

H. Candidate Mission Reference List

SSSC utilizes several mission resources. Strategic fundamental science missions are executed as **Solar-Terrestrial Probes (STP)**, The **Living With A Star (LWS)** mission line is also strategic, dedicated to research on understanding and mitigating effects of space weather. Flagship Missions (FLG) are grand challenge missions that require separate new starts outside the STP or LWS programs. **Explorer (EXP)** missions are smaller than the others and present opportunities for open competition to address scientific investigations that are relevant and timely. Some missions receive external (**EXT**) funding, either from other parts of NASA, other agencies, or other national entities. Below, we list & define acronyms for SSSC mission candidates, and categorize them, to the degree possible at this time, according to these mission lines.

Acronym	Mission Name	ProgramLine
AAMP	Auroral Acceleration Multi-Probe	STP
ADAM	Aeronomy and Dynamics At Mars	EXT
AIM	Aeronomy of Ice in the Mesosphere	EXP
DBC	Dayside Boundary Constellation	LWS
Doppler	Doppler	STP
FS	Far-side Sentinel	LWS
GEC	Geospace Electrodynamics Connections	STP
GEMINI	GEospace Magnetosphere-Ionosphere Neutral Imagers	LWS
HS	Heliosstorm	LWS
HIGO	Heliospheric Imager and Galactic Observer	STP
IE	Io Electrodynamic s	P4
IHS	Inner Heliospheric Sentinels	LWS
IBEX	Interstellar Boundary Explorator	EXP
IMC	Inner Magnetospheric Constellation	LWS
ISP	InterStellar Probe	FLG
ITMC	Ionosphere-Thermosphere-Mesosphere Coupler	STP
ITMW	Ionosphere-Thermosphere-Mesosphere Waves	STP
ITSP	Ionosphere-Thermosphere Storm Probes Plus Imager	LWS
JPO/Juno	Jupiter Polar Orbiter	EXT
L1SCE	L1 Solar-Climate Explorer	EXT
LIM	L1 Mission	EXT
LRO	Lunar Reconnaissance Orbiter	EXT
MARS	Mars Atmospheric Reconnaissance Survey	EXT
MC	Magnetospheric Constellation	STP
MSL	Mars Science Laboratory	EXT
MMS	Magnetospheric MultiScale	STP
MTRAP	Magnetic TRAnsition region Probe	P4
NO	Neptune Orbiter	EXT
PK	Pluto/Kuiper	TBD

RAM	Reconnection and Micro-scale	STP
RBSP	Radiation Belt Storm Probes	LWS
SCOPE	Solar Connection Observatory for Planetary Environments	P4
SECEP	Sun-Earth Coupling by Energetic Particles	LWS
SEPM	Solar Energetic Particles Mission	LWS
SHIELDS	Solar Heliospheric & Interplanetary Environment Lookout for Deep Space	LWS
SI	Stellar Imager	FLG
SDO	Solar Dynamics Observatory	LWS
Solar-B	Solar-B	EXT
SO	Solar Orbiter	EXT
SP	Solar Probe	FLG
SSD	Solar Sail Demo	EXT
SPI	Solar Polar Imager	LWS
STEREO	Solar-TERrestrial RELations Observatory	STP
SWB	Solar Wind Buoys	LWS
TE	Titan Explorer	P4
TLM	Telemachus	LWS
THEMIS	Time History of Events and Macroscale Interactions during Substorms	EXP
TWINS	Two Wide-angle Imaging Neutral atom Spectrometers	MOO
VAP	Venus Aeronomy Probe	P4

I. Mission Descriptions

Near-Term Missions

Aeronomy of Ice in the Mesosphere (AIM)

The primary goal of the Aeronomy of Ice in the Mesosphere (AIM) mission is to resolve why Polar Mesospheric Clouds (PMCs) form and why they vary. In addition, AIM will determine the mesospheric response to solar energy deposition and coupling among atmospheric regions.

AIM will examine the relative contributions of solar and anthropogenic effects that cause change in the upper atmosphere and it will examine long term change. AIM will also make key observations of solar energetic particle induced effects on upper atmospheric composition, in particular of odd-nitrogen compounds and ozone.

AIM is a top priority in view of current heightened scientific and public interest in PMCs and the immediate need to understand how the upper atmosphere responds to variable solar energy inputs such as solar storm events..

Geospace Electrodynamic Connections (GEC)

GEC will determine the fundamental processes coupling the ionosphere and magnetosphere. The upper atmosphere is the final destination of the chains of fields, particles and energy that start at the Sun, transit the heliosphere, and are modified by the magnetosphere and upper atmosphere. To transform and inform our understanding of this fundamental question a formation of 3-4 spacecraft must be sent to resolve the spatial structures and time variations, repeatedly and systematically, into the depths of the atmosphere to this transition region: 130 to 180 km. The spacecraft will have complete instrument packages that measure both the magnetosphere energy/momentum inputs at high latitudes and the atmosphere-ionosphere responses.

GEC will transform our understanding of the chain of events from the sun to the atmosphere by providing for the first time, comprehensive, collocated, simultaneous atmospheric measurements, the models with which to interpret them, and context setting measurements of the Sun, heliosphere, and magnetosphere. These questions cannot be addressed without actually making the in situ observations. GEC does this using proven technologies, such as formation flying, to unravel the spatial and temporal coupling of the transition region phenomena in a reconfigurable observatory.

GEC will transform our understanding of fundamental processes in the upper atmosphere. It will also enable practical applications relevant to Protecting our Home in Space, and the Outward Journey. Dipping the spacecraft from the collisionless to the collisional regime provides an analog for aerobraking and aerocapture operations at Mars.

Under current NASA funding guidelines, GEC is planned for launch in 2017, with a two -year prime mission lifetime. It is possible that GEC will overlap with the ITSP mission, with corresponding synergies that are discussed under the ITSP description. However, each mission provides unique measurements and insights, and neither one should be delayed for the sake of overlap.

Inner Heliospheric Sentinels

The four Inner Heliospheric Sentinel spacecraft flying in various formations will detect how structures change in space and time during the transit. IHS investigations will discover, model, and understand the connection between solar phenomena and geospace disturbances.

Interactions in interplanetary space make the linkage between point sampled 1 AU measurements and their solar sources difficult or impossible. IHS science is important to understanding which disturbance will be geoeffective and for developing predictive capability. The interactions relate to particle acceleration, the drivers of space weather and characterization of the extreme conditions near Earth and throughout the heliosphere. Most space weather evolves as it passes through the inner heliosphere. Understanding this influential region of space is required for safe and productive use of space.

IHS should fly in conjunction with SDO and will contribute to understanding gained by the Geospace Storm Probe missions. In an extended mission they will provide essential information about material that eventually reaches SWB or other spacecraft at 1 AU and beyond

Interstellar Boundary Explorer

IBEX will remotely sense the global interaction between the solar wind and the interstellar medium, complementing the single point direct measurements now being obtained by Voyager

IBEX places a spinning, sun-pointing spacecraft in a highly elliptical equatorial orbit with an apogee of 35 RE so that it spends most of its time outside the magnetosphere. The payload includes tightly integrated high and low energy single-pixel neutral atom cameras of very high sensitivity needed to observe the relatively weak but telltale fluxes emitted from the heliospheric boundary region. During the course of a year, the cameras will sweep out the entire sky to form a complete map of the interstellar boundary.

IBEX began development in May 2005 for launch in 2008, which may be in time for correlative operations with Voyager. Voyager 1 recently passed through the solar wind termination shock and into the heliosheath region.

