# NASA Strategic Objectives Focus Areas

## Request for Information
## NASA APIO GC-04-06

## Strategic Roadmap Area 9
## Exploration of the Sun-Earth System

## Human Exploration of Mars


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# FOCUS AREA WHITE PAPER: HUMAN EXPLORATION OF MARS

**Problem:** Radiation exposure to crews and equipment during long-duration missions will be a significant health and safety issue, which must be addressed. The radiation hazards are most significant during transit to the moon and Mars, during lunar surface operations, and secondarily during Mars surface operations.

There are two significant sources of radiation that must be considered: galactic cosmic rays (GCR) and energetic solar radiation (SR). Of these, the GCR component can be predicted accurately well in advance and throughout the inner solar system using any of a variety of well-established models. However, the SR component, which can dominate the total radiation dose for an entire year, is not accurately predictable in advance. Additionally, for missions to Mars the SR component can be due to a solar flare on the far side of the sun in a way that is undetectable from earth. The intensity distribution of SR events is such that, like earthquakes or hurricanes, the real worst-case is yet to be experienced. It will not be practical to design permanent crew quarters that provide adequate protection under all conditions. Instead, a "storm shelter" architecture will be required. This architecture will require accurate warning of severe solar events with minimal false positives and with sufficient advance notice so that the crew can be secured in an adequate shelter.

The present state of the art in the prediction of energetic solar events is such that the conditions for such events to occur can be identified by detailed multi-wavelength observations of the sun, but the specific occurrence and timing of these events is not yet predictable. Additionally, during the transit to and operations on Mars, for roughly half of the time the region on the sun that will affect the radiation environment of a crew at Mars or in transit to Mars will be on the side of the sun that is not visible from earth.

**Recommendations:** Addressing the radiation hazard due to energetic solar events will require: (1) better knowledge of the conditions that trigger the eruption of a solar active region to produce a major solar energetic particle event, and (2) the real-time observations necessary to monitor for those conditions. These two elements are discussed in more detail below.

<u>Understanding the conditions necessary to energetic solar events:</u>
The most severe solar energetic particle events involve the prompt acceleration of electrons and ions near the sun, with associated production of high-energy gamma- and x-rays and neutrons, and the subsequent propagation of these radiations throughout the interplanetary medium. The charged particles are guided by the interplanetary magnetic field and may be confined in helio-longitude. Depending on the intensity of the event, protons and other ions can be accelerated such that the SR ion intensity exceeds the background GCR intensity to kinetic energies in excess of 1 GeV. These ions and accelerated high-energy electrons have velocities comparable to the speed of light so that even if the flare is observed there may be essentially no advanced warning of this intense, energetic radiation.

A better capability to predict the time of occurrence and magnitude of major solar particle events will provide for better protection of the crew with less time spent waiting in the storm shelter. The volume of the storm shelter must be minimized to minimize its mass, which will be significant to the total mass of the Mars transport vehicle, for example. Crew productivity and comfort will be severely constrained in the shelter, resulting in strong desire to minimize its use. It will not be acceptable to confine the crew to the shelter for the period of a few days to week whenever a significant solar active region is in the longitude sector that could affect them (either the lunar or the Mars case). Our ability to predict the occurrence of such events must be reliable, but with few false positives.

The "standard model" posits that a solar flare is the result of the conversion into particle kinetic energy of the energy stored in a complex, twisted solar magnetic field configuration. On the basis of this model it should be possible to monitor the configuration of the magnetic field and its evolution on time scales of a day to a few hours to determine the conditions that trigger a significant solar flare and to use this information to improve solar flare forecasts or warnings. The first recommendation offered in this white paper is to focus more attention on this problem by supporting research specifically directed at improving solar flare forecasts, with the goal of achieving reliable forecasts with at least 1 hour of advanced notice of major solar flares and their expected magnitudes. This problem will probably best be addressed by a coordinated imaging of solar active regions with the highest possible resolution in visible through UV and x-ray wavelengths, combined with high-resolution vector magnetographs. The angular/spatial resolution of the observations and the UV and x-ray wavelengths will mandate that they be made from a space-based platform.

<u>Providing a real-time monitor of the far side of the sun:</u>
Once we understand the signatures and can forecast the occurrence of major solar flares based on solar imagery of sufficient resolution, at least three platforms will be required around the sun to monitor for these conditions, acting as the solar flare early warning system. One of these platforms can be in earth orbit, but the others must be in orbit around the sun at different helio-longitudes. (A single platform on the far side of the sun might be marginally sufficient if there were a reliable way to communicate with it.) Each of the platforms must be instrumented with the necessary solar observing instruments, and each should also include a set of radiation detectors to characterize any solar particle event that is observed. Experts like those at the NOAA Space Environment Center in Boulder, CO, will assess the data from this set of solar monitors (e.g. solar sentinels) continuously in real time as one element of the crew radiation warning and protection program. The analysis may be automated in whole or part for improved consistency and reliability.

**Summary:** Addressing the radiation hazard due to energetic solar events will require: (1) better knowledge of the conditions that trigger the eruption of a solar active region to produce a major solar energetic particle event, and (2) comprehensive real-time observations to monitor for those conditions from a set of at least three monitoring spacecraft properly located in orbit around the sun.