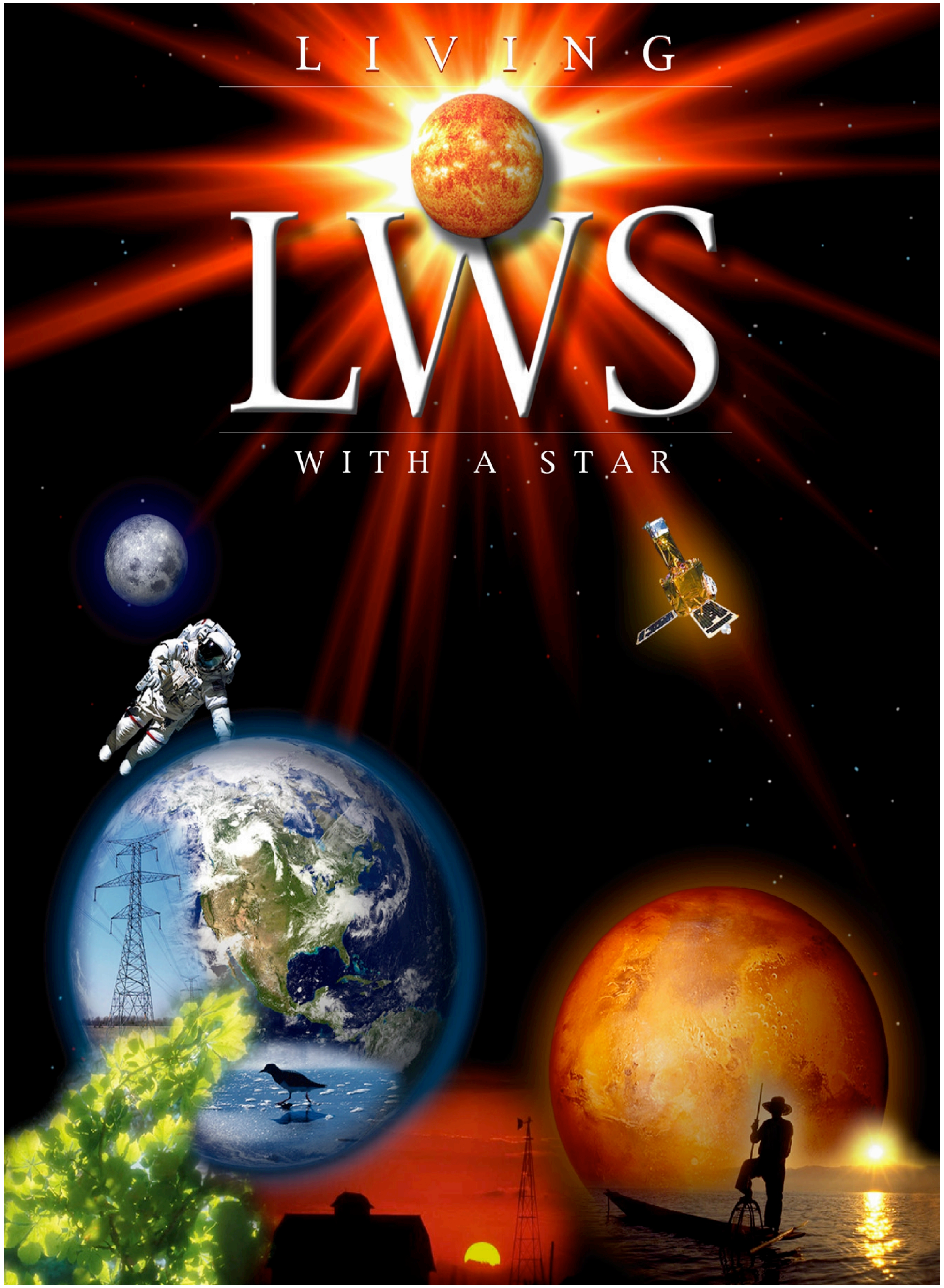
Report from NASA



Madhulika Guhathakurta,
NASA Headquarters
LWS Program Scientist

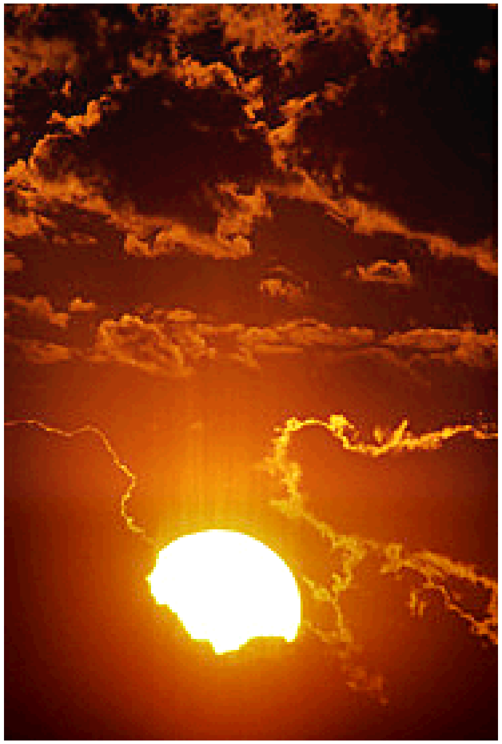
SHINE Meeting
July 11-16 2005

SDO Mission/Project Overview

- **In-house implementation at Goddard Space Flight Center (GSFC) including:**
  - In-house spacecraft build & Observatory integration/testing
  - In-house Ground System development/management & Mission Operations.
  - Management of instrument contracts with Principal Investigators responsible for development of their instrument & Science Operations Center (SOC).
  - Single ground station at White Sands with distributed SOCs.
- **Launch from KSC into GEO-Transfer Orbit (GTO), circularize to GEO-Sync Orbit, inclined 28.5 degrees with semiannual eclipse seasons.**
- **5 year prime lifetime, solar-tracking with low jitter; continuous high data rate (130 Mbps)**
- **Non-Science driven Level 1 requirements:**
  - 3200 kg SDO Observatory mass allocation with remaining LV lift capability reserved for potential secondary payload.
  - GTO insertion transfer orbit with a minimum perigee of 300 km for possible secondary GTO payload options.

What SDO Will Do…

In order to meet the needs of the Living With a Star program and determine the drivers and diagnostics of solar activity and variability that affect Earth and humanity, the Solar Dynamics Observatory must:



- ❖Provide *nearly continuous* coverage of solar activity
- ❖Observe all of the solar regimes in which the activity occurs (interior, photosphere, atmosphere)
- ❖Collect necessary data on the types of phenomena that impact Earth, near-Earth space, and humanity
- ❖Cover all of the relevant timescales of solar variability (seconds to years)

SDO Significant Issues

- SDO had to pay 20.8 M in earmark money in FY05
- This is going to change the launch date of SDO
- Initial estimate suggests a 4 month slip to 8/2008