Ionosphere-Thermosphere Storm Probes (ITSP)

The ITSP mission investigates the spatial and temporal variability of the ionosphere at mid-latitudes. ITSP combines imaging and *in-situ* measurements of the I-T system, and physics based models to inform our understanding. Two LEO satellites, in different local time orbits are required to determine how electric fields, thermospheric winds, and composition vary with local time, and generate dramatic changes of electron density in the main ionospheric layer during storms. An IT imager will fly as a Mission Of Opportunity on another spacecraft to support the LEO measurements by observing global composition changes.

To meet the needs of tomorrow and to go beyond an understanding of the climatological behavior of the ionosphere we need to make simultaneous, collocated comprehensive measurements of the global behavior of the IT system. The scientific questions addressed by ITSP have direct relevance to the Vision for Space Exploration and to the needs of society. When we prepare to go to Mars, we must be able to land with precision and communicate with assurance. ITSP informs the design of systems for precision navigation and communication without requiring that we build at Mars the equivalent of the Earth's network of ionospheric observatories. ITSP will allow us to characterize, understand, and predict plasma density gradients that degrade augmented GPS systems, and lead to the mid-latitude ionospheric

irregularities which produce scintillation of radio signals.

ITSP was designed to overlap with the SDO and RBSP missions flying in the 2008-2015 timeframe. The current schedule places ITSP at solar maximum and in the declining phase of the solar cycle – times when the ionosphere is both enhanced and disturbed. ITSP will fly during the phase of the solar cycle that is the most stressing both from the standpoint of technical systems and models. ITSP results will be available in time to guide the concept of operations for precision landing on Mars and communications (surface-surface and surface-space).

Under current NASA funding guidelines, GEC would launch in a similar timeframe (2017 with a two year lifetime) to ITSP, so the missions would potentially overlap. The GEC mission is focused on very different scientific objectives in a different altitude and latitude regime from ITSP. Each mission provides scientific insight that is unique. An overlap in the mission timeframes provides synergistic opportunities because GEC measures the high latitude drivers that contribute to the middle and low latitude response measured by ITSP. However, because of the urgency of each of these missions, each should fly as early as funding permits, regardless of any loss of overlap with the other.

L1-Earth-Sun

The L1 mission will provide the first comprehensive and continuous observation of the Earth's whole dayside atmosphere, together with measurements of the contributions to the critical solar spectral irradiance that drive the upper atmosphere.

The Earth-viewing portion of the mission consists of a combination of spectrometers in an extended wavelength range (58 nm to 2.4 mm), with high spatial resolution on the entire sunlit Earth disk. The solar portion of the mission consists of a UV/soft x-ray irradiance spectrometer, an imaging bolometer, and a UV/EUV imaging spectrograph to explain the irradiance phenomena that affect Earth's atmosphere by providing identification and realistic assessment of the contributions of evolving solar activity features to total spectral irradiance. The mission also includes magnetometer capable of high time resolution measurement of magnetic field fluctuations and shocks, and two energetic particle analyzers capable of measuring energy resolved charged particle spectra.

By observing simultaneously the Earth, the Sun, and the solar wind, the L1-Earth-Sun mission will enable the first detailed exploration of the couplings within the Earth-Sun system. It fulfills a fundamental and critical need in the S3C Strategic plan with cross-cutting synergistic objectives relevant to understanding fundamental processes which influence Earth's climate as well as strong relevance to the Vision for Exploration by improving our understanding necessary for solar activity prediction and its impact on the Earth.

The L1-Earth-Sun mission should fly in the early part of Phase 2 in order to maximize overlap with SDO and GEC. SDO provides complimentary information regarding solar energy deposition while GEC provides in situ observations of the Earth's upper atmosphere that strongly compliment and partially validate the L1-Earth-Sun remote observations. Flying L1-Earth-Sun in early Phase 2 also permits the timely replacement of key existing assets at L1.

L1-Mission

In situ observations from the Earth-Sun L1 point are essential to understanding geospace and provide about one hour of warning of disturbances traveling toward Earth in the solar wind. The essential quantities are plasma, particles and fields measurements. Enhancing capabilities include radio sensing, composition and high-energy particle detection, and even solar observations, though these can often be accomplished from other vantage points.

Without upstream information the state of the magnetosphere cannot be understood. Models of propagation in the inner heliosphere need a reference at 1 AU against which to test their models. Spatial variations in structures around L1 is not well understood. Data from L1 is needed at all times to provide adequate warning for many operational users in addition to NASA scientists.

The timing of this mission depends upon future assets launched by NASA and other agencies and the continued functioning of existing spacecraft. The existing Great Observatory provides L1 observations and some future mission must do the same. Partnerships may be the preferred method for satisfying the need for observations from L1. The possible flight of Heliostorm, an Earth Science L1 mission, or collaboration with the IH Sentinels or SWB missions may provide additional options.

Lunar Reconnaissance Orbiter

LRO is conceived as an advance exploration of the moon to prepare for a human return there with longer duration visits than previously achieved. It will contain an investigation for monitoring the radiation environment that will be encountered by astronaut-explorers.

LRO measurements will provide important information about the practical consequences of cosmic ray, solar energetic particles, and magnetotail particle acceleration for long term human presence on the moon.

LRO is needed in the near term to refresh and update our knowledge of the moon and its environments. The radiation environment in particular needs to be better documented, particularly for storm events in which potentially lethal radiation levels are expected.

Magnetospheric Multi-Scale

MMS is the first mission designed from the bottom up to separate space from time at the fine scales needed to understand the reconnection diffusion region. MMS will determine the fundamental physical properties of magnetic reconnection.

MMS is a four spacecraft mission designed to study magnetic reconnection, charged particle acceleration, and turbulence (cross-scale coupling) in key boundary regions of the Earth's magnetosphere. The primary goal of the mission is to use high time resolution, *in situ* plasma and fields measurements to determine the micro-scale processes in the exceedingly small (perhaps <100 km thick) diffusion region, where the electrons in a plasma become decoupled from the magnetic field, and the field reconnects. The close spacecraft spacing will also enable exploration of the cross-scale coupling of plasma turbulence in the Earth's magnetosheath, at the magnetopause, and in the magnetotail. Finally, charged particle acceleration processes associated with magnetic reconnection, turbulence, and electric fields in the outer magnetosphere will be determined using direct measure of the plasma and waves that cause the acceleration. MMS will resolve rapidly moving narrow structures, to yield a full understanding of the factors controlling the rate of reconnection. This will enable a predictive science of space weather, which in turn will allow us to understand energetic processes throughout the solar system.

MMS has recently entered development and its results will be needed as soon as possible as a basis for the predictive models of space weather needed to undertake heliospheric weather prediction in support of Exploration. Magnetic reconnection is a primary source of energy release and particle acceleration in plasmas. No mission has ever been properly instrumented and configured to measure the small-scale features of reconnection in space. Thus, we know little about this fundamental process that drives much of the activity on the Sun, near Earth, and throughout the Solar System.

Pluto/Kuiper

New Horizons is designed to help us understand worlds at the edge of our solar system by making the first reconnaissance of Pluto and Charon - a "double planet" and the last planet in our solar system to be visited by spacecraft. The mission would then visit one or more objects in the Kuiper Belt region beyond Neptune.

