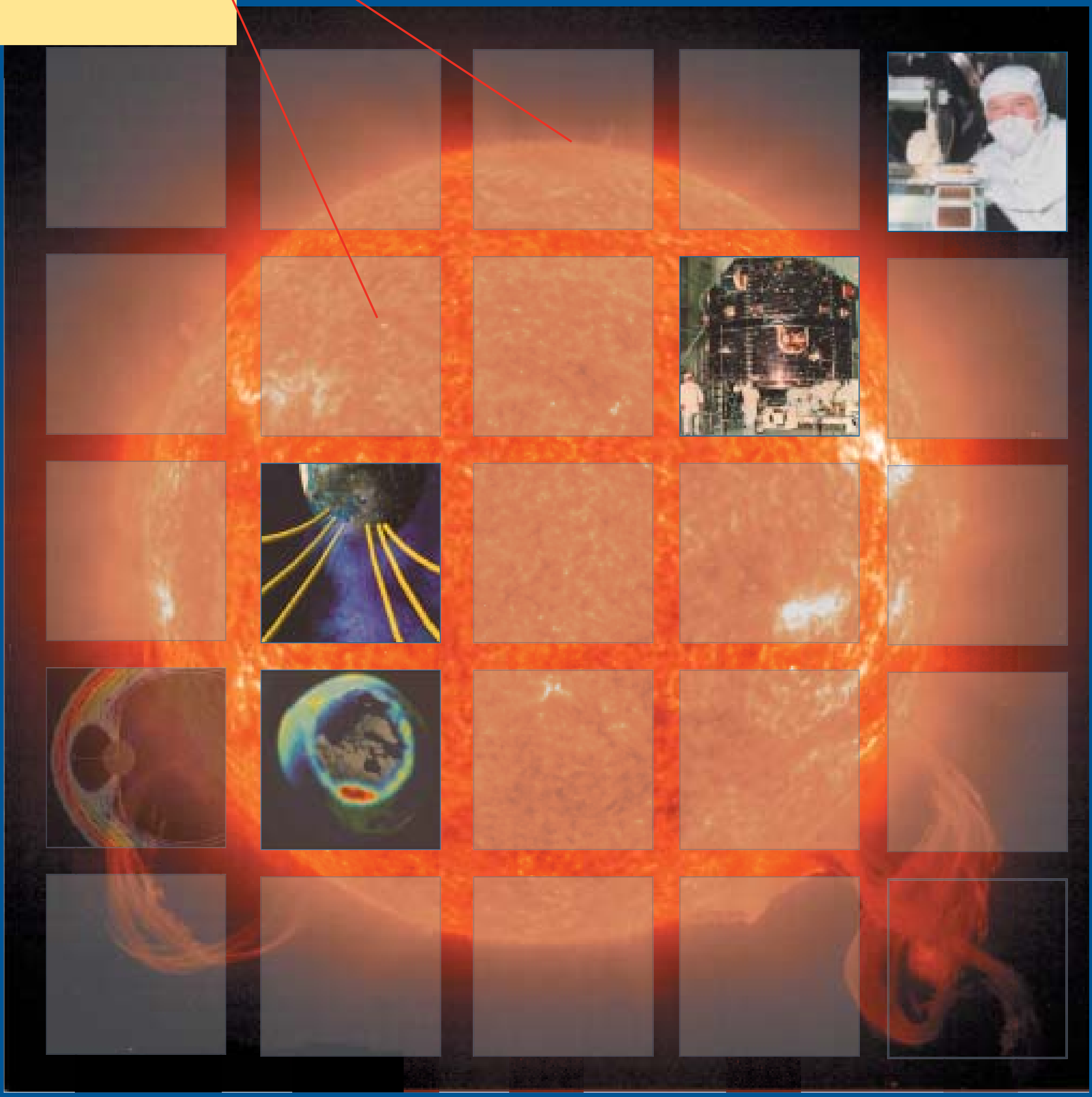
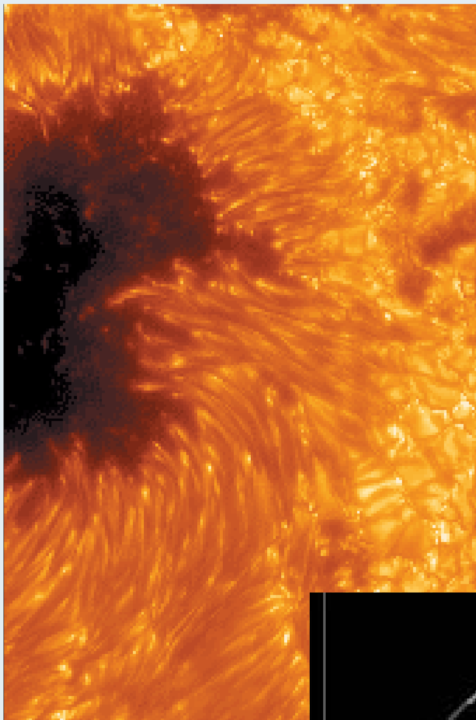
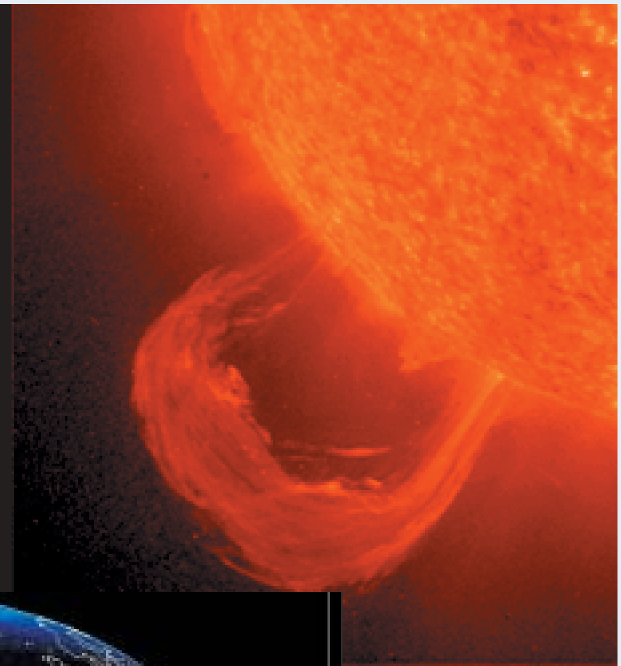
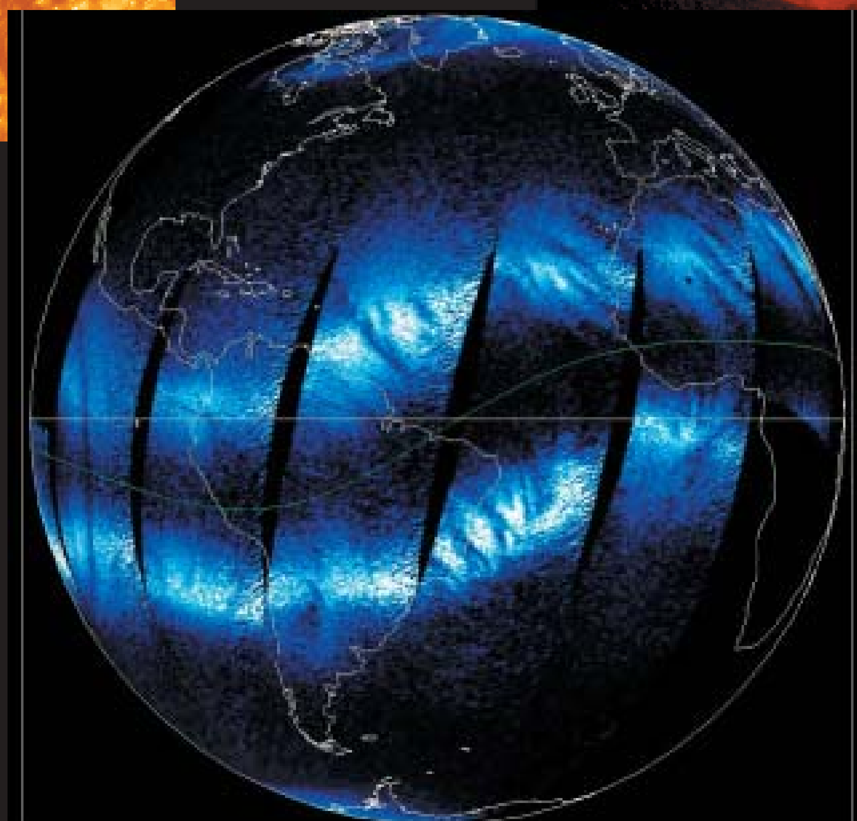