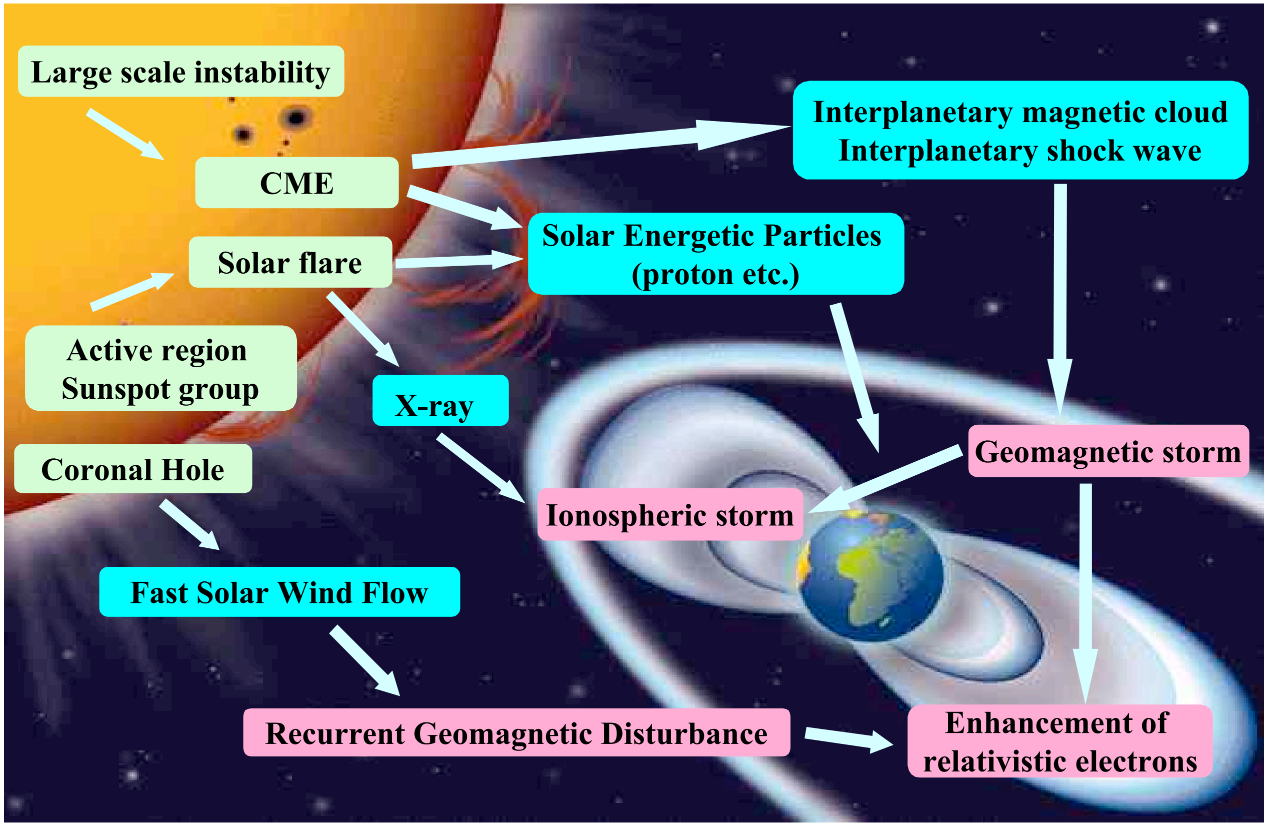
Opportunity for Participation

The National Aeronautics and Space Administration (NASA) intends to release an Announcement of Opportunity (AO) for Radiation Belt Storm Probes (RBSP) Investigations in June 2005.

The RBSP mission will require a variety of instruments to be carried on a two identical NASA-supplied spacecraft to be launched in the early 2011 with a prime mission of two years.

-Launch date for ITSP will be decided after the strategic planning process is completed.