New Horizons is scheduled to launch in January 2006, swing past Jupiter for a gravity boost and scientific studies in February or March 2007, and reach Pluto and its moon, Charon, in July 2015. Then, as part of an extended mission, the spacecraft would head deeper into the Kuiper Belt to study one or more of the icy mini-worlds in that vast region, at least a billion miles beyond Neptune's orbit. Sending a spacecraft on this long journey could help us answer basic questions about the surface properties, geology, interior makeup and atmospheres on these bodies.

The relation to the Sun-Solar System Connection presented by New Horizons is the opportunity to obtain in-situ measurements of the solar wind interaction with Pluto. Ionization of Pluto's escaping atmosphere suggests the interaction with the solar wind will be similar to that of a comet. In contrast to cometary interactions that have been measured relatively close to the Sun, the weak magnetic field and tenuous density of the solar wind in the outer heliosphere imply that the interaction with Pluto's atmosphere will include significant kinetic effects and be highly asymmetric. Understanding these interactions will expand our knowledge of the astrophysical processes affecting these bodies and that part of the solar system. The SWAP instrument on New Horizons will make measurements of the solar wind deceleration and deflection due to the interaction with Pluto. The PEPPSI instrument will measure energetic particles produced in the interaction region. SWAP will also measure solar wind conditions at large distances from the Sun and measure the effects of pickup protons from the interstellar medium in the distant heliosphere.

Radiation Belt Storm Probes (RBSP)

RBSP will focus on the variability and extremes of energetic radiation belt ions and electrons by identifying and evaluating their acceleration processes and transport mechanisms and identifying and characterizing their sources and losses. The RBSP instruments provide comprehensive measurements of the particle phase space densities plus the local AC/DC magnetic and electric fields in the inner magnetosphere where the intense radiation belts reside.

RBSP consist of two small satellites in "chasing" elliptical orbits with low perigees, $\sim 5.5 R_E$, geocentric, apogees and slightly different orbital periods. The different periods generate an orbital evolution that provides both variable radial separations in the same local time frame and local time separations at a range of constant radial distances to separate space-time effects in the radial transport and azimuthal drifts of the particles.

RBSP provides one link in the chain of evidence that tracks the Geospace response to solar and interplanetary sources and variability. ACE, TWINS, SDO, MMS, ITSP and IHSentinel will fill in many of the other links. Flying together, they would provide a nearly complete picture of geospace, its the external environment and the its responses to solar variability and evolving interplanetary plasma and field structures. RBSP is important to objectives H and J because it provides the observations needed to characterize and develop models of the near Earth space weather. Its data will form the basis for

specification of the near Earth radiation environment and its variability on a time scale that meets the needs of the Exploration Visions early operations near Earth.

RBSP data will provide a measure of the magnetospheric energy inputs to the ionosphere and atmosphere important to space station and crew vehicle communications, reentry and atmospheric drag induced orbit variations. In addition, RBSP observations will also provide new knowledge on the dynamics and extremes of the radiation belts that are important to all technological systems that fly in and through geospace. This includes many platforms that are important to life and society as we rely ever more on space platforms to link us together through communications, to provide Earth resource data and to provide entertainment streams. It is also very important that we understand the space weather in geospace as we resume human exploration because it can impact the many US space assets that play a role in our national security and support human exploration.

Solar-B

Solar-B will reveal the mechanisms of solar variability and study the origins of space weather and global change. NASA is a 1/3 partner with the Japanese space agency (JAXA) on this mission to investigate the detailed interactions between the Sun's magnetic field and the corona. High resolution observations of active region on the photosphere together with an X-ray telescope and imaging spectrograph will help understand the creation and destruction of magnetic fields, variations in solar luminosity, generation of UV and X-radiation, and the dynamics of the solar atmosphere.

Solar B addresses most of the expected achievements in Phase 1: reconnection, the mechanisms of particle acceleration near the Sun, the origins of solar disturbances, understanding of the sources of irradiance variations, causes of the extremes in the local environment, and prediction of space weather. Many Phase 2 topics are also covered.

Solar B complements SDO, STEREO, and SOHO by providing high resolution imaging and understanding of detailed mechanisms of variability. The essential next step in understanding the origins of solar activity requires the high resolution data from Solar B.

Solar Dynamics Observatory (SDO)

SDO will help us to understand the mechanisms of solar variability by observing how the Sun's magnetic field is generated and structured and how this stored magnetic energy is released into the heliosphere and geospace. SDO's goals are to understand the solar cycle, the transfer of energy through the solar atmosphere, and the variable radiation output of the Sun. SDO measures subsurface flows, photospheric magnetic fields, high-temperature solar atmospheric structures, and the extreme ultraviolet spectral irradiance that affects Earth's atmosphere.

Solar magnetism drives the variability that causes most space weather. Helioseismology measures the internal causes of activity. Photospheric and coronal observations trace the evolution of magnetic field structures and the origins of disturbances. The upper atmosphere is highly sensitive to solar EUV variability. SDO's investigations are essential to many phase 1 and 2 achievements relevant to all three SSSC Objectives.

SDO needs to fly immediately to provide crucial understanding of solar activity, the solar cycle, and the inputs to geospace. Predictive modeling cannot improve without the improved data SDO will provide. SDO is an essential replacement for the aging SOHO spacecraft.

Solar Sail Demo

Because of the inability to fully validate this technology on the ground, the application of solar sails to a strategic science mission absolutely requires a prior successful flight validation. Such a Sail Demo (40-m edge length, 25 g/m²) could be readily scaled then to fit the needs of the Heliostorm mission (100-m edge length, 14 g/m²). Once a mission in the class of Heliostorm has flown, further scale-up could be accomplished for Solar Polar Imager (160-m edge length, 12 g/m²). A further, third generation solar sail would be required for a visionary mission such as Interstellar Probe.

The flight of a Sail Demo must precede the first strategic launch by 5-6 years. A Sail Demo mission in mid-2010 would permit the flight of Heliostorm in 2016 or thereafter. Approximately 5 years would then be needed after Heliostorm to enable the scale-up to Solar Polar Imager.

Solar Orbiter

Solar orbiter is a European Space Agency (ESA) mission with U.S. participation that will fly as close as 45 solar radii to the Sun in order to study the solar atmosphere with unprecedented spatial resolution (~100 km pixel size).

Its science goals are to characterize the properties and dynamics of the inner solar wind, to understand the polar magnetic fields using helioseismology, to identify links between activity on the Sun's surface and coronal disturbances using co-rotating passes, and to fully characterize coronal regions from high inclination orbits. Using Venus gravity assists, the orbital inclination will shift over time providing the first high latitude views of the solar poles. Solar Orbiter will provide key components to NASA's LWS program by understanding the causes of Space Weather and thus will answer science questions of Objective H. It will also provide data to increase our fundamental understanding of particle acceleration and the role of the solar dynamo in structuring the solar magnetic field (Objective F).

Both science areas are essential in developing a short and long term predictive capability for the Exploration Vision (Objective J). Solar Orbiter is positioned to fly in the 2015-2025 (Phase 2) time frame which will coincide with Inner Heliospheric Sentinels to continue the system science of our Great Solar Observatory.

Solar Probe

Solar Probe is the first flight into the Sun's corona, only 3 solar radii above the solar surface. Solar Probe's instruments measure plasma, magnetic fields and waves, energetic particles, and dust that it encounters. They also image coronal structure surrounding Probe's orbit and in polar structures at the coronal base. Probe makes two passes into the corona, separated by 4.5 years, exploring why the corona changes its whole form over the solar cycle.

