Solar Probe's Contributions to the Exploration Vision

The only way to understand and ultimately be able to predict the sources of solar energetic particle radiation and modulation of galactic particle radiation that are so dangerous to manned spaceflight is to travel to the Sun and make the critical measurements of their source populations, acceleration processes, and sources of magnetic shielding in situ. This is the goal of Solar Probe – a mission of exploration that is truly enabling for Exploration.

The radiation environment

As human explorers venture beyond earth orbit, perhaps the greatest single hazard that they will have to face is the space radiation environment. By traveling into and directly exploring the sun's outer atmosphere and inner edge of the solar wind for the first time, the Solar Probe mission will provide uniquely the direct, in situ information required to understand and model how this critical region produces and modulates dangerous space radiation.

The radiation environment seen by human and robotic explorers is composed mainly of two components: galactic cosmic rays (GCRs), which are very energetic particles accelerated outside the solar system and solar energetic particles (SEPs), which are produced sporadically by processes occurring in the sun's atmosphere and inner regions of the solar wind (or heliosphere). GCRs are accelerated to very high energies by a variety of processes within the galactic environment and then propagate into the solar system. Much of the GCR flux is shielded by the outer heliosphere and the remaining flux (approximately 10% at 100 MeV/nucleon) that enters the solar system is modulated by variations in heliospheric structure over the solar cycle and by sporadic events such as coronal mass ejections (CMEs). Substantial variability is observed in the differential fluxes of GCRs with energies below several hundred MeV/nucleon. So far ongoing intensive research has not achieved a complete physical understanding of the processes responsible for factor of 10 or more solar cycle variation in the fluxes of these potentially hazardous particles.

SEPs are produced by a variety of processes occurring near the sun: Solar flares and coronal mass ejections both can accelerate particles to very high energies, but predicting which events will produce threatening fluxes of energetic particles and how effectively these particles will propagate through the solar system is still an inexact science. Understanding the processes that produce these particles and modulate their intensity is critical for the development of the predictive models that, combined with solar and heliospheric monitoring, will allow nowcasting and forecasting the space radiation environment. In situ observations very close to the sun are required to make significant progress in this area and the Solar Probe mission is the only way to make these observations.

The Solar Probe Mission

As the first spacecraft to fly through the sun's outer atmosphere (Figure 1), Solar Probe will play a crucial role in pursuing the necessary understanding of energetic particle acceleration and transport. By flying as close as 3 solar radii above the sun's surface Solar Probe will explore the inner boundary of the solar wind, where the wind is heated and accelerated, and uncover the physical mechanisms that take place there. From this inner boundary the solar wind expands throughout the solar system and ultimately forms a barrier between the heliosphere and the local galactic medium.

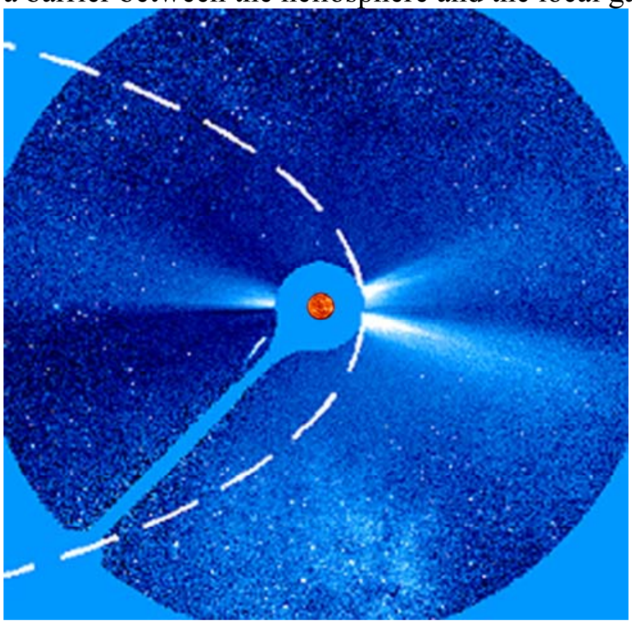

Figure 1) Solar Probe's close flyby of the sun, shown superimposed on images from the LASCO coronagraph on SOHO, illustrates structures in the solar corona that the spacecraft will explore. The particle acceleration, magnetic turbulence, MHD shocks, etc., in this close-in region ultimately determine the radiation environment in interplanetary space.

The measurement of characteristic particle and magnetic field properties close to the sun by the Solar Probe is critical for the development of models for energetic particle acceleration, solar wind heating, and acceleration dynamics. These observations will eliminate the need for assumptions and hypotheses that limit predictions today. Solar probe will provide direct observational constraints relevant to the origin of the large-scale structure of the heliosphere and the distribution of turbulent fluctuations, which are the two main factors influencing transport of SEPs and GCRs in the solar system.

Solar Probe mission will contribute to human exploration missions beyond earth orbit in several broad categories: In the pre-mission phase models derived from Solar Probe results will help develop shielding requirements for space vehicles, space suits and in-situ shelters. These models will also provide the input to biological response models and to dosimetry and forecasting requirements. Results from the Solar Probe mission will be particularly important in developing requirements for deep space monitoring networks that will be required to support the human exploration mission operations.