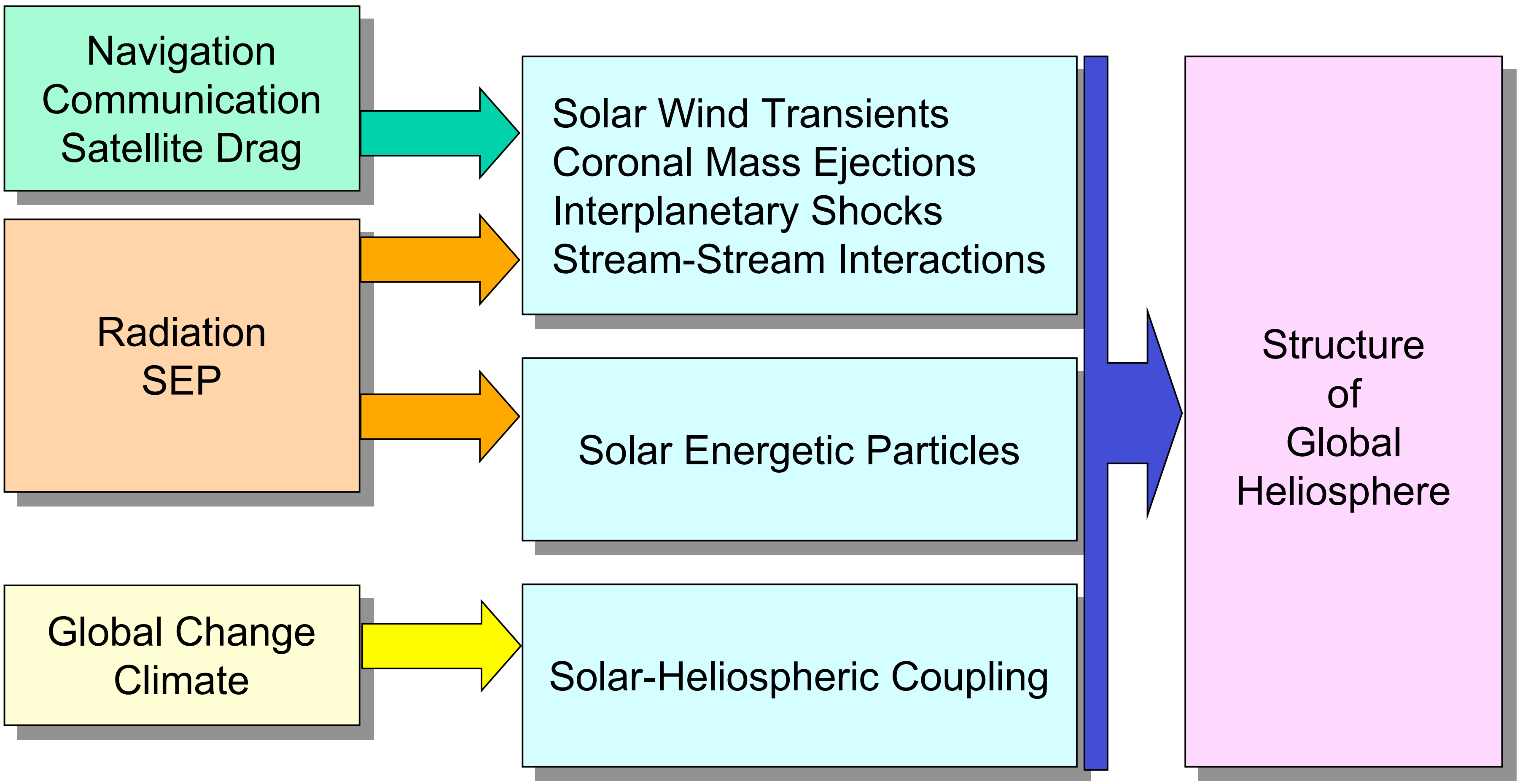
Solar Sentinels: Primary Objective



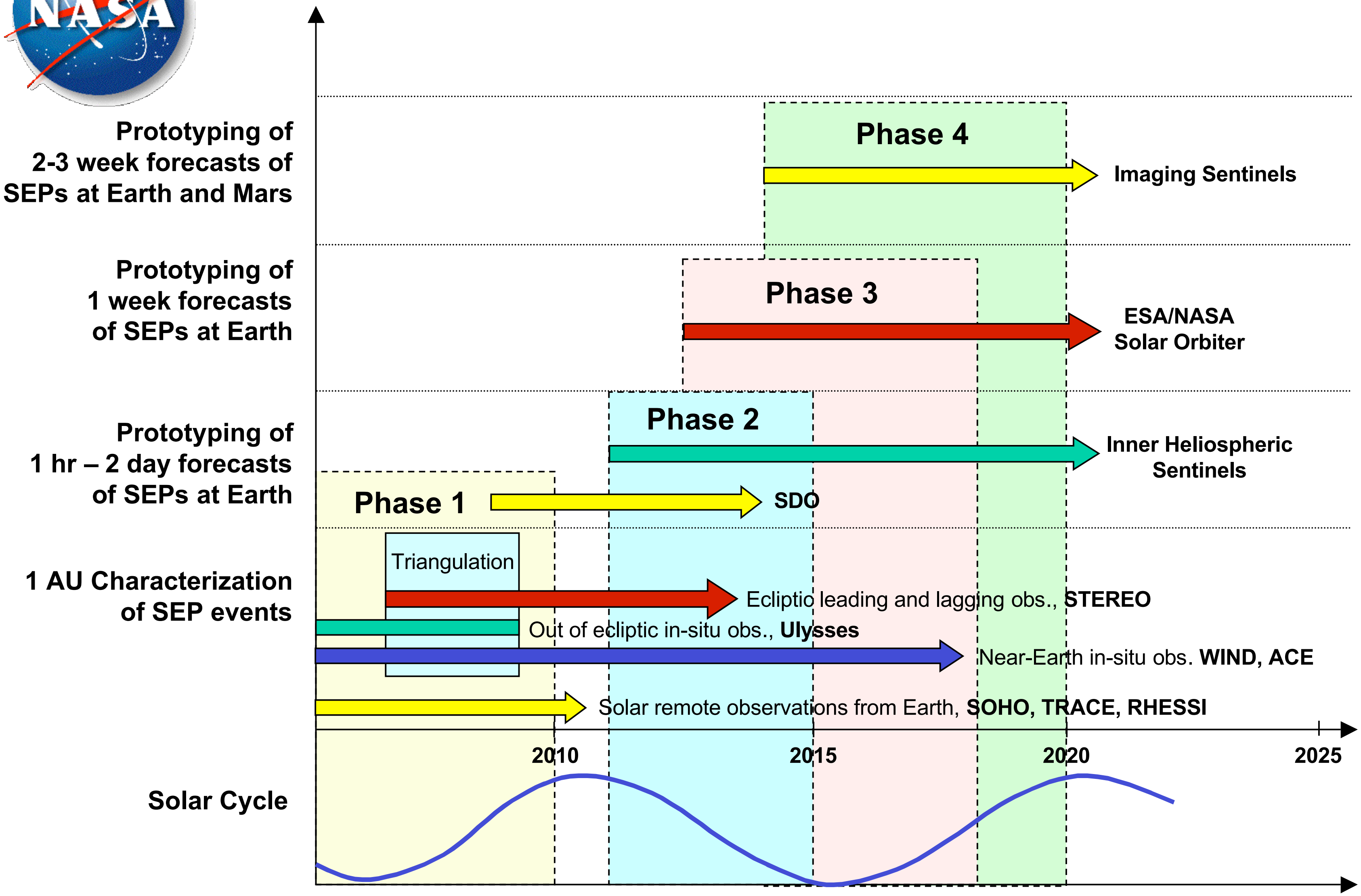
Discover, understand and model the <u>connection</u> between solar phenomena and geospace disturbances.

Societal Impacts

Sentinels Science Focus Areas

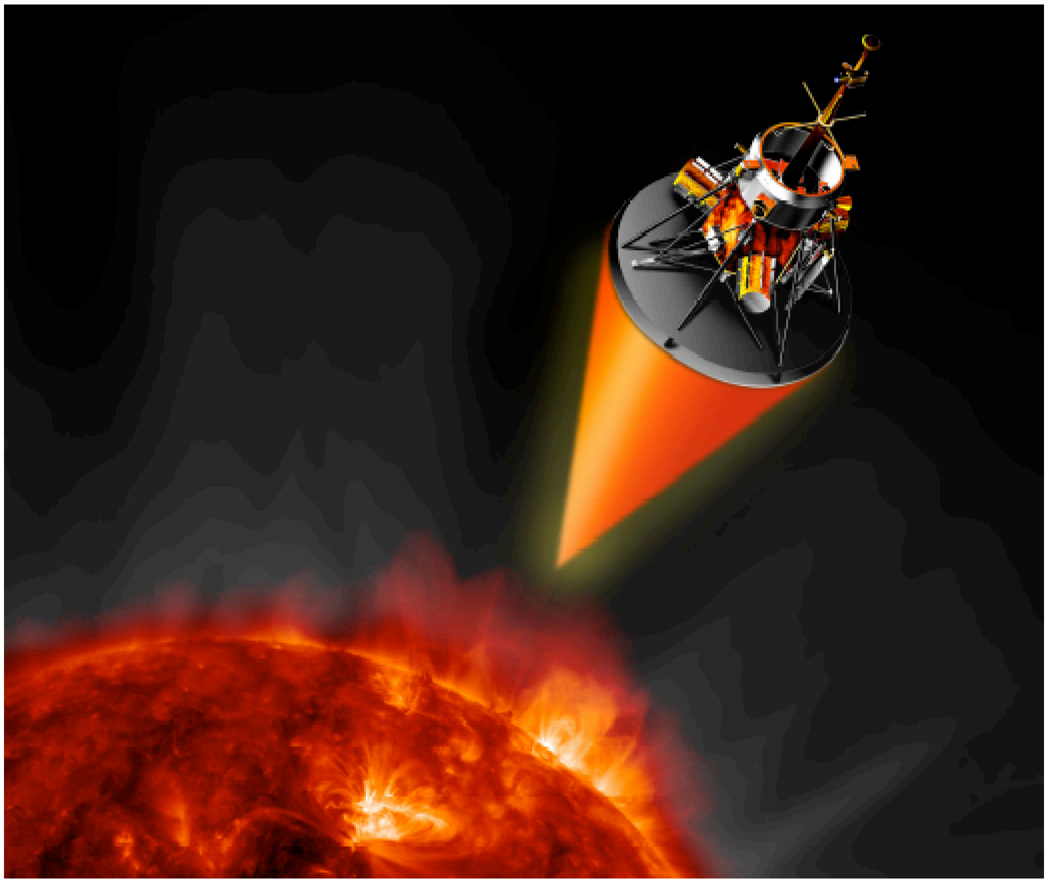


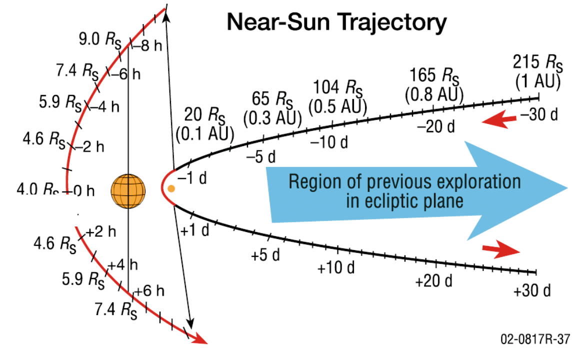
The Phases of Sentinels

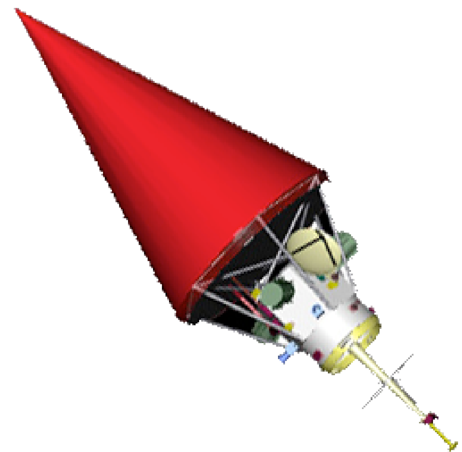


Report due in Spring of 2005

Our First Visit to a Star

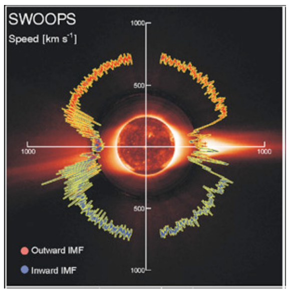


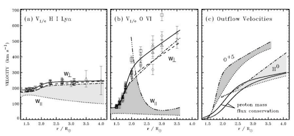


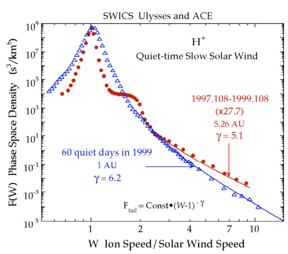


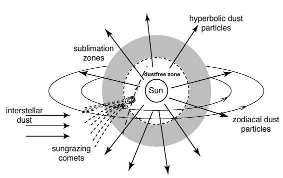
Report of the Solar Probe Science and Technology Definition Team