The corona is heated to millions of degrees by poorly understood processes governed by its magnetic field. The UV radiation from the hot solar atmosphere affects the chemistry of the atmospheres of the Earth and other planets. The boundary where the corona accelerates to the solar wind governs the heliosphere and its interactions with the planets and the interstellar medium. That boundary is also critical to the release of solar disturbances that travel throughout the solar system, to the Earth and other planets, producing energetic particle events and magnetospheric storms. Probe will transform our understanding of the physical processes that control the heating of the solar corona, the acceleration of the solar wind, and the release of eruptive activity. Accurate prediction of events that disturb the Earth's human systems and deepspace explorers require this understanding.

One factor sets the placement of Solar Probe in the Roadmap: Probe is the most technically challenging mission attempted. It must function in the cold and intense particle radiation of its orbit-

shaping flyby at Jupiter, and in the heat and high-speed dust impacts of the solar corona. The path to meet the technical challenges is now well defined and Solar Probe is ready for a mission start. Probe can only be achieved with specific budget augmentation because the work to ensure surviving its difficult environment keeps it more costly than any line mission.

Solar TErestrial RElations Observatory

The Solar-Terrestrial Relations Observatory (STEREO) will determine the 3-D structure and evolution of coronal mass ejections (CMEs) from their eruption on the Sun through the inner heliosphere to Earth's orbit. The mission will employ remote sensing and in situ measurements from two spacecraft drifting in opposite directions away from the Earth at 1 AU to triangulate CME-driven shocks, detect preceding shock-accelerated particles, and analyze in situ CME and solar ejecta signatures, including heavy ion mass and charge states. In addition, as the spacecraft reach large separations, one spacecraft will observe the propagation of CMEs that will be directly sampled by the second spacecraft to provide a definitive determination of the relation between the white light and in situ features of a CME. The instrumentation package on each spacecraft includes a coronal and heliospheric imaging package (with an EUV imager, two coronagraphs, and heliospheric imager)s, a set of radio wave receivers, and an array of in situ measurements for measuring the solar wind, energetic particles, and interplanetary magnetic fields.

This mission will provide not only fundamental knowledge about the 3D structure and propagation of CMEs, but also provide important information on CME-shock-accelerated particles, contributing to the characterization of the space environment. This mission is a high priority for SSSC science because of the central role of CMEs in determining "space weather."

The Solar-Terrestrial Relations Observatory (STEREO) is nearly complete and ready to be launched in 2006.

Time History of Events and Macroscale Interactions for Substorms (THEMIS)

THEMIS is a MIDEX Explorer mission that addresses the spatial and temporal development of magnetospheric substorms. The mission consists of 5 identical spacecraft and a array of ground-based all-sky cameras. The cameras are a mission-critical element of THEMIS, providing a global context for the in situ measurements and also detecting auroral substorm onset for mission operations decisions. When the spacecraft are on the dayside, it will address the question of solar wind control of the magnetosphere and the coupling of energy across the various dayside boundaries.

THEMIS addresses the issue of onset and evolution of the substorm instability, an explosive yet fundamental mode of the magnetosphere. This was identified by the National Research Council as one of five main strategic questions in space physics.

The mission was selected in the last MIDEX proposal solicitation and is currently in Phase C/D development.

The Two Wide-angle Imaging Neutral-atom Spectrometers (TWINS)

TWINS provides stereoscopic viewing of the magnetosphere by imaging charge exchanged energetic neutral atoms (ENAs) over a broad energy range (~1-100 keV) using identical instruments on

two widely spaced high-altitude, high-inclination spacecraft. TWINS will enable a 3-dimensional visualization of large scale structures and ion dynamics within the magnetosphere. The TWINS instrumentation is essentially the same as the MENA instrument on the IMAGE mission and provides a 4°x 4° angular resolution and 1-minute time resolution ENA image. In addition, a simple Lyman-alpha imager is used to monitor the geocorona. The first TWINS spacecraft may overlap with the IMAGE mission, providing an early (2005-2006) opportunity for magnetospheric stereo imaging that could evolve into three spacecraft imaging with the launch of the second TWINS in 2006.

TWINS will provide a 3D view of the ring current ions in the magnetosphere. These ions carry much of the energy and most of the mass into and through geospace. Different from in situ observations, TWINS will provide a dynamic picture of the whole geospace system with a cadence that resolves the radial and azimuthal ion motions. The in situ measurements provided by RBSP, MMS and ITSP, are truth data that can be used to further validate the necessary inversion process that will be applied to the TWINS data to obtain 3D ion flux distributions. These TWINS distributions will provide a global geospace input for space weather models. The 3D ion distributions will enable inferring the inner geospace currents and electric fields which penetrate to low altitudes and high latitudes where they couple energy into the ionosphere-thermosphere system partially driving its space weather.

While TWINS is not a subject of the current roadmap, except as a mission of opportunity element of the Great Observatory, it does support many of the objectives H and J, as can be seen in the discussion above. TWINS value is greatly enhanced if it is flying simultaneously with RBSP, ITSP and MMS. While those missions are to be launched in the next decade, it should be noted that the first of the current sister platforms in the TWINS orbits have been flying since 1994 and will probably be operated for years to come. Thus we expect the TWINS instruments, if they survive, could be operating out through 2015 or so.

Candidate Missions for Phase 2 and Phase 3

Aeronomy and Dynamics at Mars (ADAM)

Aeronomy and Dynamics at Mars (ADAM) will determine the direct, dynamic coupling of a dusty atmosphere with the solar wind. It is a single spacecraft that will orbit Mars, taking in situ and remote sensing data of the upper atmosphere, ionosphere, and solar wind. Instruments will measure the composition, thermal profile, and circulation in the Martian upper atmosphere. Mars Aeronomy will determine the sources and sinks of ionospheric plasma, its coupling to other regions of the atmosphere, and its to the solar wind.

The dynamics, evolution, and fate of the Mars upper atmosphere addresses fundamental science questions as well as providing pertinent information for manned flights to Mars. Aerobraking and aerocapture require a detailed knowledge of the Martian upper atmosphere, as well as an understanding of how and why the atmosphere varies, for hazard prediction and risk mitigation.

This is a high priority mission with direct relevance to the manned flight component of the Vision for Space Exploration. It should be flown as soon as possible in order to allow time for the scientific investigations of the Mars upper atmosphere to progress to a point of transferring the lessons learned from ADAM to the manned flight program with sufficient lead time to impact mission development. Therefore, it should be a Phase 1 or early Phase 2 mission.

Auroral Acceleration Multi-Probe

The Auroral Acceleration Multi-Probe (AAMP) mission is designed for extremely high time resolution measurements of particle distributions and three-dimensional electric and magnetic fields in

situ within the Earth's auroral acceleration region. The auroral acceleration region provides a unique laboratory for the study of acceleration processes, both because it reveals many of the critical processes and because it is readily accessible to measurement. Our basic understanding of particle acceleration in parallel electric fields and kinetic Alfvén waves, as well as the structures that support parallel fields, have come from in situ auroral observations. To make the progress required for a predictive understanding requires simultaneous measurements both along and perpendicular to magnetic fields. The AAMP four satellite mission is designed to provide the needed conjunctions through a careful orbit strategy.

One of the key goals of Objective F is providing the detailed understanding of the processes that accelerate particles to high energies that will be necessary to predict fluxes of high energy particles throughout the solar system. This predictive capability is the goal of RFA J.3. In addition, by providing a better understanding of energetic particles in the Earth's space environment, AAMP is also important to Objective H because it will enable mitigation of impacts on space assets, and, by quantifying the auroral input to the ionosphere/thermosphere, it will improve models of lower latitude composition and variability of the ionosphere, which affect communications/navigation activities.