Specific Contributions made by Solar Probe

While much has been learned about the nature of the solar wind since the first space missions, a number of fundamental questions remain about its source at the sun and the processes that heat and accelerate it. Within a few solar radii of the sun's surface the solar wind is accelerated to speeds of several hundred km/s and heated to temperatures of millions of degrees. It is impossible to extrapolate back from measurements made outside this region of heating and acceleration to determine the processes involved.

Remote sensing measurements can tell us much about the region nearest the sun – from the photosphere into the corona, however the regions of the outer corona that provide the interface between the surface and the heliosphere (solar wind) cannot be studied in this way. Figure 2 shows a model of the solar wind speed and Alfven wave speed in the heliosphere and highlights the region of exploration extended by the Solar Probe mission.

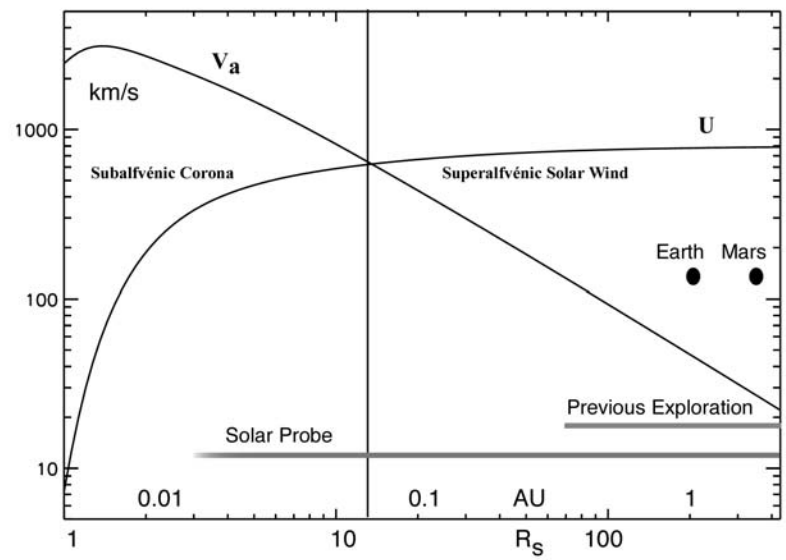

Figure 2) Profiles of solar wind speed and Alfvén wave speed with distance from the sun. The vertical bar separates the source, or sub-alfvénic, region of the wind from the supersonic solar wind flow. Solar probe is the first mission to fly inside the source region

Beyond ≈15 Rs from the sun, the solar wind speed is higher than any of the embedded wave speeds, so it is not possible to extrapolate back from measurements made outside this region to determine the physical mechanisms at work there. Within this inner region of the heliosphere, the solar corona is heated to millions of degrees and accelerated to form the supersonic solar wind. Understanding the physics of this critical region is necessary to produce models that can use remote measurements of the sun and sparse measurements in interplanetary space to characterize and predict the radiation environment throughout the solar system.

The ongoing definition of the Solar Probe mission has resulted in several additional features that will enhance its value for Exploration. In particular, the use of radiothermal generators allows the collection of data along the entire orbit of the spacecraft, allowing us to monitor continuously the evolution of the solar wind from the sun to beyond the orbit of Mars. Also, the emphasis on global remote sensing measurements of key solar parameters will enable simultaneous comparison between activity on the sun and in-situ measurements made by the spacecraft.

Solar Probe will make fundamental contributions to understanding the space radiation environment in three important ways:

1 Solar Probe will provide in-situ ground truth for later early-warning solar remote-sensing missions

a. Solar Probe will fly through plasma and energetic particles while measuring the magnetic fields and EUV emissions on the sun at the point from which they emanate, enabling us to directly relate the remote sensing observations at the surface to the solar wind conditions measured in-situ by the Solar Probe spacecraft.
b. Observations from Solar Probe will allow us to develop physical models that relate remote observations to the resulting heliospheric radiation environment.

2 Data from Solar Probe will improve understanding of the generation of SEP events and SEP transport

a. By examining the acceleration and transport of energetic particles in the inner heliosphere of the type and energy range that contribute to significant human biological effects and by studying the seed populations of these particles that are ultimately accelerated to high energies close to the sun.
b. By identifying the different processes that lead to gradual and impulsive solar energetic particle events over all latitudes
c. Ground truth, in situ observations of seed populations and processes that generate SEPs will enable detailed physics-based models of these dangerous space radiation sources for the first time.

3 Solar Probe data will improve knowledge of variability in GCR fluxes

a. By exploring latitudinal gradients up to the sun's pole
b. In combination with Ulysses measurements, SP will determine the radial variation in solar wind properties, structure and turbulence at high latitudes, which are necessary to understand transport of galactic cosmic rays
c. Insights gained by Solar Probe into the large scale structure of the heliosphere, and the solar conditions that influence it will provide a critical input into models of solar modulation of GCR fluxes

In addressing the above goals, Solar Probe provides unique and critical information for models that currently rely on inferences from remote sensing data and in-situ data collected far outside the region where many of the important physical processes take place. Data from Solar Probe will be a critical component of an accurate theoretical framework, linking solar and inner heliospheric sources with predictive models. This framework will enable nowcasting and improved forecasting of solar energetic particle events and a significantly better understanding of the solar modulation of galactic cosmic rays.