Section 1: Science Objectives







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 roadmap approach ... each should connect firmly with the others as a seamless story ...

Add a paragraph or two for explaining the priority RFAs ... make clear why are these are our priorities and not something else ...

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.

more text ... and figures

more text ... and figures

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 enegized 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?

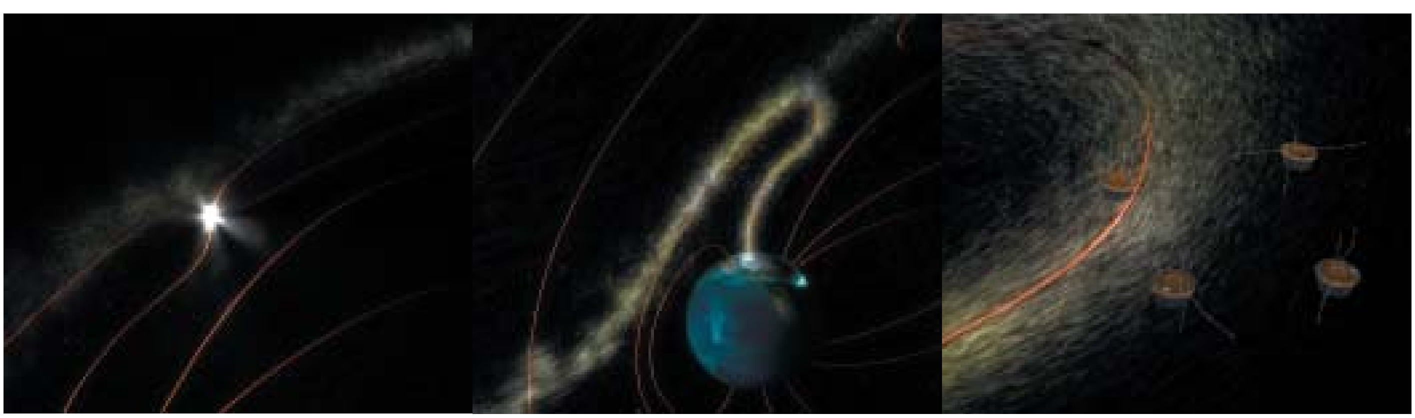
microphysics of mag reconnection [mms]

Investigation 2.