The fundamental understanding of acceleration processes is critical to the NASA SSSC goals and, thus, the mission should be flown as soon as possible. Its placement in the mission queue indicates the need to inform activities that occur in the intermediate time frame.

Dayside Boundary Constellation

DBC will determine the global topology of magnetic reconnection at the magnetopause. It is a network of ~30 Sun-pointing, spinning, small spacecraft, separated by ~1 R_E , that skim both the dawn and dusk sides of the dayside magnetopause. The multi-spacecraft provide simultaneous comprehensive observations of boundary phenomena including turbulence over a wide range of latitudes and local times. Three spacecraft are boosted to have apogee outside the bow shock to provide continuous monitoring of the foreshock-preconditioned solar wind input.

This mission addresses critical unresolved questions about the transfer of energy across the magnetopause boundary. It also will robustly measure the global magnetic field topology on the Earth's dayside magnetopause, something which has not been done before.

MagCon is a precursor mission to DBC, as it will have a constellation of spacecraft in the magnetospheric equatorial plane. Therefore, DBC should be in the Phase 3 mission queue.

Doppler

Doppler consists of a suite of small, lightweight, moderate resolution spectral imagers (UV/EUV imaging spectrograph, 2 EUV imagers, and a Magnetograph) to detect, observe and study remotely all of the relevant signatures of solar activity responsible for space weather events and disturbances.

Doppler

addresses issues directly relevant to supporting the Vision for Exploration by enabling improved nowcasting and future forecasting of solar activity by identifying and developing new precursor signatures of CME initiation and onset, flare eruption, and flare initiated SPEs. The DOPPLER mission enables improved nowcasting and forecasting of solar activity by providing improved understanding of the physical processes and mechanisms of energy storage and release on the Sun. Measurements of motions and changes in nonthermal velocity distributions in the lower corona and chromosphere are crucial to understanding and separating various models of CME initiation and onset. Depending upon the specific

physical process, Dopplergrams and other derived data products are likely to be the most reliable indicators that a specific region is about to erupt.

The DOPPLER mission should fly in the early part of Phase 2 (2015-2020), with overlap with SDO to identify and develop new solar activity precursor signatures necessary to protect astronauts during surface EVAs on the Moon (late Phase 2). The small, lightweight instrumentation developed by DOPPLER would then be available for Phase 3 missions required to provide nowcasting and forecasting capability at Mars and beyond.

Farside Sentinel

Farside Sentinel is a mission with a spacecraft placed at 1 AU viewing the far side of the Sun. It will provide new knowledge about the solar dynamo, solar activity, and the dynamic space environment in general. It contains both remote sensing and in situ instruments. Remote sensing instruments include a magnetograph-Doppler imager and a radio science package for coronal sounding. Its location at about 180 degrees from Earth allows, in conjunction with similar observations from near Earth, helioseismological measurements of the deep interior flows that are thought to drive the dynamo. The magnetograph will provide more longitudinal coverage of the Sun so that the evolution of solar magnetic fields and active regions can be observed for longer times. Farside Sentinel also provides an additional in situ observation post for the space environment. The in situ instrument package would be similar to that on the STEREO spacecraft.

Farside Sentinel provides information crucial for understanding fundamental processes (Objective F) and for developing the capability to predict the space environment. Farside will aid predictions of space weather and provide inputs for SWB, MARS, and high-latitude solar observatories.

While it would be advantages to have this (or the SHIELDS) mission earlier, it was placed in Phase 3 because it was considered lower priority.

Geospace Magnetospheric and Ionospheric Neutral Imager (GEMINI)

GEMINI is a mission that will provide the first 3-dimensional observations of the global Geospace dynamics in response to external solar drivers and internal coupling. Stereoscopic views of the radiation belt associated ring current and thermal ions of the plasmasphere, simultaneous images of the aurora in both hemispheres, and coordinated ground based observations are used to determine the coupling dynamics between the ionosphere, ring current, and plasmasphere and to discover the important feedback and dissipative mechanisms between these regions.

The power of GEMINI is that imaging this complex coupled system to unravel its macro-scale interactions simultaneously provides the global context for correct interpretation of in-situ observations. It is to magnetospheric space-weather what the Solar Terrestrial Relations Observatory is to the solar-wind observations. The discoveries from this mission are applicable to understanding fundamental processes at work not only in Geospace but other magnetized planetary systems and thus are important to Objective F. Global Geospace observations are needed to provide the system level context for nowcasting and prediction of the plasma environment where exploration activities are occurring within Geospace. In addition, these results are significantly augmented when coupled with inner heliospheric and solar disk observations. The conjugate auroral observations are essentially the “footprints” of the magnetosphere and therefore provide the magnetospheric configuration to distances beyond the lunar orbit. For these reasons GEMINI is important to Objective J.

Operating GEMINI in conjunction with the RBSP and ITSP missions is ideal as documented in the

LWS Geospace definition report. However, even without mission overlap, the system level understanding of the coupling between regions in Geospace that creates, evolves and annihilates radiation belts and how that induces and impacts ionospheric variability is extremely significant to operational space based assets that society has become so dependent on. As such, GEMINI is important to objective H.

Heliostorm

The Heliostorm mission would measure the solar wind and heliosphere state "upstream" of the Earth and Moon. Through the use of breakthrough solar sail technology, it would fly 50% further from the Earth (farther upstream) than the current ACE measurement at the Earth-Sun L1. A set of in-situ measurements then would provide 50% greater warning time (compared to ACE) of CMEs and shock-accelerated energetic particles. In conjunction with other assets outside the Earth's magnetosphere, the mission would determine the structure of the solar wind on spatial and temporal scales that are relevant for driving magnetospheric processes.

Heliostorm safeguards our outward journey by providing an input that is absolutely vital to the prediction of space weather in cislunar space. Astronauts on the lunar surface will benefit greatly as the enhanced warning time will permit reaction to actual upstream conditions measured remotely by Heliostorm. The solar wind input to the Earth is required by all models of the Earth's magnetosphere, and would be provided by Heliostorm or a conventional L1 monitor.

Heliostorm could be flown 5-6 years after a successful Solar Sail Flight Validation (Sail Demo). Heliostorm (or a conventional L1 monitor) must be flown in time to replace the current ACE/Wind configuration. This suggests a launch in the 2016-2020 timeframe.

Inner Magnetospheric Constellation

IMC will determine the interaction among the radiation belts, ring current, plasmasphere, and outer magnetosphere. It is multiple spacecraft in at least two ecliptic plane "petal" orbits. Large day/night and dawn/dusk asymmetries exist in the inner magnetosphere and complicate the global specification of particles and fields. Through simultaneous measure of radial and longitudinal variations in the radiation belts, the temporal and spatial asymmetries will be resolved.

The in-situ measurements from these multiple positions allow the construction of comprehensive "weather maps" of the inner magnetosphere (1.5-12 Earth radii) that evolve in response to Sun-induced disturbances. This spacecraft fleet focuses on detailed specification of the orbital environment of most spacecraft and manned missions, to determine in detail the origin and evolution of particle populations and their interaction with the evolving electro-magnetic field during magnetic storms.

These observations extend the radiation belt storm probe results by making simultaneous maps of the radial as well as the longitudinal variations in the radiation belts. It should fly after RBSP, and probably after GEMINI, putting it into Phase 3 of the mission queue.

