1.0 Introduction

Life on Earth prospers in a biosphere that is sustained by energy from the Sun. The Earth's upper atmosphere and magnetic field generally protect the biosphere against the more dangerous electromagnetic radiation and particles emanating from the Sun. In turn, the extended magnetic field of the Sun shields the Earth from very high-energy radiation that originates at supernovae and other cataclysmic events outside the solar system.

In the process of protecting the Earth, the upper atmosphere and magnetic field form a system that is connected in various ways to the Sun and *heliosphere*. The tremendous energy dissipation in the Earth's high-latitude auroral displays is dramatic evidence of this connection. Associated ionospheric disturbances can disrupt terrestrial communications, and associated electric currents can disrupt power grids. The connection between the heliosphere and the Earth's *magnetosphere* also results in the formation of time-variable radiation belts consisting of high-energy charged particles that encircle the Earth. These belts of dangerous, high-energy particles extend out to distances where communication and weather satellites operate.

The *heliosphere* is the region of space influenced by the Sun and its expanding solar wind. The outer boundary of the supersonic solar wind, called the *termination shock*, is probably located 1.5 x10^{10} km (~100 Astronomical Units, AU) from the Sun.

The *magnetosphere* is the region of space influenced by the Earth's magnetic field. Its boundary is the *magnetopause*, which is shaped like a windsock whose nose is located about 60,000 km upstream (i.e., in the sunward direction) from the Earth.

A *plasma* is a gas of positively and negatively charged particles. Most of the universe, including nearly every region of interest to the SEC Division, contains plasma. This includes the Sun, the solar corona, the solar wind, the interstellar medium, and the magnetospheres and ionospheres of Earth and other planets.

The Sun-Earth Connection

Within NASA's Office of Space Sciences, the Sun-Earth Connection (SEC) Division's primary goal is to understand these interconnections, that is to:

Understand the Sun, heliosphere, and planetary environments as a single connected system.

To accomplish this overarching goal, the SEC Division investigates the physics of the Sun, the heliosphere, the local interstellar medium, and all planetary environments within the heliosphere. Taken together, these studies encompass the scientific disciplines of solar physics, heliospheric physics, magnetospheric physics, and aeronomy (the study of planetary upper atmospheres). They address problems such as solar variability, the responses of the planets to such variability, and the interaction of the heliosphere with the galaxy.

Recent years have witnessed the growing importance of SEC investigations focused upon space weather, the diverse array of dynamic and interconnected phenomena that affect both life and society. Space weather effects disturb radio and radar propagation through the ionosphere, damage objects or astronauts outside the Earth's atmosphere, substantially modify the ozone layer, and may induce some climate shifts. Understanding space weather effects becomes more important as the government and private sectors rely increasingly on space- and ground-based assets subject to the influences of the space environment.

2.0 Sun-Earth Connection Goal and the Space Science Enterprise Strategic Objectives

The SEC is one of three divisions in the Office of Space Sciences (OSS). The SEC Division's overarching goal is linked to the OSS Space Science Enterprise Strategic Plan through Strategic Science Objectives. These objectives define the multi-decadal studies needed to thoroughly understand the environment as a system and this system's impact on life and society. The three primary science objectives are to:

1) Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments.

Determining how energy and matter are transferred from and through each link in the system and how the system responds to this transfer.

2) Explore the fundamental physical processes of space plasma systems.

Understanding how *plasma* processes within and outside the heliosphere create links in the Sun-heliosphere-planet system.

3) Define the origins and societal impacts of variability in the Sun-Earth connection.

Determining the effects of short-time scale variability on space weather and the Earth's atmosphere and the effects of long-term variations that lead to "space climate" and climate change on Earth.