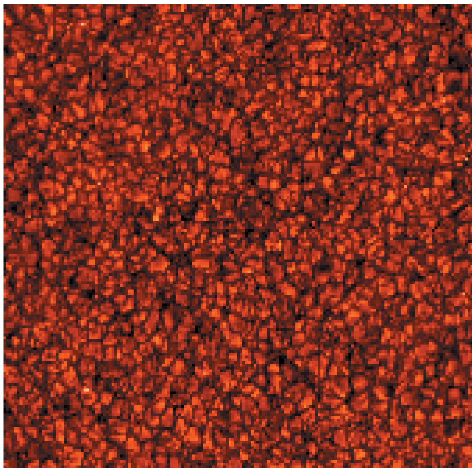
solar

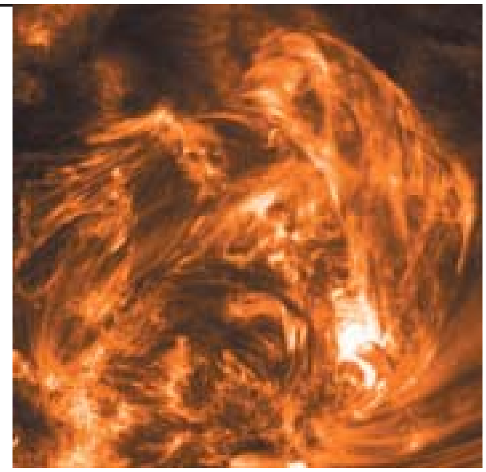
Investigation 3. What are the mechanisms of particle acceleration in reconnection?

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 ....

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 plasmas. 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 Alfven 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 fromVoyager-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?

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]

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.

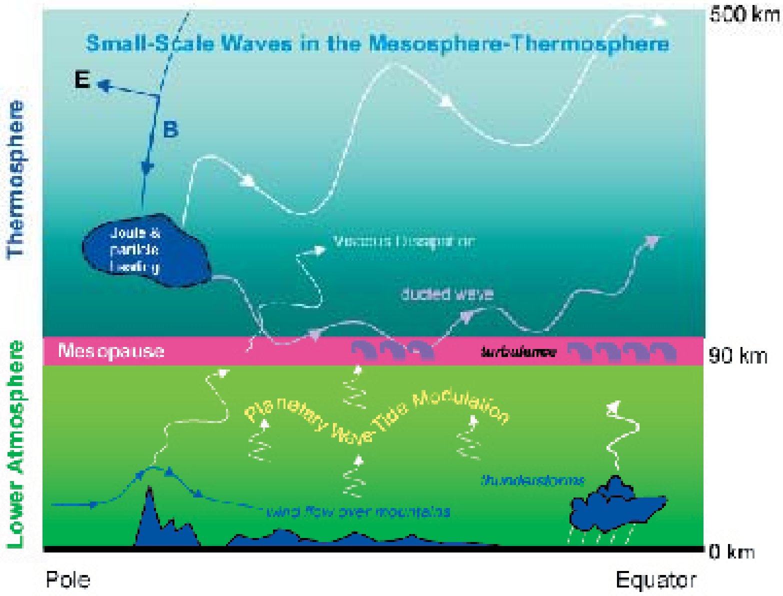
Investigation 1. Understand the nonlinear dynamics governing transfer of momentum and energy between different spatial and temporal scales.

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 NOx 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 NOx 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

sential for understanding and predicting both ɘ quiet- and storm-time behaviors of these geoace regions. The exchange takes place mainly the IT "boundary layer" between about 100 and 0 km, where ion motions undergo a transition m dominance by collisions with air molecules at ver altitudes to dominance by electromagnetic ds at higher altitudes. It is here that energetic rticle precipitation increases ionization levels and hances the inherent electrical conductivity of the jion, modulating the magnetosphere-ionosphere ctrical circuit that transfers the energy. The rate energy and momentum transfer is also influenced winds that are set into motion by collisions with ɘ rapidly moving ions, creating a time-dependent edback. 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.

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.

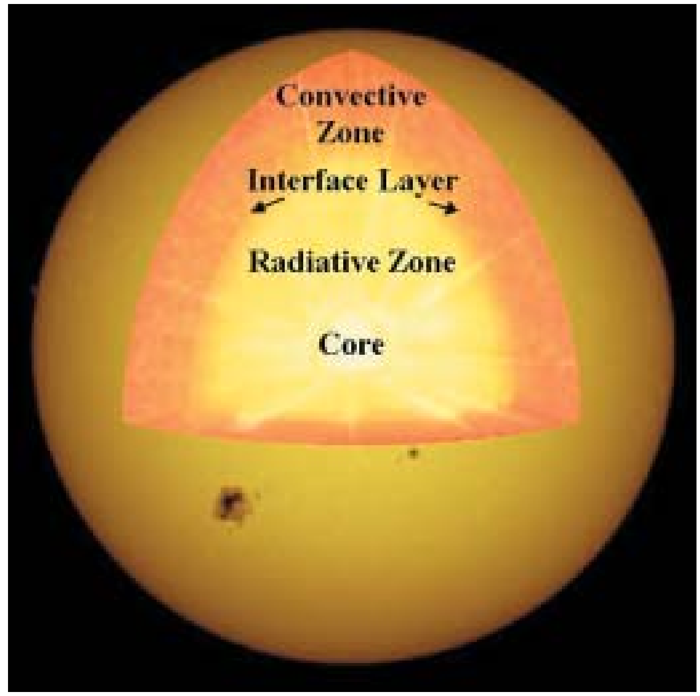
Investigation 1.