Ionosphere Thermosphere Mesosphere (ITM) Waves

ITM Waves is designed to observe the sources and sinks of gravity waves, including modes of interaction between multiple wave sources, as well as modes of interaction with the neutral and ionized constituents of the atmosphere, and with tides and the zonal mean circulation.

The wave processes studied by ITM Waves are fundamental to the coupling between distinct altitude regions, and to the overall dynamics of the Earth's atmosphere. These processes play a key role in the response of the atmosphere to solar storms. Gravity waves are also thought to be a critical factor

in preconditioning the ionosphere by contributing to the initial conditions necessary for plasma instabilities to form near the magnetic equator, and perhaps also at mid-latitudes. These unstable conditions can result in the formation of large-scale depletions in the plasma density, coupled with small-scale irregularity formation and severe radio wave disruptions. The ITM-Waves mission will thereby enable further development of the theory and models necessary for comprehensive understanding of the phenomena. Insight into these phenomena in geospace may help to mitigate issues related to aerobraking and aero-capture in the Martian atmosphere, so ITM-Waves is pertinent to exploration mission requirements.

ITM-Waves should follow GEC and ITSP as closely as possible in time because these two missions provide key information on how the atmosphere responds to solar energy, storms, and substorms. Together the three missions are synergistic in that they address the overall goal of understanding the Earth's response to solar energy. If possible, ITM-Waves should overlap in time with the Mars Dynamics mission because additional synergies would be created by studying the responses of both atmospheres to simultaneous solar forcing.

Interstellar Probe

Interstellar Probe is the first mission that will leave our heliosphere and directly sample and analyze the interstellar medium. It is a single spacecraft that will use an advanced in-space propulsion system such as a solar sail or nuclear electric propulsion to reach the upstream interstellar medium at a distance of 200 AU within about 15-20 years. This spacecraft will carry the first payload specifically designed to directly determine the characteristics of the local interstellar medium, including dust, plasma, neutral gas, energetic particles, and electromagnetic fields.

On its way, it will provide only the second opportunity after Voyager to directly observe the thick region of interaction between the solar wind and the interstellar medium, from the termination shock to the heliopause and beyond. This region plays a central role modulating the Galactic Cosmic Ray flux and in the creation of the anomalous component and understanding this modulation will help increase the productive and safety of human explorers. Additional advanced instrumentation used en route could determine the nature and chemical evolution of organic molecules in the outer solar system and interstellar medium and measure the cosmic infrared background (CIRB) radiation normally hidden by the Zodiacal dust.

Because this mission is enabled by advanced propulsion, it has been placed in Phase 3. The Solar Polar Imager mission would provide a technology demonstration of the solar sail propulsion system needed for Interstellar Probe. It is expected that additional resources would be needed for this mission because of its 15+ year lifetime coupled with the need for advanced propulsion.

Io Electrodynamics

Io Electrodynamics uses a spinning spacecraft, placed in an elliptical Io-resonant orbit that provides repeated encounters with the Io flux tubes. A radiation hardened payload of fields and particles instrumentation will complement a UV imager for context observations.

IE will investigate the magnetic coupling and energy conversion process in a unique magnetized plasma situation, while determining the role of Io in Jovian radio emissions.

The timing of IE is non-critical relative to the other SSSC missions, but the mission is complementary to other missions that support Exploration of the terrestrial planets, for comparative purposes.

Jupiter Polar Orbiter

JPO places a spinning radiation hardened spacecraft in polar elliptical orbit around Jupiter at 75° inclination. The payload includes fields and particles instruments, planetary imagery and radio science. Measurements will be made of the Jovian auroral acceleration regions and radiation belts, the polar magnetic field and plasma waves. Radio occultations of the ionosphere and atmosphere will determine their characteristics.

JPO will conduct a comparative test of magnetospheric models in a case where planetary rotation is dominant over the solar wind interaction in powering the system.

JPO timing relative to other missions is non-critical but the mission is highly complementary to other missions that support Exploration of the terrestrial planets, for comparative purposes.

L1 Solar-Climate Explorer

L1SCE examines the mechanisms that potentially link solar variability to changes in Earth's climate via solar irradiance or Earth albedo variations, energetic particle precipitation.

L1SCE measures the spatial, spectral, and temporal variation in the Earth's albedo, while simultaneously measuring the solar photon, electromagnetic, and particle flux incident upon Earth. A platform in Earth-Sun L1 halo orbit provides continuous viewing in both directions for >3 yrs. The payload includes multi-wavelength imaging spectro-radiometer, solar irradiance, in-situ plasma, magnetic field, and energetic particles instruments.

This mission is needed as soon as possible to complement other missions. It represents an interdisciplinary partnership between Sun-Solar System Connections and Earth Science.

Magnetospheric Constellation

MC will employ a sensor web of ~36 spacecraft to describe the temporal and spatial structure of complex processes occurring throughout vast regions of the Earth's magnetosphere, including most of cislunar space between the Earth and its Moon. *In situ* plasma, magnetic field, and energetic particle observations, and possibly imaging, will be used to distinguish between nonlinear internal dynamics of the magnetosphere and global responses to varying solar wind conditions. The data will be provided on spatial and temporal scales sufficient to enable close cooperation with state-of-the-art numerical simulations capable of describing where magnetic flux, mass transport, energy conversion, and dissipation occur. By removing the spatial and temporal ambiguities that limit single spacecraft or clustered spacecraft missions, MC will reveal the global pattern of changes within the magnetosphere to quantify the location and extent of the instabilities that trigger the explosive release of solar wind energy and mass stored in the magnetosphere, and how these quantities are transported between regions.

MC is the first sensor web for space weather in geospace and is focused on Earth's dynamic magnetotail, the origin of severe storms in geospace. By removing the spatial and temporal ambiguities that limit single spacecraft or clustered spacecraft missions, MC will reveal the global pattern of changes within the magnetosphere to quantify the location and extent of the instabilities that trigger the explosive release of solar wind energy and mass stored in the magnetosphere, and how these quantities are transported between regions.

Understanding the mass and energy flow in the magnetotail and throughout the rest of the magnetosphere is an unresolved issue of fundamental importance. With the flight of the New Millennium ST-5 mission, many of the technological obstacles of this mission have been addressed. It should be the next STP mission after GEC, which puts it in the Phase 2 mission queue.

Magnetosphere-Ionosphere Observatory (MIO)

MIO will determine the processes that drive auroral arcs. It is a tight cluster of satellites in geosynchronous orbit that are magnetically connected to a ground-based observatory, with a satellite-based electron beam establishing the precise connection to the ionosphere. One of the longest standing problems in magnetosphere-ionosphere coupling is the fundamental question how large-scale processes in the magnetosphere (with spatial scales of many thousands of kilometers) effectively couple to the ionosphere to produce very narrow auroral arcs (with scales less than 1 km). The MIO spacecraft cluster will perform the local gradient measurements required to identify the causal mechanism for generating auroral arcs.

The MIO mission examines the still unresolved relationship between magnetospheric dynamics and auroral arc features. The electron beam explicitly addresses the ambiguities of ionosphere-magnetosphere connectivity. It addresses fundamental scientific questions that are of direct relevance to life and society.

Conceivably, MIO could fly at any time. However, it did not make it in to the mission phasing diagram within the available resources. Therefore, it is part of the Phase 4 mission queue.

