

Linkages between Sun-Solar System Connections and other NASA Activities

Linkages Between SSSC Strategic Roadmap and other NASA Strategic Roadmaps

Sun-Solar System Connection (SSSC) science focuses on space plasma physics in our cosmic neighborhood. It encompasses the Sun and the processes and phenomena that determine the space environment near the Sun, in the Earth-Moon system, in the vicinity of other solar system bodies, and throughout interplanetary space to the very boundary with interstellar space.

To the degree that the space environment matters to people or their technological systems, whether on Earth or in space, SSSC science has application to human activities. Penetrating energetic particles and photons produced by acceleration and radiation processes in space plasmas profoundly and adversely impact any exposed living organism through cellular damage and mutation. They also adversely impact exposed technological systems through episodic and cumulative damage to microcircuits and cumulative degradation of materials. Therefore, the processes that produce and transport energetic radiation are of direct interest to modern humans.

The situation for long-duration space flight is somewhat analogous to deep-ocean operations of naval ships. Vessels are designed to survive in various climatic conditions; yet the weather, which can be extreme, limits operations and determines how vessels should be configured in any situation. Similarly, operations in space will depend on space weather, viz., extravehicular activities (EVAs), maneuvers, operations on lunar and planetary surfaces, and safe harbor. Space weather in the vicinity of planetary bodies affects the state of the upper atmosphere – density and wind distribution – that is critical to vehicle aerocapture, ascent, and descent scenarios as well as the state of the ionosphere – spatial and temporal electron density distributions – that influences navigation systems and high band-width communications. As for terrestrial weather, space weather awareness, understanding, and prediction will be essential enabling activities for space exploration operations. Therefore, we recognize strategic linkages between the SSSC Roadmap and all three Exploration Roadmaps (Lunar exploration, Mars exploration, and the development of the Crew Exploration Vehicle).

The effects of space weather on Earth's atmosphere are of special interest. Enhanced ozone depletion is a documented consequence of energetic particle precipitation. We are aware of space plasma processes that erode the Earth's atmosphere, removing ~103 kg of hydrogen and oxygen daily, and vastly greater quantities during space storms. We have performed computer simulations that imply even greater loss of atmospheric constituents at Mars, which lacks the shielding provided by an intrinsic planetary magnetic field. The potential role of local space weather and/or solar variability in terrestrial climate change is as yet unknown. The state of the Earth's ionosphere is thought to be subtly modified by terrestrial seismic activity. Quantitative determination of the intrinsic terrestrial magnetic field requires an accurate accounting of field sources external to the solid Earth. These external sources are dominated by electrical currents carried in the space plasmas surrounding the Earth. For these reasons, we also recognize strategic linkages between the SSSC Roadmap and the Earth Science Roadmap.

The same processes and phenomena that drive space weather in our solar system also shape environments throughout the universe. We have a typical, variable, main sequence star (the Sun) in our cosmic back yard. We live on a habitable planet that is largely protected from hazardous elements of our local space environment by a magnetic shield (the magnetosphere), a feature not shared by all astronomical, or even planetary bodies. As we try to understand the remote universe and its potential to evolve life, it is

imperative that we take as full account as possible of the lessons we learn from the specimens we can virtually touch with our hands. Therefore, we recognize important linkages between the SSSC Roadmap and other Science Roadmaps that seek to understand nearby planetary systems (SRM03) and the larger universe (SRM08) and also between the SSSC Roadmap and the Roadmap to search for other habitable planets (SRM04).

Linkages Between SSSC Strategic Roadmap and NASA Capability Roadmaps

Continued progress in Sun-Solar System Connection (SSSC) science requires new capabilities based on the development of new technology. Future technology needs are driven by diverse requirements. Cluster and constellation missions are required to simultaneously sample large-scale space plasmas at multiple points (Magnetospheric Constellation, Inner Heliospheric Sentinels, Solar Weather Buoys, Dayside Boundary Layer Constellation, Inner Magnetospheric Constellation). Highly focused missions require improved measurement resolution and sensitivity (MMS, GEC, RAM, MTRAP, GEMINI, DOPPLER). Missions with special orbital requirements will need in-space propulsion. Examples include requirements to dwell at a point farther upstream in the solar wind from the L1 libration point (Heliostorm), to achieve a polar heliocentric orbit (Solar Polar Imager), or to escape from the solar system (Interstellar Probe). As the missions in our roadmap are developed, they will require new technologies in instrumentation, data visualization, communication, and analysis systems. Future SSSC technology needs fall into several focus areas.