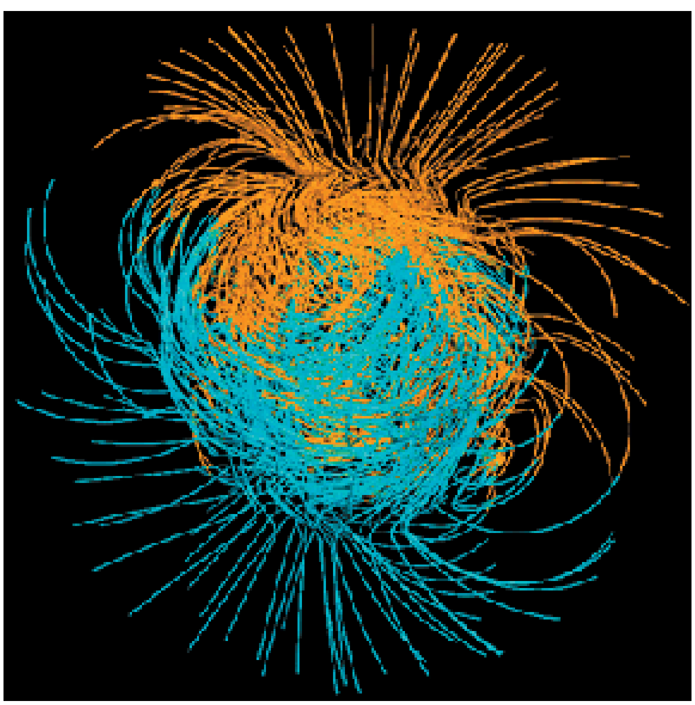
- solar dynamo: prediction of solar cycle (long-term planning for lunar/mars colonies),

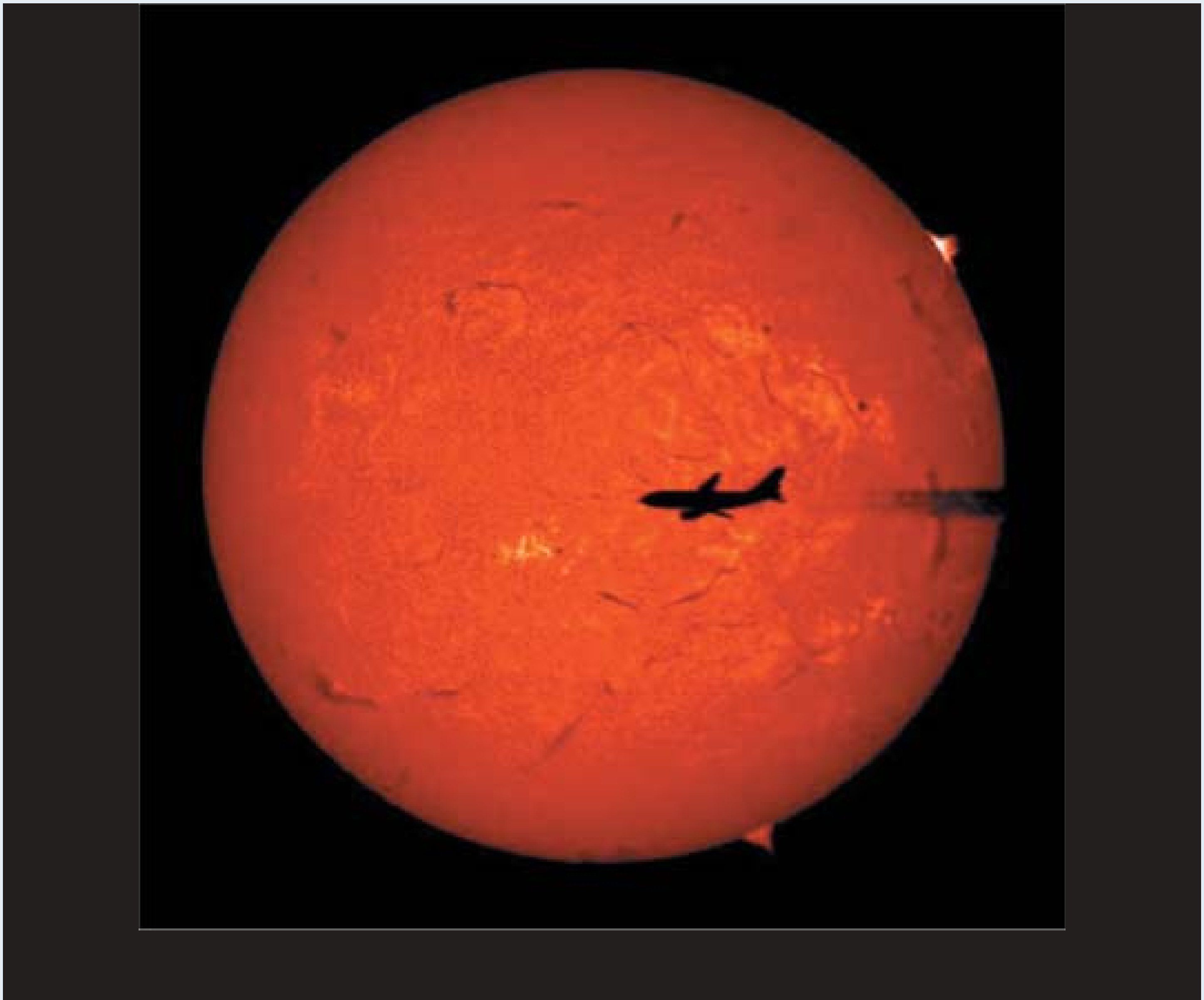
prediction of emergence of active regions (short-term warning