Science Objectives









- Determine the structure and dynamics of the magnetic fields at the sources of the fast and slow solar wind
- Trace the flow of energy that heats the corona and accelerates the solar wind
- Determine what mechanisms accelerate and transport energetic particles
- Explore dusty plasma phenomena in the near-Sun environment and their influence on the solar wind and energetic particle formation

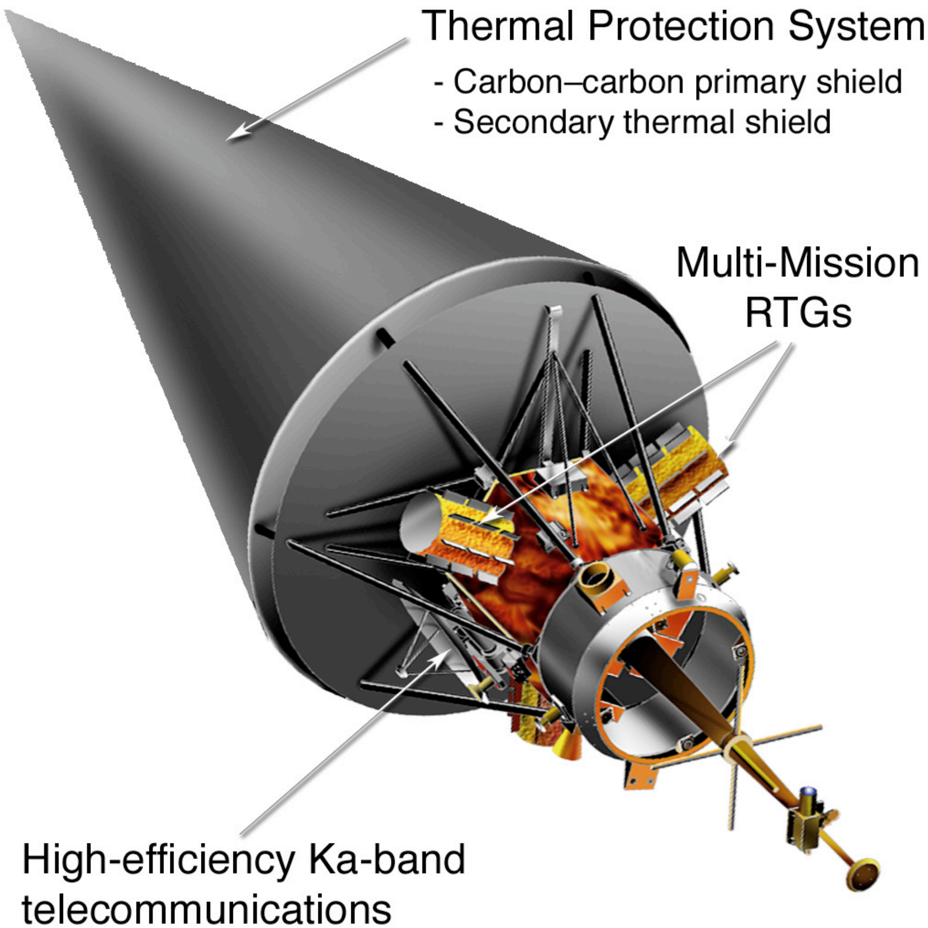
Science Implementation

- **In-Situ measurements**
  - Plasma, suprathermals, energetic particles, magnetic fields, waves and dust
- **On-board remote-sensing observations**
  - Polar source and hemispheric white light imaging provide context for in-situ measurements
- **Extensive remote-sensing from other assets**
- **Coordinated theory and modeling program**

Baseline Payload

- **In-Situ**
  - Fast Ion Analyzer (FIA)
  - Two Fast Electron Analyzers (FEAs)
  - Ion Composition Analyzer (ICA)
  - Energetic Particle Instrument (EPI)
  - Magnetometer (MAG)
  - Plasma Wave Instrument (PWI)
  - Neutron/Gamma-ray Spectrometer (NGS)
  - Coronal Dust Detector (CD)
- **Remote-Sensing**
  - Polar Source Region Imager (PSRI) – EUV & Magnetograph
  - White-light Hemispheric Imager (HI)
- **Serviced by Data Processing Unit (DPU) and Low-Voltage Power Supply (LVPS)**

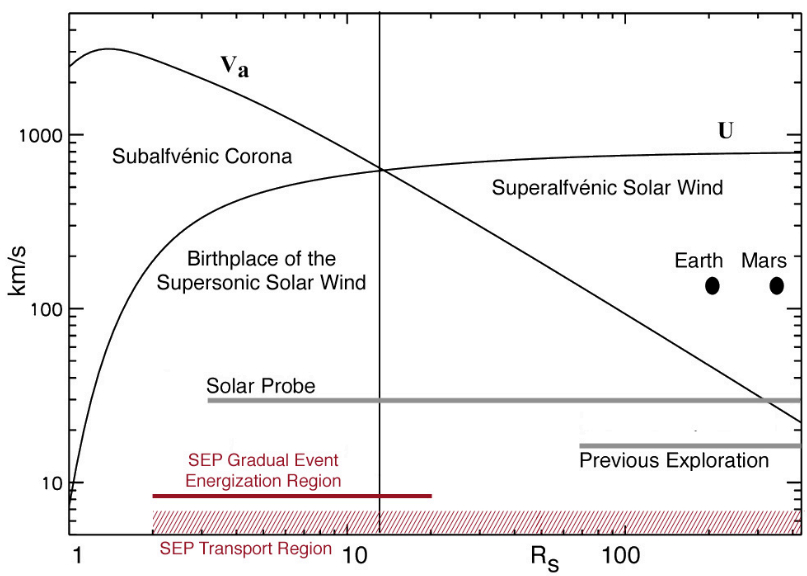
Spacecraft



- **3-axis stabilized S/C designed to survive and operate successfully in intense thermal environment**
- **Thermal Protection System (TPS)**
- **Three Multi-Mission Radioisotope Thermal-electric Generators (MMRTGs)**

Supports Human Exploration

- **Provides critical ground-truth data needed for development of predictive models that, combined with solar and heliospheric monitoring, will enable forecasting of space radiation environment in support of human exploration**



Model profiles of the solar wind speed (U) and the Alfvén wave speed (Va) with distance from the Sun. The vertical bar separtes 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 solar wind source region and to sample the region where gradual SEPS are energized