Propulsion and Power: A number of SSSC missions will study solar system plasmas from unique vantage points. Propulsion systems that can supply a larger delta-V than conventional rocket engines, or that can provide large delta-V without a large mass or power penalty, can enable such challenging missions. For high-performance, cost-effective propulsion in the inner solar system, or for exiting the solar system in timely fashion, solar sails are the ideal choice. Significant ground demonstrations of solar sail technologies have been performed already. We encourage continued development of this technology and support the idea of a flight demonstration during Phase 1 of this Roadmap (CY 2005 – 2015). We also encourage renewed capacity to produce RTGs that have low-EMI, high-efficiency power conversion.

Micro-spacecraft: Owing to the large scale and complexity of solar system plasmas, future discoveries will depend on deployment of spacecraft in clusters and constellations, making simultaneous multi-point measurements within the plasmas under study. Enabling technologies will include low mass/power/volume instruments, and low-mass, low-cost spacecraft.

DSN: NASA's Deep Space Network (DSN) is evolving to meet the communication and navigation needs of the agency's increasingly complex, data-intensive missions. Analysis of Sun-Solar System Connection Roadmap missions suggests that, over the next 25 years, downlink rates will need to increase by a factor of at least 1,000, even from the more distant regions of our solar system. The trend toward multi-spacecraft missions will likely cause a large increase in the number of required supportable links back to Earth. Near-Earth missions should use and cultivate the continued evolution of commercial space networks.

Advanced Computing: Advanced supercomputing is a vital capability for enabling space weather model development and innovative data analysis and visualization. Examples of successful innovation in this area include NASA's Information Power Grid, Project Columbia, and the VisBARD project.

Instrumentation: Many future SSSC missions will require development of new scientific instrumentation, including large focal plane arrays, large-scale adaptive optics, and solar-blind energetic particle and photon detectors. The development of hyperspectral and three-dimensional detectors are needed for solar and

geospace remote sensing. Miniaturization of high voltage power supplies will relieve mass and volume resource constraints. Increased quantum efficiency of UV and EUV detectors will enable significant savings in mass as small but sensitive instruments can be developed. The shear strength and impressive electronic properties of carbon nanotubes may lead to the development of stronger, lighter materials and power efficient ionization sources. Conductive polymers and other exotic materials and coatings may lead to development of solar blind detectors, new and better dust analyzers, and miniature mass spectrometers. It is important to develop and maintain ground test facilities for simulating particle and radiation environments in space. Radiation test facilities will be particularly important as technological innovations and the push to develop more power efficient instruments results in smaller electronic instrumentation. Ground testing is extremely valuable, but NASA's low-cost access to space (LCAS) program is required for complete testing and full validation of advanced instrumentation. Imaging is an area of instrumentation where we should place significant development effort. Remote imaging provides more information than any practical number of single-point measurements. Imaging is crucial to understanding the complex interacting set of systems that make up the Sun-Solar System well enough to develop the properly constrained and accurate predictive models that are critical to support exploration, including a sustained human presence in space. The three primary imaging tools include Energetic Neutral Atom (ENA), Radio Tomography, and Photon Imaging, Photon imaging includes x-ray, extreme ultraviolet (EUV), far ultraviolet (FUV), visible (VIS) and infrared (IR).

Space Environment Testbeds (SET): The LWS SET technology development project performs spaceflight experiments of new approaches for mitigating the effects of the dynamic space environment that are driven by solar variability. Its investigations validate new hardware, methods, models, and tools, all geared toward mitigating the effect of the space environment on systems.

External Cost Drivers Beyond Our Control

Scientists and engineers working on Sun-Solar System Connection science have overcome many of the problems of building, flying, and operating space missions. But our science is affected by factors beyond the control of the community. Each is founded on rational decisions made by groups in the larger society within which we work. Like St. Francis, we need “the serenity to accept the things [we] cannot change, the courage to change the things [we] can, and the wisdom to know the difference.”

Space Launch Cost in the Free Market The single largest cost in most space missions is the launch vehicle. Unlike other technologies, the cost to orbit a kilogram has remained nearly constant over the past decade. Why is the cost so high? Space launchers are the most difficult challenges in engineering and manufacture because the forces and energies present in a launch vehicle are so great that they prevent graceful failures. From 1988 to 1999, 4% of launches failed in ways that required their destruction to insure public safety. As an Aeronautics and Space Engineering Board report states “Destruct commands are often superfluous because vehicles explode or break up because of dynamic forces.” In the early years of spaceflight, NASA solved this problem by building duplicate satellites, so that one might succeed if another failed. Today the response of the users has been to emphasize reliability of a small number of satellites.