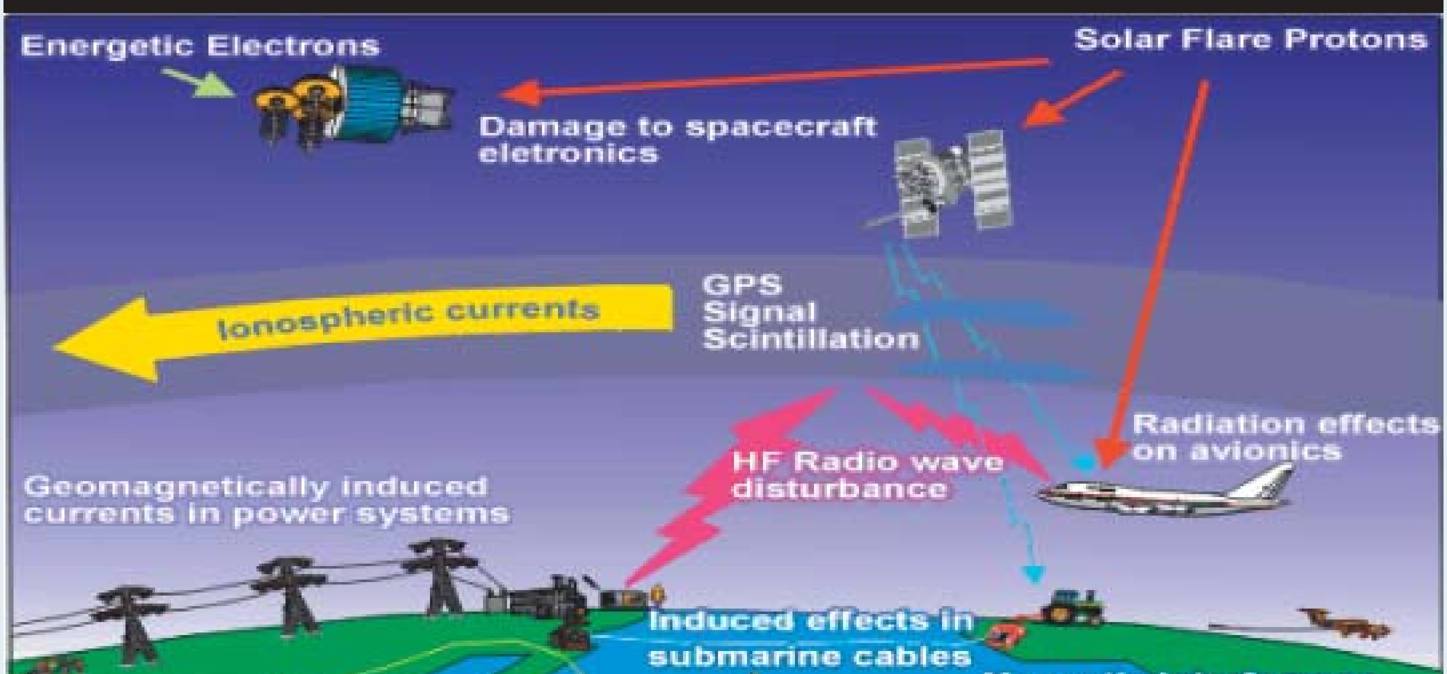
prediction of Maunder minimum (Ice ages ?, ozone holes?)

Earth dynamo: prediction of magnetic field flipping








Energetic Electrons
Solar Flare Protons
Damage to spacecraft
eletronics
Ionospheric currents
GPS
Signal
Scintillation
Radiation effects
on avionics
HF Radio wave
disturbance
Geomagnetically induced
currents in power systems
Induced effects in
submarine cables
Magnetic interference
in exploration surveys
Telluric currents in pipelines

Objective 2

Understanding the nature of our home in space

We will understand how society, technological systems, and the habitability of planets are affected by the variable space environment.

This objective addresses the impact of the space environment on humankind, principally on Earth but also throughout the solar system as part of our exploration of the solar system. We do not live in isolation; we are intimately coupled with the space environment through our technological needs, the habitability of planets and solar system bodies we plan to explore, and ultimately the fate of Earth itself. Variability in the near-Earth space environment affects the daily activities that constitute the underpinning of our society, including communication, navigation, and weather monitoring and prediction.

As we extend our presence throughout the solar system, we are increasingly interested in the planetary environments awaiting us and how the study of these environments can be applied to our home on Earth. A casual scan of the solar system is sufficient to note that habitability to humankind is a rare congruence of many events. At least some of these factors, especially the role of magnetic fields in shielding planetary atmospheres, are a subject of immense importance. We think we understand some of the features that make planets habitable, but we need to understand much more.

Because of the intimate coupling of solar system processes, the interplanetary medium, and the near-Earth environment, it is necessary to conduct a series of coupled investigations covering each of these regions. Specifically, investigations of impacts on humankind must start from the sun, then follow propagation of solar disturbances through the interplanetary medium, and finally investigate the interaction of the solar wind with the Earth's MIT (magnetosphere-ionosphere-thermosphere) region.