In addition to these three primary science objectives, the SEC Division contributes to five additional science objectives. These objectives, from the 2000 OSS Strategic Plan, are primary objectives for astrophysics and planetary physics. They concern the structure and evolution of the universe, the formation of the solar system, and the search for the origin of life in the solar system. Specifically, they are to:

- **Understand the structure of the universe, from its earliest beginnings to its ultimate fate.**
- **Learn how galaxies, stars, and planets form, interact, and evolve.**
- **Understand the formation and evolution of the solar system and Earth within it.**
- **Probe the origin and evolution of life on Earth and determine if life exists elsewhere in our solar system.**
- **Chart our destiny in the solar system.**

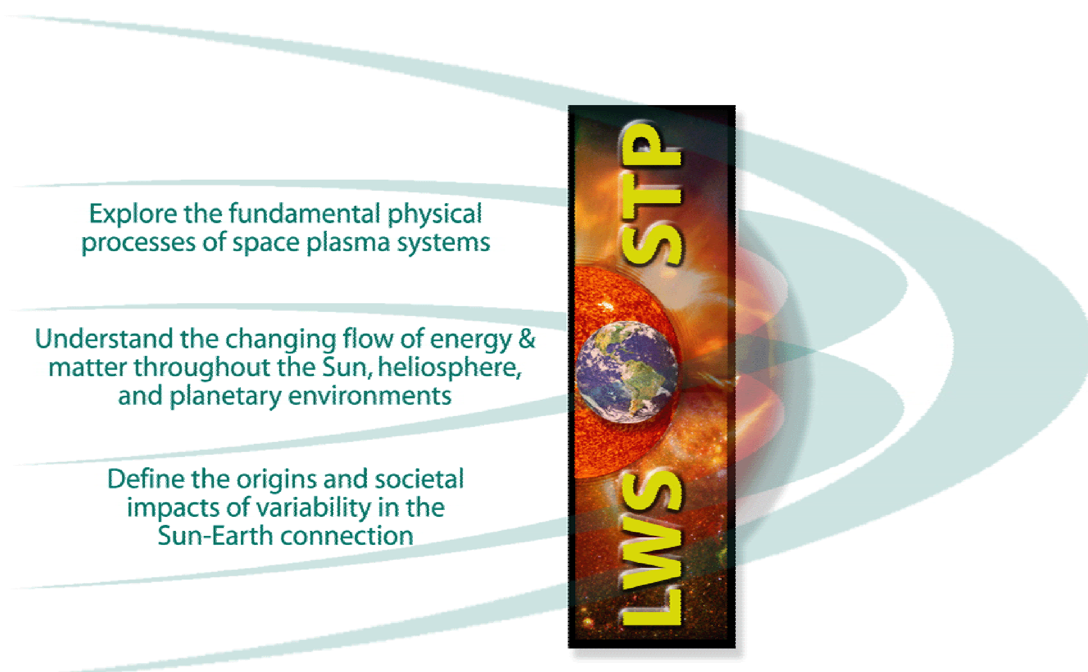

Figure 1.1 The three primary science objectives of the SEC Division and their relationship to the Solar Terrestrial Probe (STP) and Living With a Star (LWS) missions.

To accomplish the primary science objectives, the SEC Division has developed a cohesive, multidisciplinary plan that focuses on specific research areas through the combination of space missions. Most of these missions are in the Solar Terrestrial Probe (STP) or Living With a Star (LWS) mission lines within the SEC, with primary objectives and mission lines delineated in Figure 1.1 and Table 1.1. The new missions focus on processes that connect the elements of the Sun-heliosphere-planet system. To understand these processes, the measurement approaches are evolving from single-point or widely spaced multi-point missions that have previously employed a single measurement technique, to coupled, multi-point missions that employ a variety of measurement techniques.