Mars Atmospheric Reconnaissance Survey (MARS)

The Mars Atmospheric Reconnaissance Survey (MARS) mission will provide a robust assessment of the upper atmosphere of Mars to enable safe human space flight to that planet. It will consist of a comprehensive package of in situ and remote sensing instruments to quantify the dynamics and chemistry throughout the Mars atmosphere. It could be one or several spacecraft, depending on what is thought to be needed to resolve the remaining questions about the Mars space environment.

This mission will provide as complete a set of measurements as possible to answer any remaining questions about the Mars upper atmosphere and its interaction with the solar wind before manned flights to Mars begin.

It should fly after ADAM, but before astronauts go to Mars. Therefore, it is part of the Phase 3 mission queue.

Magnetic TRAnSition region Probe

The primary objective of MTRAP is to measure the build up and release of magnetic energy in the solar atmosphere. MTRAP will measure the vector magnetic field from the photosphere to the magnetic transition region, where the solar atmosphere changes from being plasma to magnetic field dominated. MTRAP will also obtain simultaneous plasma diagnostics of the magnetic transition region with UV/EUV imaging spectrograph measurements. MTRAP has two orders of magnitude greater collecting area and one order of magnitude improvement in angular resolution over Solar-B and will greatly improve our ability to follow rapid changes in the magnetic field geometry. MTRAP is centered around a very large solar optical telescope with a 6m aperture, providing over 100 times the collecting area and 10 times the angular resolution (0.05 arcseconds) of Solar-B.

MTRAP addresses fundamentally important questions and issues related understanding magnetic reconnection and micro-scale instabilities in the chromosphere/corona interface on the Sun.

MTRAP should fly early in Phase 3 of the STP line (2025-2035), benefiting from knowledge learned from Solar-B and SDO.

RAM Mission Description

The Reconnection and Microscale (RAM) mission is a next generation, high resolution mission focused on understanding the basic small-scale processes in hot magnetized plasmas that are ubiquitous throughout the universe. In hot magnetized plasmas the physical processes governing the dynamics take place on remarkably small spatial and temporal scales. RAM addresses several fundamental questions such as what are the mechanisms and magnetic topology that lead to reconnection, what micro-scale instabilities lead to global effects and how do magnetic stresses form and release in the solar corona? RAM includes a 0.02 arcsec/pixel EUV imaging telescope, a 0.1 arcsec/pixel UV/EUV imaging spectrograph, and a small x-ray calorimeter to perform simultaneous high resolution imaging and imaging spectroscopy to understand the small scale dynamic processes and mechanisms of reconnection on the Sun.

RAM addresses fundamentally important questions and issues related understanding magnetic reconnection and micro-scale instabilities on the Sun.

RAM should fly as one of the first missions in Phase 3 of the STP line (2020-2025), benefiting from knowledge learned from Solar-B and SDO.

SHIELDS

Solar Heliospheric and Interplanetary Environment Lookout in Deep Space (SHIELDS) is a new mission concept developed specifically in response to the Vision for Exploration to help ensure the safety and productivity of human and robotic explorers.

SHIELDS places two spacecraft in fixed locations 120° from Earth in order to view the entire solar surface and to determine the direction of propagation of CMEs anywhere in the inner heliosphere. Remote sensing instruments include coronagraphs (for observing CME onset and propagation), magnetographs (to observe evolution of the surface magnetic fields and active regions) and EUV telescopes (to observe flare activity). Observations of the entire solar surface should help enable the predictability of longer periods that are “all clear” of solar activity (Objective J). The spacecraft would also carry in situ instruments similar to those on STEREO and FARSIDE to observe the CMEs and associated solar energetic particles, also in support of Objective J.

This mission could replace the Farside Sentinel by providing the farside views of the Sun. To provide the helioseismology needed to understand the dynamo and origins of solar activity (Objective F), a Doppler-magnetograph would also be needed. This would be a more costly mission than Farside since it uses two spacecraft, and, at some point the community will decide which of the two to pursue. Like Farside, this mission has been placed in Phase 3. It will support RAM, SWB, MARS, high latitude solar observations, and provide inputs for studies of impacts on planets other than Earth.

Solar Connection Observatory for Planetary Environments (SCOPE)

SCOPE measurements will be made using dual meter-class telescopes (EUV & UV) covering bandpasses from 55 – 31 nm. The instruments will provide Hubble Space Telescope (HST) - class performance for UV observations and the highest sensitivity and spatial resolution yet achieved below 120 nm. High spectral resolution ($R < 105$) measurements of diffuse emissions will be made with 50 times the etendue of HST-STIS permitting inner solar system observations of Venus, Mercury, and comets to within ~0.35 AU of the Sun, L1-halo orbit for observations for uninterrupted measurements of the Earth's North or South polar regions and a remote perspective on planets giving full hemisphere

studies up to rotational poles. The potential operational lifetime is 5+ years.

The SCOPE mission will compare the global effects of external and internal driving mechanisms on planet and comet near-space environments through observations of auroral, airglow, coronal, and/or internal plasma emissions. It will differentiate features of Jupiter's (and other giant planets') auroral emissions due to internal processes (rotation and internal plasma sources) from those due to solar wind interactions and will measure the response of ionosphere-solar wind coupling to changes in solar activity in planetary systems without magnetospheres (Mars, Venus, Comets). The mission will also refine and expand our knowledge of Earth's global geospace response by extending auroral observations into new domains of spatial and spectral resolution. A key result will be a data base that can be used to directly compare the terrestrial solar interaction with those of superior (Mars-Neptune) planets from opposition campaigns that monitor both systems along the same Sun-planet line.

SCOPE will provide fundamental science observations and understanding of key planetary and interplanetary processes that are critical to the exploration vision and the overarching goals of the SSSC program. SCOPE should be launched as soon as possible in Phase 4 when our understanding of more basic planetary processes has matured.

Solar Energetic Particle Mission (SEPM)

SEPM – the Solar Energetic Particle Mission will determine how, when, and where solar energetic particles (SEPs) are accelerated and help determine how the solar wind is accelerated. A large aperture UV coronagraph-spectrometer and a large aperture visible light coronagraph-polarimeter will observe the corona from 1.15 to 10 solar radii. SEPM instrumentation will be about 100 times more sensitive than current coronagraphs. New diagnostics will determine velocity distributions for electrons and minor ions and derive magnetic field strengths in coronal streamers and coronal mass ejections (CMEs). SEPM will measure critical plasma parameters in pre- and post-shock CME plasmas including suprathermal seed particle populations and it will characterize upstream turbulence which is believed to play a critical role in particle acceleration.

When combined with an integrated theory and modeling program, SEPM measurements will be used to significantly advance our fundamental understanding of energetic particle acceleration (Objective F). Ultimately this understanding will be used to develop a predictive capability for the flux, energy spectrum, and composition of SEP's – thus enabling the Exploration Vision (Objective J) and providing information about the solar sources of Space Weather that affect our home planet (Objective H).

Ideally the remote sensing SEPM spacecraft should fly in concert with a near-Sun spacecraft (e.g. Inner Heliospheric Sentinels or Solar Orbiter) that will detect energetic particles before significant scattering in the interplanetary medium. SEPM should start as early as possible during a period of high solar activity to inform the development of SEP hazard prediction before human explorers return to the moon.

The possible combination of the SEPM and Doppler missions promises a powerful tool for understanding the physical processes of solar energetic particle acceleration and relating SEPs to flares on the disk and to coronal mass ejections that propagate out into interplanetary space.