To this end, we present three Research Focus Areas (RFA's). The first attempts to understand the sun to the degree that we can predict solar activity and the evolution of solar disturbances as they propagate to the earth. The second RFA tries to understand the response of the near-Earth plasma regions and the third addresses the atmospheric responses. A fourth RFA addresses the importance of understanding additional, vitally important topics such as the impact of solar wind on other solar system bodies and the advantages of studying stars other than our sun. These investigations provide important opportunities for linkages with other NASA fields of study.

It is important to note that it is not enough to just study variability and change. Coupled systems have complex internal forcings, e.g. gravity wave breaking in the upper atmosphere. Even in the absence

Priority Research Focus Areas

Develop the capability to predict solar activity and the evolution of solar disturbances as they propagate through the heliosphere and affect space climate/ environment.

Determine changes in the Earth's magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects

Understanding the role of the Sun as an energy source to the Earth's atmosphere, and in particular the role of solar variability in driving change.

Apply our understanding of space plasma physics to the role of stellar activity and magnetic shielding in planetary system evolution and habitability of solar variability, we still have to understand the internal dynamics of the near-Earth coupled systems that protect us. The RFA's outlined below therefore focus on both internal linkages and external forcing mechanisms.

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 ...

more text ... and figures

more text ... and figures

more text ... and figures

more text ... and figures

RFA 3.1 Develop the capability to predict solar activity and the evolution of solar disturbances as they propagate through the heliosphere and affect space climate/environment

This RFA focuses on the solar-heliospheric component of the solar system. It addresses the variability of the Sun and how disturbances are transmitted through the heliosphere. The research topics include short-term impacts from energetic particles, moderate-term impacts from coronal mass ejections (CMEs), and longer-term impacts from changes in irradiance. They also include study of the impacts on planetary space environments, in particular Earth's magnetosphere, but the details of this influence are captured in the following RFAs.

This RFA necessarily overlaps with RFA 2 of Objective 2, and much of the discussion there applies here as well. However, the emphasis in this RFA, and throughout Objective 3, is to understand the impact of solar activity directly relating to human activities on Earth. This RFA highlights the fact that the Sun is the primary driver of the detrimental impact of the space environment on human society and technological systems. A solid understanding of the physical processes beyond the planetary environment is thus critical to understanding the physical processes within the planetary environment.

This RFA is important because solar disturbances are the energy source for almost all near-Earth activity. If we can show that our understanding of the solar and heliospheric physics is correct, then we can produce a predictive capability that works here at Earth as well as anywhere in the solar system.

3.2 Determine changes in the Earth's magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects

The near-Earth space environment, geospace, is unique in the solar system and central to the protection of Earth and its inhabitants. This region includes the magnetosphere, ionosphere, and thermosphere (MIT) bound together as a tightly coupled system characterized by plasma processes of ionized gases.

The variability within geospace and the nearby interplanetary environment is generically termed space weather. Much of space weather is driven by the external processes addressed by RFA3.1. This RFA (3.2) focuses on the geospace consequences of those processes. In addition, internal drivers of the MIT region, such as the upward propagation of gravity waves, wave-particle interactions, and auroral current systems are equally important and must be investigated. This means that even in quiet solar wind condition, there can be significant variability within the MIT region.

Geospace is the location of most of our space activities. Communication, navigation, Earth weather and remote sensing, emergency location, defense reconnaissance, and NASA space science and astronomy missions are all affected by space weather. Space weather also causes disturbances of electric power grids and sensitive electronic systems on the ground. These include navigation systems used by commercial airliners.

The technological systems sensitive to disturbance in geospace are increasing in importance and urgency to human society.

3.3 Understanding the role of the Sun as an energy source to the Earth's atmosphere, and in particular the role of solar variability in driving change.