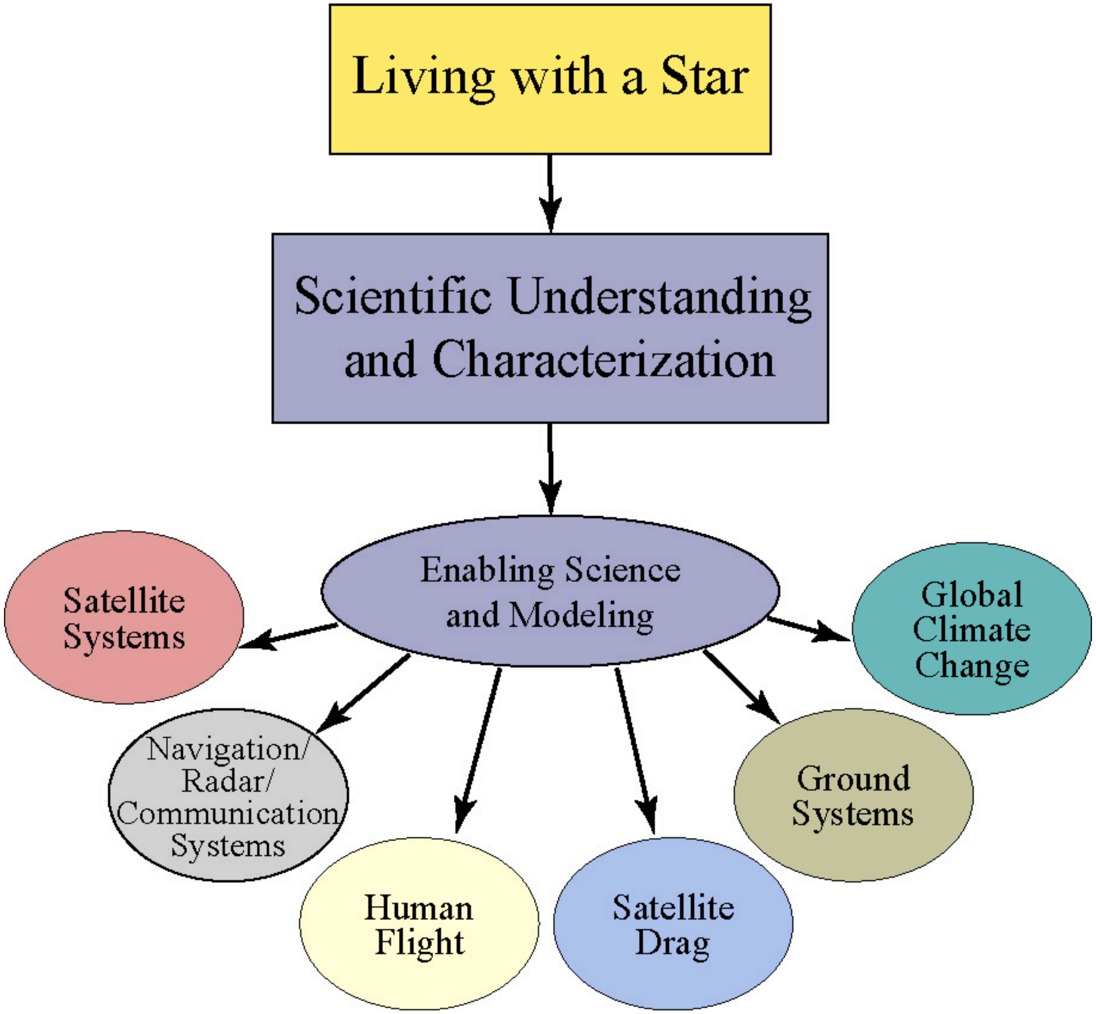
Summary and Conclusions

- **Exploration of one of last unexplored regions of solar system that is also relevant for human exploration**
- **Completed rigorous engineering study for mission**
  - Fully instrumented with *in situ* and appropriate remote sensing observations
  - Resolved broad range of technical trades including safety and risk
  - Identified lowest cost approaches
- **Complete program combining SP observations with other remote-sensing, theory, and modeling**
- **STDT report to be released soon (summer/fall)**
- **It is time to make the required *in situ* observations, in coordination with remote sensing, theory and modeling, to finally explore the near-Sun environs and understand coronal heating, solar wind acceleration, and much more!**

Science Application as the Focus

The primary goal of the LWS Program is to develop the understanding necessary to enable the U.S. to effectively address those aspects of the Connected Sun-Solar system that directly affect life and society.

- **Space Weather**
- **Space Climate**
- **Sun-Climate Connection**



Research Priorities Based on Report
Targeted Research and Technology Science Definition Team

Research Topics:

1.0 Effect of Solar Variability on Terrestrial Global Climate Change

1.1 Sun-Climate relationship
1.2 Stratospheric ozone change

2.0 Space Weather

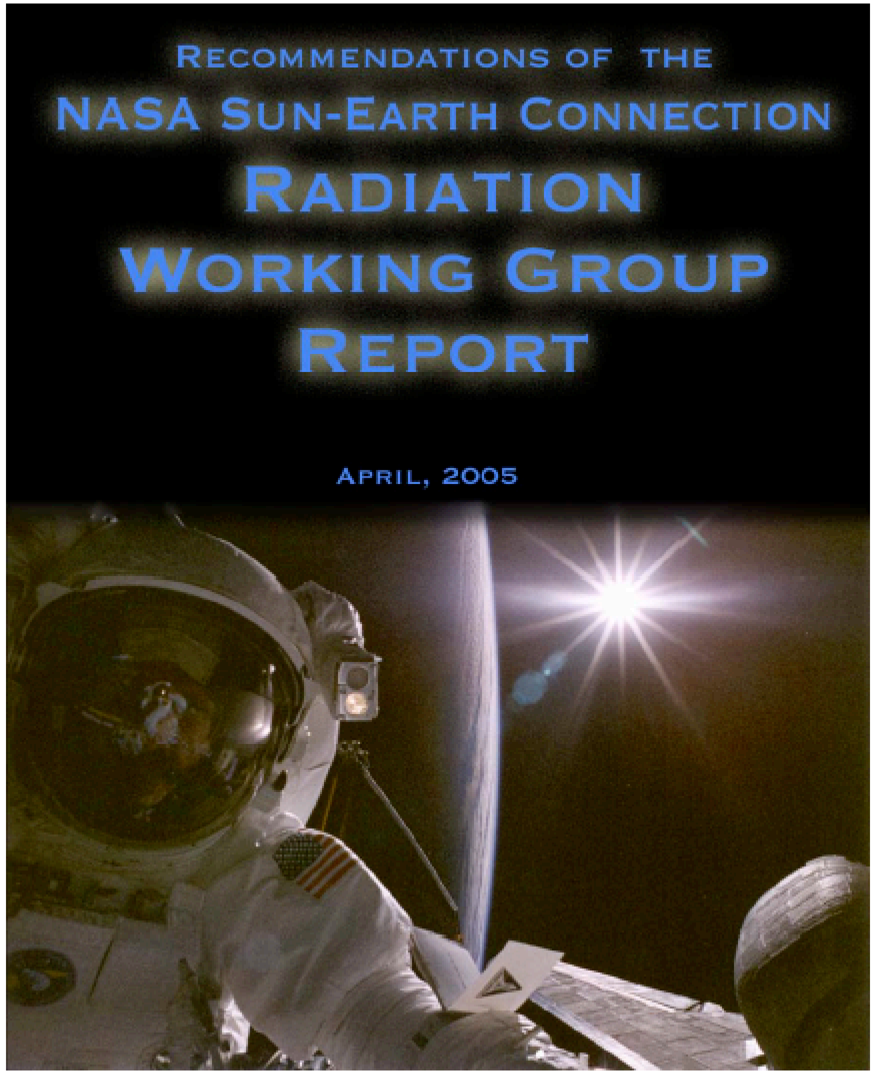
2.1 Background ionosphere
2.2 Ionospheric scintillations
2.3 Density and composition of the neutral thermosphere
2.4 Geomagnetically-induced currents
2.5 Energetic particle environment in the magnetosphere
2.6 Radiation associated with explosive events on the Sun
2.7 Radiation from Galactic Cosmic Rays*

LWS TR&T Update

- HQ used TR&T Steering Committee report to modify and focus 2005 NRA objectives
- Selected 50 proposals for a total of 6.6 M, one summer school and some workshops.
- Six focused topics selected with team leaders. SEP group will have their first meeting at SHINE.
- New focus topics for 2006 NRA. Please read the NRA carefully to note changes made to the program.
- In partnership with NSF there will be a new element in 2006 ROSES NRA to implement large-scale strategic capability. Announcement will be made in early August.
- 2nd TR&T Steering Committee report available on the web.

trt-lws.gsfc.nasa.gov

Task group report on radiation environment and exploration will be available in Spring 2005