- New solar/heliospheric missions will employ combinations of imaging and *in situ* measurements that will directly link the particles to transient features imaged on the Sun, (e.g., by identifying the particles accelerated by a solar flare). These new missions will view the Sun as it has never been seen before, including new vantage points such as high-latitude and polar regions, where the origin of the magnetic activity that starts a new solar cycle remains a mystery.
- New heliospheric missions will visit unexplored regions of space including the region within a few solar radii of the Sun, where the solar wind originates. Other new missions will explore, first indirectly, and later directly, the properties of the local interstellar medium.
- Magnetospheric missions will use combinations of imaging and multi-point *in situ* measurements to explore the very center of reconnection regions. In these regions, the electrons in the plasma decouple from the magnetic field, allowing the field to "reconnect" and mass, energy, and momentum to flow across plasma boundaries.
- Ionospheric missions will sample the ionosphere near 100 km altitude, where the bulk of the energy from the magnetosphere is collisionally dissipated. This region has previously been accessed only by brief visits from sounding rockets.
- Combined results from missions that explore individual links in the Sun-heliosphere-Earth chain will result in true systems-level understanding. For example, the near-term Solar B, STEREO, SDO, MMS, Radiation Belt Storm Probes and IT Storm Probes missions (see Table 1.1) represent a combination that provides unprecedented detailed measurements extending from inside the Sun down to the ionosphere. SDO will provide measurements of the solar interior and development of solar disturbances, Solar B and STEREO will determine the evolution of these disturbances in the heliosphere, MMS will determine the coupling between the solar disturbances and the Earth's magnetosphere and the Geospace Storm Probes will determine consequences for the radiation belts and ionosphere. The result will be a system-wide understanding of the physics behind solar disturbances and their geo-effectiveness.

A strong theory and modeling program is essential to the success of the focused research that these new missions will provide. The systems under study are complex, requiring well-tailored development of representative models. The space weather element of Living With a Star program places additional requirements that include development of models with predictive capability. Such predictive models must be deeply rooted in the underlying theoretical physics derived from the observations provided by multiple spacecraft.

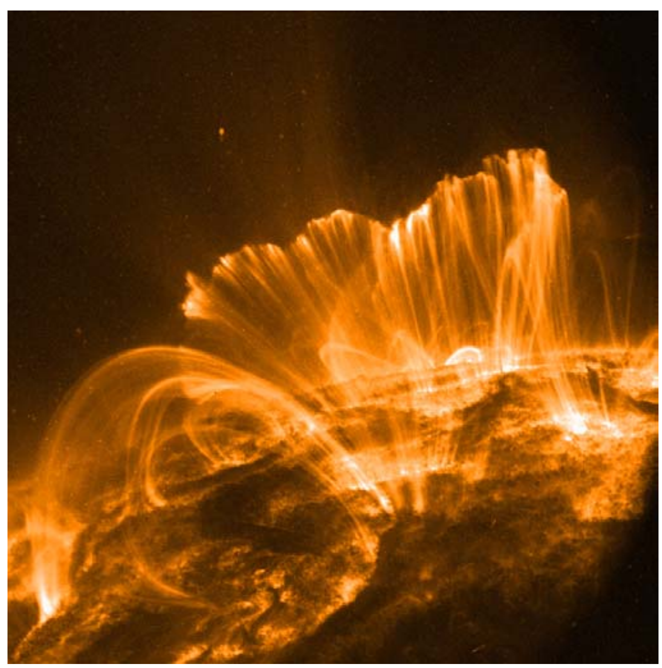

Figure 1.2 Transition Region And Coronal Explorer (TRACE) image of the solar corona illustrate the dynamic Sun.

Technology will play an important role in maximizing the science return from these SEC missions. Improving the technology for spacecraft manufacture and operations will be critical for reducing the cost of multi-spacecraft missions. High spatial and temporal resolution, multi-spectral imaging and the optimal use of data obtained from multi-spacecraft missions will require new techniques for data assimilation and analysis. Remote sensing instrumentation that produces high-resolution multi-spectral images will benefit from additional detector development. Finally, advanced propulsion systems such as solar sails will be needed for access to orbits, including "non-Keplerian orbits," that would otherwise require significant increases in launch vehicle capability, spacecraft propulsion requirements, and cost.