The commercial space market provides about half of the global demand for launch vehicles. The 2004 FAA/COMSTAC forecast of commercial demand shows that the launch rate is static at ~22 per year from 2000 until 2013. The principal change has been the demand for very large satellites, with the average mass

per satellite growing from 2,400 kg in 1993-94 to 4,100 kg in 2003-04. The recent development of EELVs by the DoD suggests that their needs are similar to those of the commercial market. Some of the other Federal space activities, including NASA, also need large spacecraft and launchers. Taken together, the manufacturers of space launchers have good reason to focus on larger vehicles. The constant, small numbers of launches prevents economies of scale. To recoup the high development costs of new launchers, it is desirable to stop the production of older, smaller vehicles. Opportunity for small, simple, inexpensive, or risky payloads is absent when only large, expensive vehicles are available. Only large, expensive spacecraft make commercial economic sense.

Yet, many NASA science missions can be accomplished with much smaller, less costly spacecraft. The SMEX, MIDEX, Discovery, ESSP, and New Millennium mission lines are all highly productive and depend on smaller vehicles.

Public Trust and Risk Tolerance. NASA provides the visible demonstration of the value of American technological society to solving grand problems. The inspiration provided by a great success such as the Mars Rovers is matched by the disappointment and concern attached to failures of other missions. Success and failure are visible and owned by the American public.

Personal freedom is one foundation of American society. We accord individuals the right to pursue activities that have significant risk of failure, even injury or death, as a price of that freedom. These private risks, taken voluntarily, are accepted. Risk in systems supported or controlled by tax funds is not accepted. Public safety and fiscal responsibility require detailed investigation to determine causality and future improvement. Examples include airline or other controlled transportation accidents, military accidents, and NASA accidents.

NASA missions are growing in size, cost, and complexity. Growing complexity drives a compounding of levels of risk management, including detailed process control, frequent reviews, and greater requirements on project management. Risk management seeks to minimize avoidable failures, which imposes delay and unplanned costs on all missions because they share common technologies independent of their science focus. As with other complex aspects of our society, the cost of risk management is an increasing fraction of the total.

Yet, risk is a critical part of the process of learning to succeed. NASA fosters future success by offering broad range of projects and missions to permit new generations to learn through trial and error, and help the best progress to larger projects. The desire to minimize risk must be tempered by a desire to maximize long-term success.

National Security. Space technology provides unique contributions to national security, in reconnaissance, navigation, and communication (and space weather effects on such systems). American technological advantages over potential adversaries drives restrictions on civilian space interactions with foreign collaborators. Recent increases in these restrictions, founded in the International Traffic in Arms Regulations (ITAR) and Export Administration Regulations (EAR), apply even to scientific interactions with friendly nations. NASA has accorded Principal Investigators (PI) freedom to involve foreign collaborators. The cost of these positive foreign interactions is increasing in order to insure the required compliance with ITAR/EAR restrictions. One result is decreased opportunities for the cost-sharing of space missions.

Yet, foreign contributions, such as the Huygens lander on the Cassini mission, have immeasurably improved the quality of many science missions. Strengthening the technical teamwork between the U.S. and our

partners permits activities that could not be achieved separately.

NASA and External Factors These problems are opportunities for NASA leadership. Fiscal responsibility, scientific and technological opportunities are strong arguments for working to maintain a range of launch vehicles, both large and small. This is a capability important to NASA.

The public and future scientists are inspired by spaceflight because it challenges us to advance the limits of our abilities. Engaging the public in the challenges and inherent risks of pioneering spaceflight and exploration is an opportunity for E/PO on these issues in modern systems. NASA's work with its communities to develop the most cost-efficient methods for appropriate risk management of complex space projects is a capability that can improve many areas of our technical society and economy.

Foreign collaborations add value that advances America's space goals. Aiding its projects to achieve cost-effective compliance with ITAR rules is a capability important to NASA. Continued dialog and negotiation between NASA and the other relevant agencies to develop and clarify more appropriate rules for space research missions will enhance the capability of those agencies for dealing with other critical technical issues.