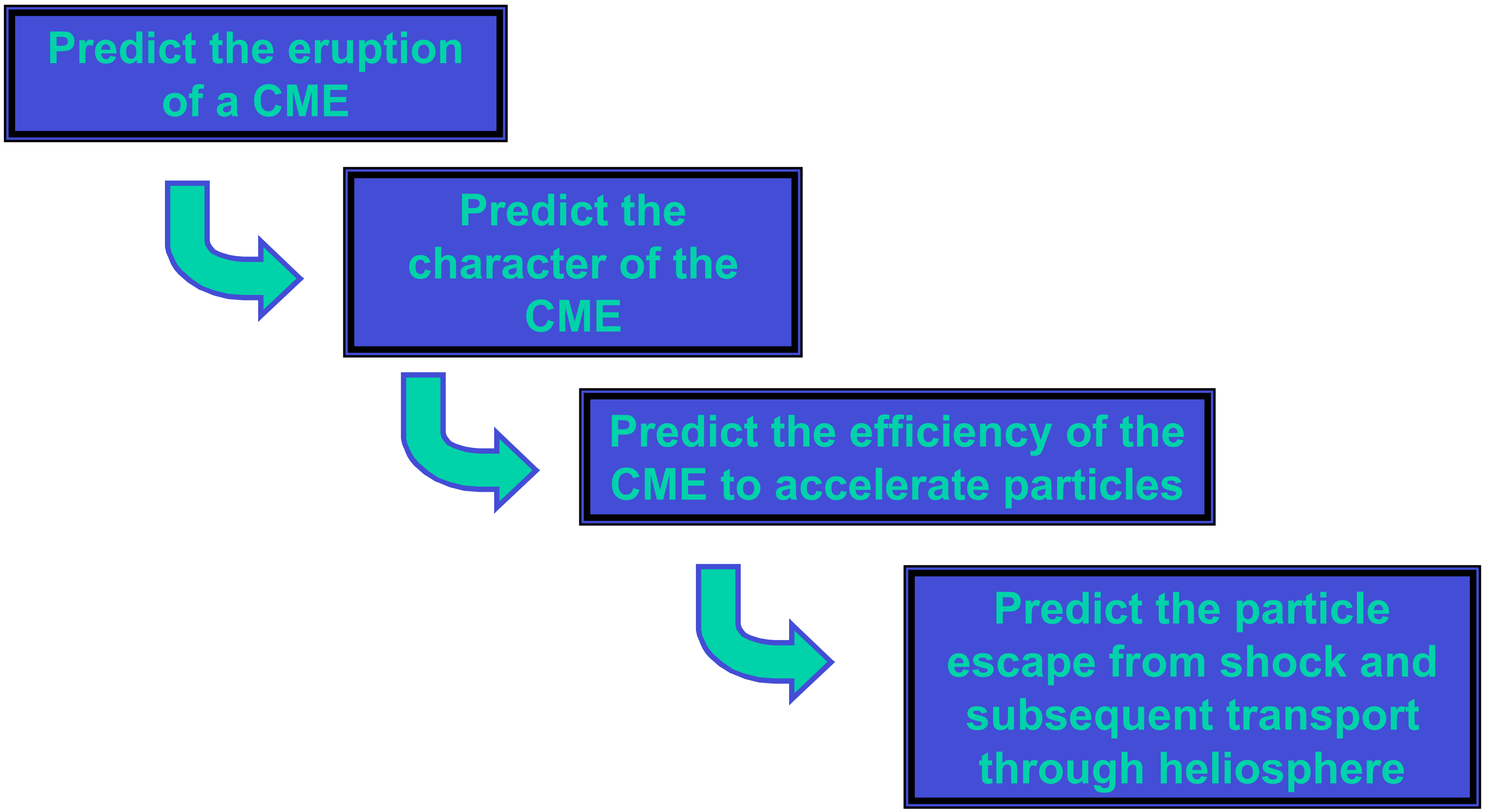


Executive summary is available at: lwsscience.gsfc.nasa.gov

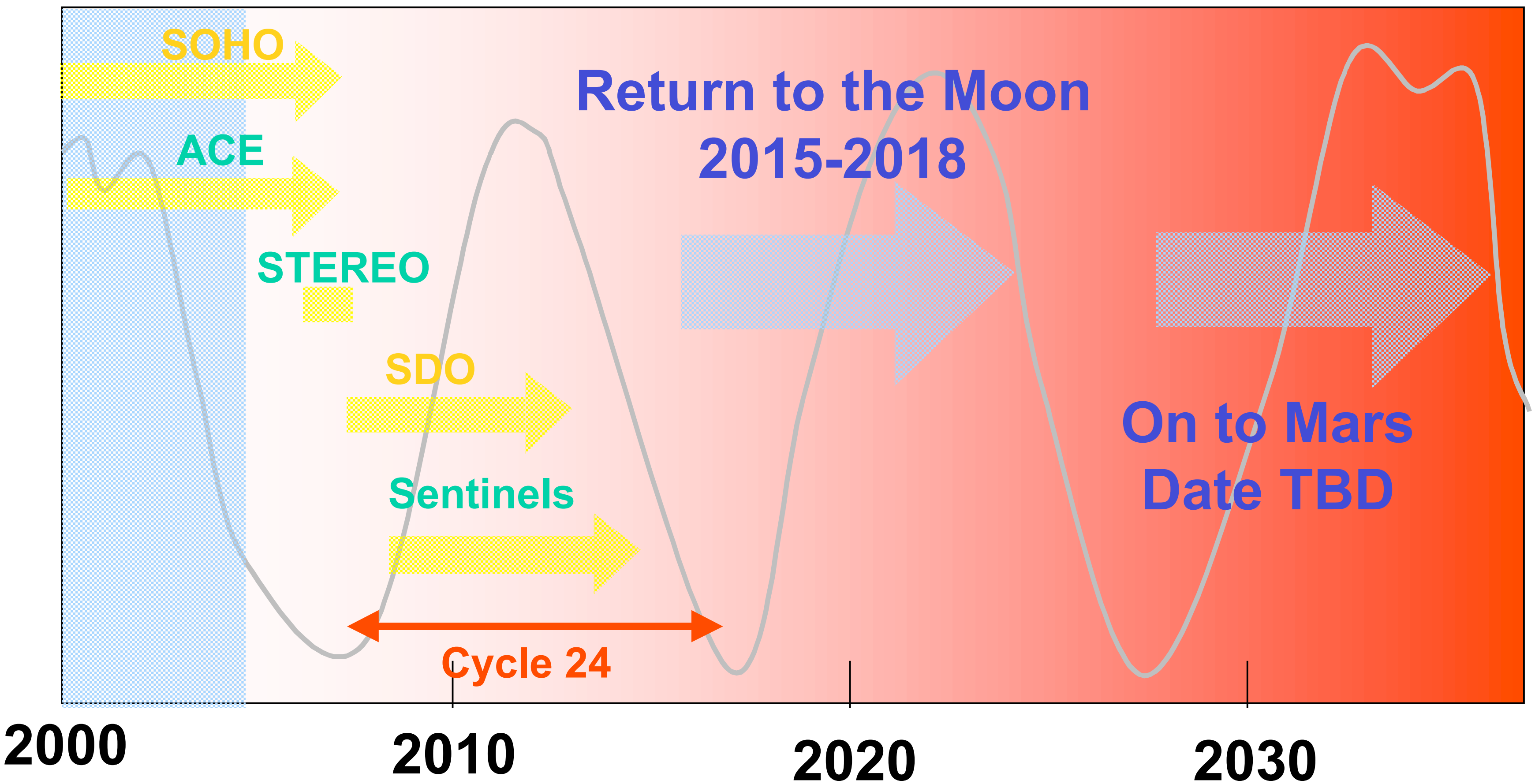
The Greatest Single Challenge to LWS is to Improve Our Ability to Forecast Solar Particle Events

- **While significantly lower in energy than the GCR, the proton flux of SPEs is orders of magnitude greater for hours to days**
- **Principle of ALARA requires that exposure to SPEs be minimized**
- **Potential to be caught away from shelter on the Lunar or Martian surface will impose operational rules that will limit flexibility and reduce efficiency**