Solar Polar Imager

Solar Polar Imager will provide critical missing observations need to understand the solar cycle and the origins of solar activity. It is a single spacecraft mission that uses a solar sail to achieve a final 0.48

AU circular orbit with a 75° inclination to the ecliptic. The spacecraft carries a magnetograph -Doppler imager for high-resolution helioseismology and surface magnetic field measurements of the polar regions, a coronagraph for polar views of the corona and CMEs, and *in situ* particles and fields instrumentation for solar wind and energetic particle observations.

This mission is necessary to understand the solar dynamo because the polar orbit enables us to measure the convective surface, subsurface and deep interior flows that control the solar dynamo and to observe the correlation between the flows and solar magnetic field activity and evolution. The rapid four-month polar orbit also allows us to observe the relationship between solar activity and solar wind structure and energetic particles at all latitudes, crucial for characterizing the near-Sun source region of the space environment. In addition, the polar magnetic field measurements are needed to provide the solar surface boundary conditions for the global MHD models used for space weather prediction.

Because this mission requires a solar sail to achieve the near-polar orbit, it has been placed after the Helios storm mission that will be the first science mission utilizing solar sail propulsion. The Telemachus mission can also address the goal of characterizing the space environment at all latitudes and give some information on the magnetic fields and flows in the polar regions. Thus at some point, the community may choose between Solar Polar Imager and Telemachus, based in part on the maturity of the solar sail propulsion technology.

Solar Weather Buoys (SWBs)

SWBs are ~15 small spacecraft distributed every $\sim 20^\circ$ in ecliptic longitude around the Sun at 0.9 AU, identically instrumented with plasma, magnetic field, energetic particle, and hard x-ray detectors.

The initial function of SWBs is to answer definitively the yet un-resolved basic scientific question: what is the spatial longitudinal extent and evolution of the major Solar Energetic Particle (SEP) and Coronal Mass Ejection events that occur during the maximum of the solar cycle? Their complementary function is to give prompt and unambiguous warning of the injection of biologically damaging doses of high-energy particle radiation for astronauts exposed on the surface of the Moon or in transit to the surface of Mars.

SWBs will attack the fundamental problem (F.2) of bringing our understanding of the acceleration and propagation of SEPs and CMEs from the Sun to 1 AU up to the level of prediction. In its complementary role, it will safeguard our outward journey (J.2) to the surfaces of the Moon and Mars.

By launching in 2022, the 5-year deployment phase will be completed in time to catch the rise-to-maximum phase of the solar cycle (2027-2030). During the remainder of the solar cycle (2031-2036), SWBs will paint a definitive scientific picture of how large SEPs and CMEs propagate from the inner heliosphere (being simultaneously observed by IHSentinel, Solar Orbiter, and solar imagers) to 1 AU and beyond towards Mars orbit at 1.4 AU. During this time SWBs' prompt warning capability will be honed and perfected so that they will function with high reliability at the anticipated launch time for the manned mission to Mars (2035).

Sun Earth Coupling by Energetic Particles (SECEP)

SECEP seeks to understand and quantify the impact on atmospheric composition, in particular of odd nitrogen, odd hydrogen, and ozone, by solar energetic particle precipitation (EPP). EPP is thought to be a significant source of ozone destruction through production of high altitude odd nitrogen and odd hydrogen compounds which can be transported lower in altitude where they will catalytically destroy ozone. In order to understand these processes SECEP will measure the precipitating energetic particle influx as well as the descending odd nitrogen and odd hydrogen compounds and ozone densities. Other relevant parameters which affect these processes such as temperature and winds will also be observed.

SECEP is crucial to SSSC goals because it studies a key link between solar energy and its impact on the habitability of Earth. Dramatic effects of EPP on stratospheric and mesospheric ozone have been demonstrated by recent observations. The impact is greatly magnified by the long lifetime of odd nitrogen compounds at stratospheric altitudes. The descent of the odd nitrogen compounds from the ionosphere where it is created to the mesosphere and stratosphere occurs primarily in the polar night where destruction by photolysis can not occur. Therefore SECEP provides valuable fundamental science on how atmospheric regions are coupled.

Because ozone plays a key role in Earth's habitability by shielding the population from harmful UV radiation, SECEP is a high priority mission. SECEP should follow GEC and ITSP closely in time because these two missions provide key information on how the atmosphere responds to solar energy and the three missions together are synergistic for the overall goal of understanding the Earth's response to solar energy and the effect on the human population.

Stellar Imager (SI)

Stellar Imager (SI) is a mission that will obtain the first direct images of surface magnetic structures in sun-like stars. It will image the evolving dynamo patterns on nearby stars by repeatedly observing them with ~1,000 resolution elements on their surface using UV emission to map the magnetic field. SI will achieve at least 30 resolution elements on stellar disks with 1-min. time resolution in one or more broad optical pass bands.

The power of SI lies in its ability to provide information on the dependence of the dynamo on stellar properties, and enable by its population study dynamo model validation within years rather than many decades. It therefore gives solar physicists a unique 'laboratory environment' within which to test predictive models of stellar activity. SI thus addresses the goals of the Exploration Initiative under Objective J by improving long-term space weather forecasts throughout the heliosphere to guide vehicle design and mission planning, and forecasts of extended periods for safe construction at Moon, Mars, Earth-Moon L1, Sun-Earth L2, and LEO staging orbits. By observing planet harboring stars and their evolving environments it will also provide an improved understanding of formation of planetary systems and habitability zones of extra-solar planets. Stellar Imager provides crucially needed information for several of the SSSC Objectives by observing patterns of magnetic activity and underlying atmospheric structure of a population of stars to compare with the sun. It supports Objective F by enabling an understanding of the creation and variability of magnetic dynamos, Objective H by promoting an understanding of the causes and subsequent evolution of activity that affects Earth's space climate and environment and how the habitability of planets are affected by solar variability.

SI must fly as early as possible in the Phase 3 mission window (near 2025) to provide the information critical to our planned exploration activities as humans head out through the potentially dangerous interplanetary environment whose character is controlled by the sun.

Tropical ITM Coupler (T-ITMC)

T-ITMC will explore how neutral and plasma interactions distribute energy within and between Earth's low-latitude mesosphere, thermosphere, ionosphere, and inner plasmasphere.

T-ITMC will improve our understanding of the influence of geospace on Earth (Objective H), explore the fundamental interactions between atmospheric plasmas and neutrals across scales from 1 cm to 1000 km (Objective F), and provide a fundamental database of atmospheric dynamics (winds, gravity waves, and ion drifts) that can be applied to exploration of other planets (Objective J).

It should be flown after the GEC and ITSP missions and should be reconfigured as necessary to address unanswered questions from those missions. In the event of limited flight opportunities, the

importance of T-ITMC can be evaluated in light of the GEC and ITSP results.

Venus Aeronomy Probe

Venus Aeronomy Probe will study the robust upper atmosphere and solar-wind atmosphere interaction of a planet with essentially no intrinsic magnetic field. This mission will determine the processes by which solar wind energy is transmitted to the ionosphere and upper atmosphere. It will also study how charged particles are accelerated to create auroral-type emissions, how magnetic field ropes form and dissipate, how ionospheric plasma is lost, as well as other electrodynamic interactions.

The dynamics and evolution of the Venus upper atmosphere and its direct interaction with the solar wind is a critical component of the reasons why this planet digressed from habitability. Understanding the physical processes responsible for the development of the present-day Venus atmosphere is vital to understanding the evolution of planetary atmospheres in general, including that at Earth.

Because Venus is not hospitable to humans and is therefore not a manned-flight destination, this mission should be flown after one or more similar missions have gone to Mars. Therefore, it is part of the Phase 3/4 mission queue.