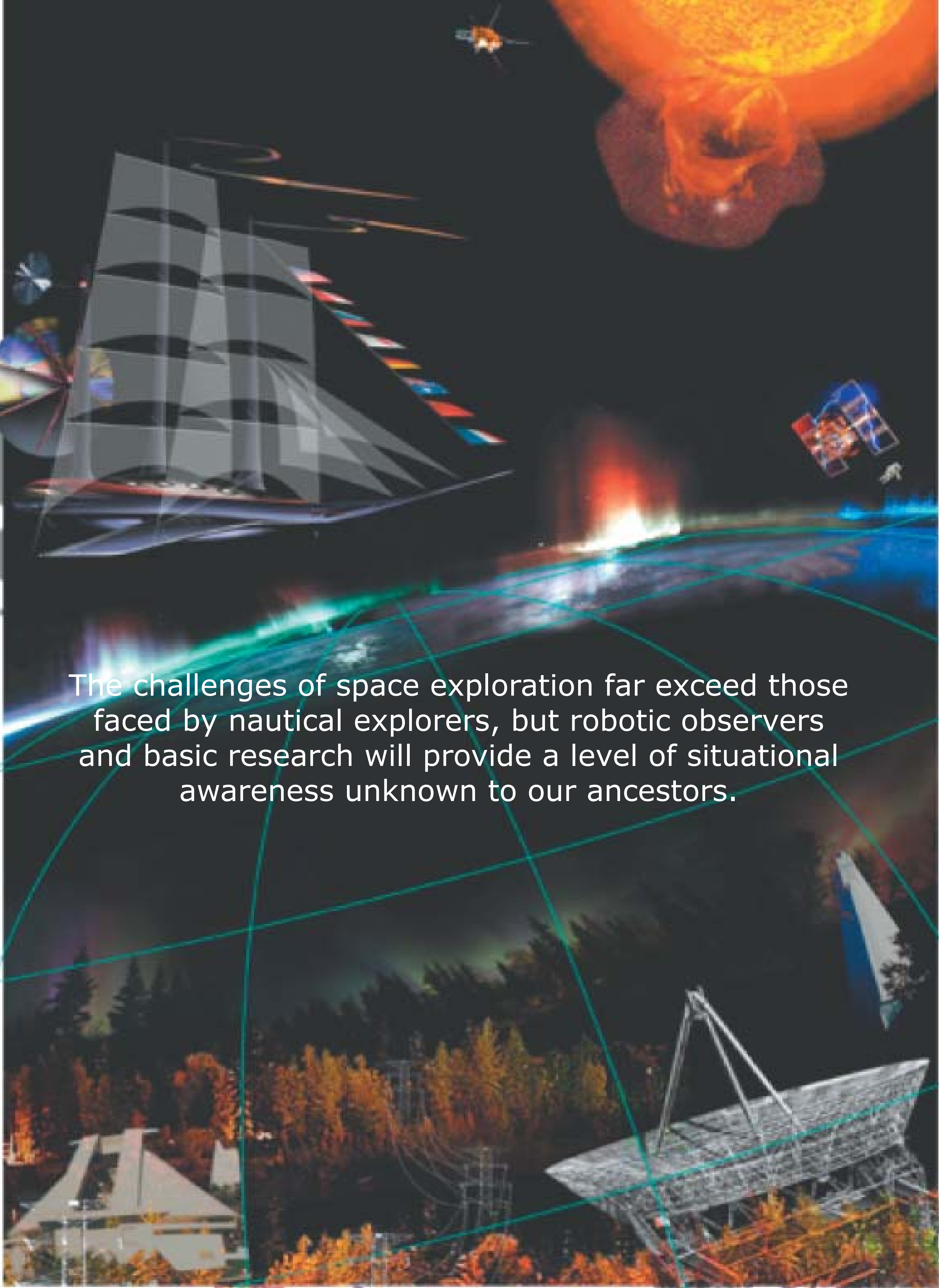
Solar energy in the form of photons and particles drives the chemical and physical structure of the Earth's atmosphere. Ultraviolet and more energetic radiation is deposited globally and throughout the stratosphere, mesosphere, and thermosphere and is responsible for the formation of the ionosphere. Particles primarily deposit their energy at high latitudes but the resulting ionization, dissociation, and excitation of atoms and molecules can have a global effect as a result of dynamical processes occurring within the Earth's atmosphere that transport energy over the globe. Ultimately these processes combine to drive the temperature and chemical composition of the entire Earth's atmosphere. A key example of how solar modification of the atmosphere affects life is ozone in the upper atmosphere. Ozone provides a shield for humans from the effect of solar UV radiation. The presence of ozone is a direct result of solar energy deposition. Nitric oxide is created at higher altitudes by processes involving solar energy but may be transported to lower altitudes where it will destroy ozone.

Because life is dependent upon the atmosphere and its climate, studies of the modification of the atmosphere by solar energy are critically important. Solar energy and its variation are thought to have effects throughout the atmosphere including the troposphere where humans live. The magnitude and variability of the solar energy deposition remain poorly understood. In addition, the coupling processes that spread the effects of that energy deposition in altitude and latitude are also poorly understood. To resolve these issues, spectral measurements of the solar energy deposition which are resolved in space and time are required. Observation, theory, and modeling of the dynamical processes which distribute the effects of the solar energy are also crucial.

3.4. Apply our understanding of space plasma physics to the role of stellar activity and magnetic shielding in planetary system evolution and habitability

Plasmas and their embedded magnetic fields play an important part in the formation, evolution and destiny of planets and planetary systems. The only habitable planet we know is shielded by its magnetic field, protecting it from solar and cosmic particle radiation and preventing the erosion of the upper atmosphere by the solar wind. It is important to establish the extent that this is necessary for the formation of a stable planetary atmosphere that can sustain life. Planets without a shielding magnetic field, such as Mars, are exposed to additional physical processes (such as direct momentum transfer between the variable solar wind and their atmosphere) that may have a significant role in their evolution.

It is believed that planetary systems evolve from debris disks around young stars. Plasmas and magnetic fields are thought to play an important part in this process, both in the internal structure of the disk and its interaction with its parent star. The study of analogous plasma processes in the solar system (for example dusty plasmas in magnetospheres of Saturn and Jupiter) can lend insight into the significance of these effects. The coupling between planetary magnetic fields and their magnetospheres (e.g. Jupiter and its magnetodisc and Earth and the plasmasphere) will provide insight into the mechanisms that couple young stars to their debris disks.


The challenges of space exploration far exceed those faced by nautical explorers, but robotic observers and basic research will provide a level of situational awareness unknown to our ancestors.

Objective 3

Safeguarding our outbound journey

We will work to assure the safety and maximize the productivity of human and robotic explorers by developing a predictive capability for the extreme and dynamic conditions in space.