Forecasting SPE is a Multidiscipline Challenge



Significant Events in the Moon, Mars, and Beyond Vision



Only One More Solar Cycle Left to Learn What We Must Learn

Solar Observing/Monitoring

Routine solar observation is the necessary first step to forecast and characterize of SPEs

Near-real-time observations of solar active regions and emerging Coronal Mass Ejections (CMEs) may provide data useful to forecast the progress of an on-going SPE over a period of hours to days

Additional progress in understanding the physics of CMEs may lead to a multiday forecast of the probability of an SPE

LWS Solar Dynamics Observatory and the Sun-Earth Connections STEREO Mission can build on the current suite of research spacecraft and ground-based facilities to select the appropriate operational instruments for solar monitoring

Heliospheric Observing/Monitoring

Heliospheric observations provide information necessary to model or monitor the propagation of solar energetic particles from the source to the astronauts

The data that may be necessary for SPE propagation models include

- **State of the ambient solar wind plasma**
- **Interplanetary magnetic field**
- **Local disturbances moving through the inner heliosphere**

LWS Sentinel Missions will provide experience and proof of concept from which we will be able to learn more about the underlying physics and select the appropriate operational instruments for solar monitoring

What We Must Know About Solar Particle Events to Reduce the Risk to Astronauts

- **Priority 1 Critical Question** ***What are the risks from SPE's and what is their impact on operations, EVAs and surface exploration?***

- **For astronaut radiation safety, the important SPE energy range is from 30 MeV up to 100-200 MeV**
  - **Spectral slope is very important**

- **SPE forecast goal according to findings of 1996 SPE risk mitigation workshop is**
  - **10 to 12 hour forecast prior to a likely event**
  - **6 to 8 hour forecast of magnitude and spectral slope after event on-set**
  - **3 to 4 hour rolling forecast as SPE progresses**
- **Realistic near-term challenge:**
  - **8 hour rolling forecast as SPE progresses**
  - **Predict, at event on-set, the time of arrival and magnitude of shock-enhanced peak**
  - **Reliably forecast 3 to 7 day "all clear"**

How Can LWS Science Support the Moon, Mars, and Beyond Vision

Better understanding of Solar Dynamics

- Improved Forecasting of Coronal Mass Ejections
  - Improved forecasting of SPEs

Better understanding of Heliospheric Dynamics

- Improved Forecasting of Solar Wind profiles
  - Improved forecasting of SPEs

Better understanding of SPEs

- Improved design of habitats and shelters
- Higher confidence in mission planning

Better forecasts of SPE evolution after on-set

- Higher confidence in exposure forecast
  - Implementation of more flexible flight rules
- Reduced period of uncertainty
  - Greater EVA scheduling flexibility
  - Less down-time of susceptible electronics

Prediction of SPEs before on-set

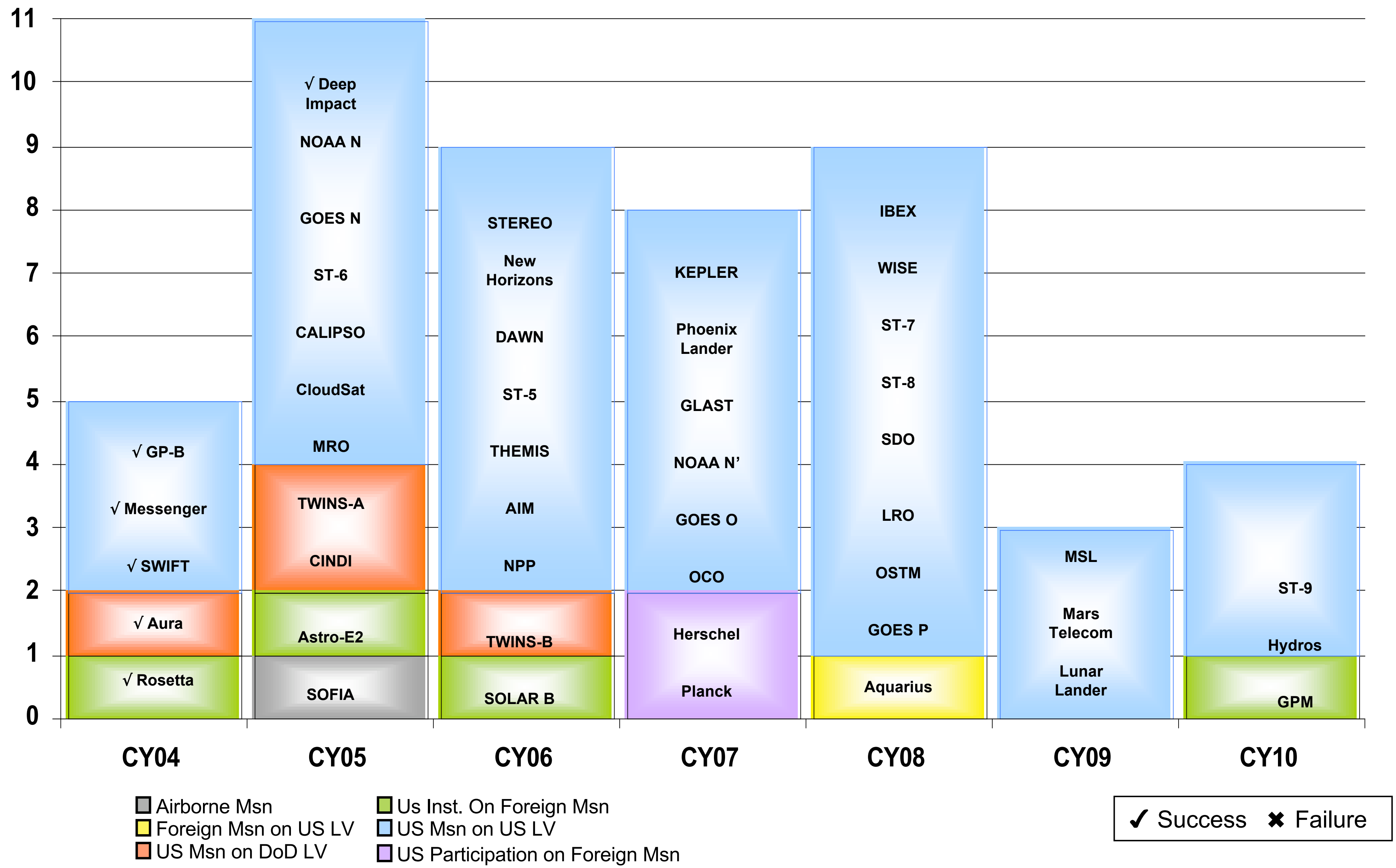
- Higher confidence in exposure forecast
  - Greater mission schedule assurance
  - Less down-time of susceptible electronics

Prediction of "all clear" periods

- Higher confidence in exposure forecast
  - Greater EVA scheduling flexibility
  - Greater mission schedule assurance

Improved Safety and Enhanced Mission Assurance

NASA Science Launches (CY04-CY10)