The new SEC missions will expand the frontiers of human knowledge and ignite curiosity in students and non-specialists. Newer, higher resolution images of the Sun, many times the resolution of images currently available from the TRACE mission (see Figure 1.2), will continue to fascinate the general public. While these new images will result in a revised and improved understanding of the solar corona and a new view of the Sun's atmosphere in three dimensions, they will also be recognized for their inherent beauty. Heliospheric spacecraft will voyage to unexplored regions of the solar system and will become the first man-made objects to leave the heliosphere and venture into interstellar space. Close-up images of the Jovian aurora, the most powerful in the solar system, will bring a new public appreciation to the Earth's auroral displays (see Figure 1.3). Finally, new measurements of the Earth's upper atmosphere will demonstrate the fragility of this region and will establish the role of solar forcing in its modification.

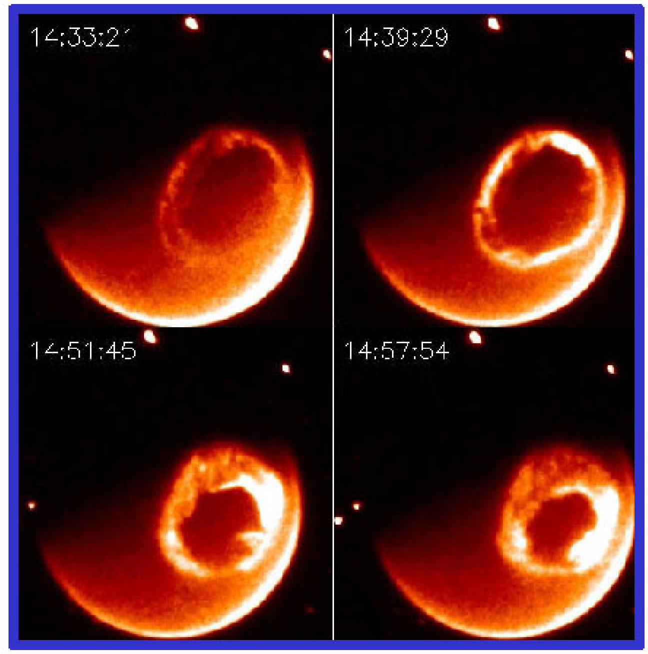

Figure 1.3 Imager for Magnetopause-to-Aurora: Global Exploration (IMAGE) images of the Earth's auroral oval during a powerful geomagnetic storm.

Table 1.1 The SEC goal and strategic science objectives and their links to SEC near- and intermediate-term missions. The missions under a particular objective are listed in chronological order.

Goal	**Understand the Sun, heliosphere, and planetary environments as a single connected system.**		
Strategic Science Objectives	1) Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments	2) Explore the fundamental physical processes of space plasma systems.	3) Define the origins and societal impacts of variability in the Sun-Earth connection
Near-Term Missions (2003-2008)	- Solar B - Solar-Terrestrial Relations Observatory (STEREO) - Geospace Electrodynamics Connections (GEC) - Solar Probe	- Magnetospheric Multiscale (MMS) - Bepi-Colombo	- Solar Dynamics Observatory (SDO) Geospace Storm Probes: - Ionosphere Thermosphere Storm Probes - Radiation Belt Storm Probes
Intermediate Term Missions (2009-2014)	- Magnetospheric Constellation (MagCon) - Telemachus - Ionosphere Thermosphere Mesosphere Waves Coupler - Heliospheric Imager and Galactic Observer (HIGO)	- Jupiter Polar Orbiter (JPO) - Reconnection and Microscale (RAM)	- Inner Heliosphere Sentinels (IHS) - Solar Orbiter - Inner Magnetospheric Constellation (IMC) - Tropical ITM Coupler - Magnetic Transition Region Probe (MTRAP)