Priority Research Focus Areas

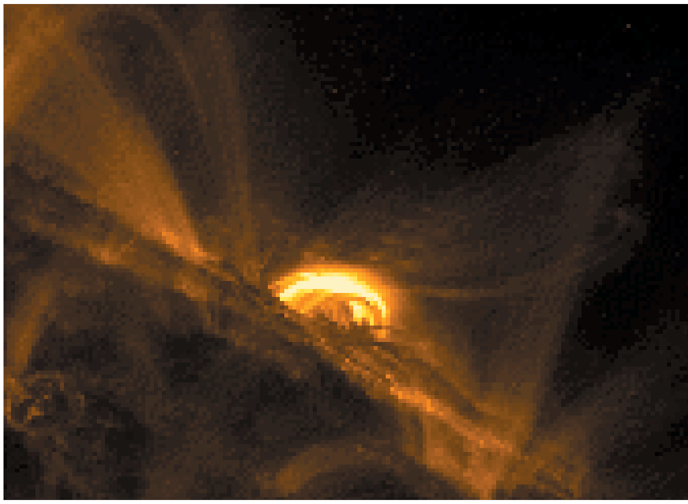
Characterize the energetic particle, plasma and neutral particle environments, and electromagnetic radiation that will be encountered by human and robotic explorers.

Develop the capability to predict the origin and onset of solar activity and disturbances (CMEs/SPEs/GLEs) associated with potentially hazardous space weather events.

Develop the capability to predict the energetic particle radiation and other hazards associated with the propagation of solar disturbances. (Shocks/CMEs/SEPs/ CIRs) to enable safe travel for human and robotic explorers.

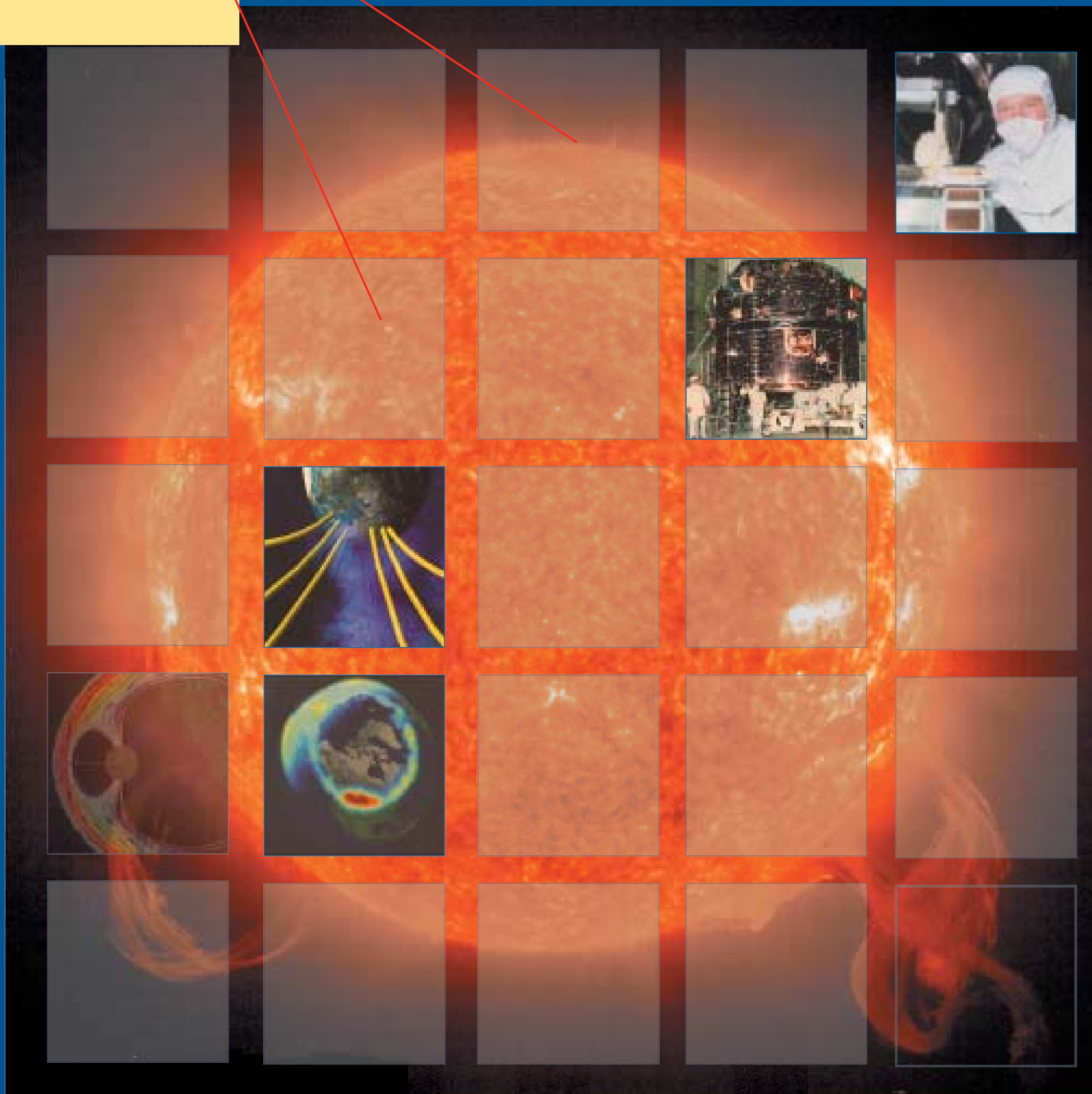
Understand and characterize the space weather effects on and within planetary environments to minimize risk in exploration activities.

“There are no such things as applied sciences, only applications of science.”
- Louis Pasteur



This solar X-class flare was observed by TRACE at 16:43UT on 22 November 1998. The flare heats up an arcade of loops at the edge of the disk that light up in the extreme ultraviolet.

Fill all these squares with pictures representing the missions and technologies ...



Section 2: Recommended Investigations

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771