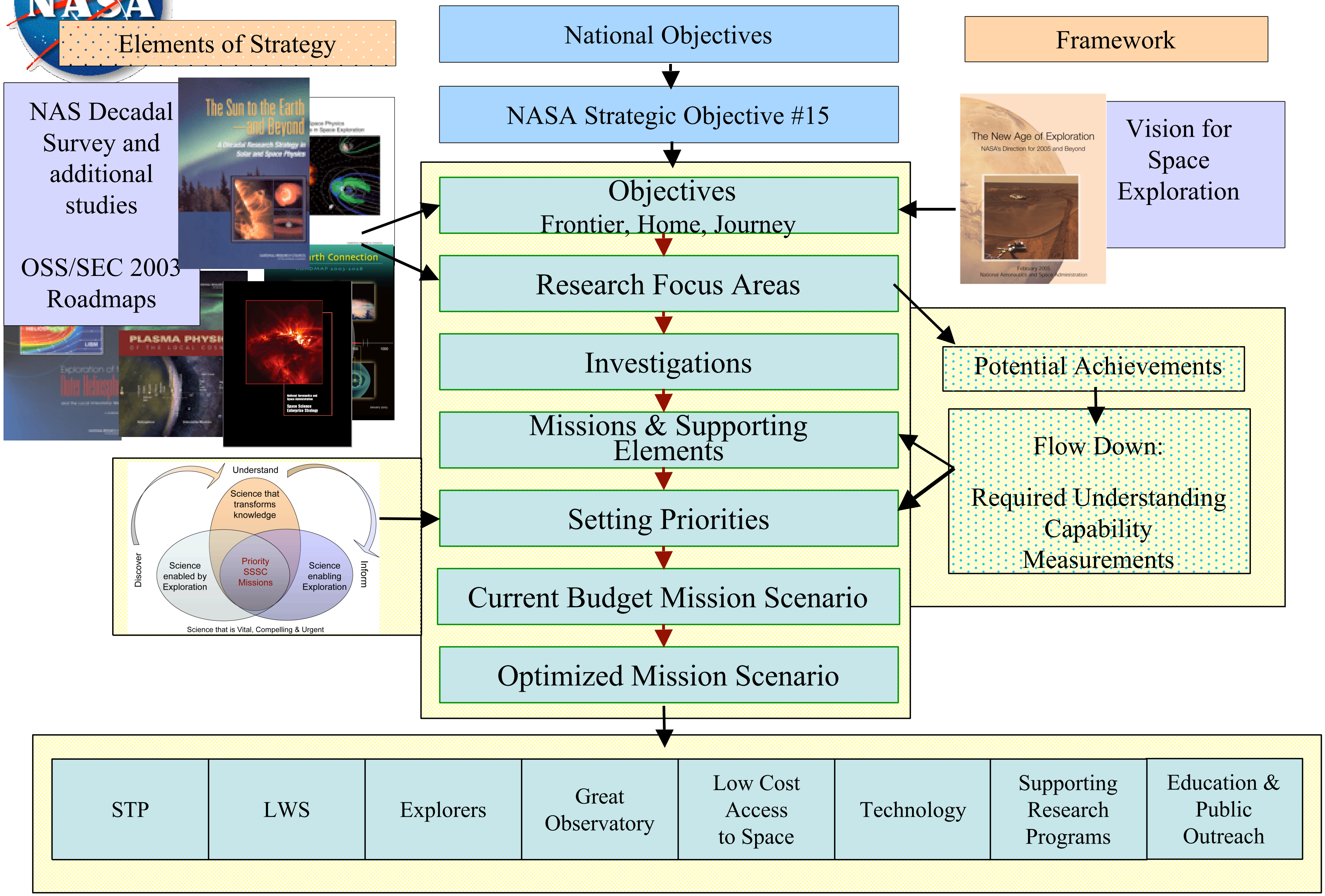


Sun-Solar System Connection Roadmap: Knowledge for Exploration

Explore the Sun-Earth system to understand the

- *Sun and its effects on*
- *Earth,*
- *the solar system,*
- *the space environmental conditions that will be experienced by human explorers, and*
- *demonstrate technologies that can improve future operational systems*

Sun Solar System Connection Roadmap Development



SSSC Roadmap Strategic Elements

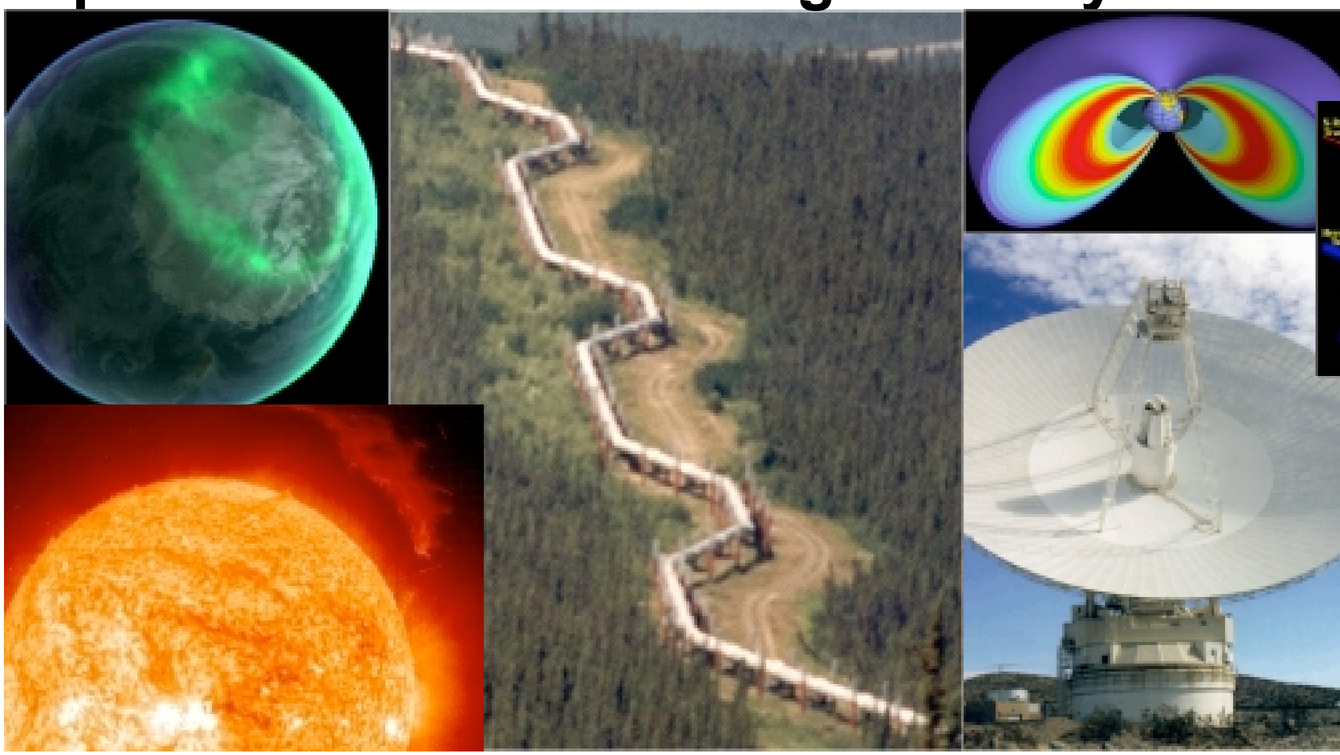
STP	LWS	Explorers	Great Observatory	Low Cost Access to Space	Technology	Supporting Research Programs	Education & Public Outreach

- Implement the program currently underway
- Use strategic lines to address key problems
- Emphasize need for Explorer & LCAS programs
- Evolve the SSSC Great Observatory
- Consider new initiatives for new objectives and flagship missions
- Develop analysis, modelling & forecast tools
- Focus technology development
- Maintain human resources
- Strengthen & focus E/PO efforts

LCAS = Low cost access to space
Sounding rockets and balloons

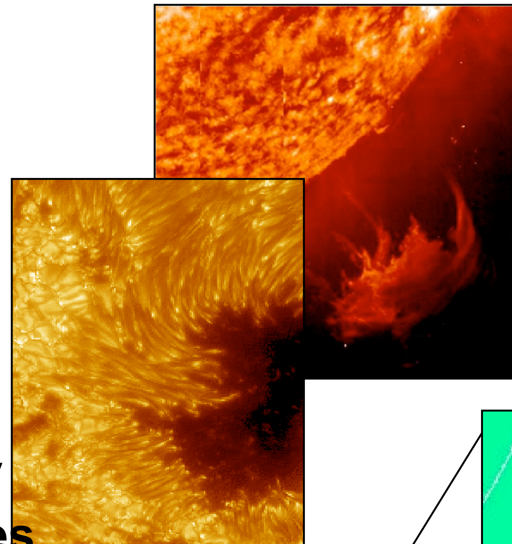
External and Internal Factors

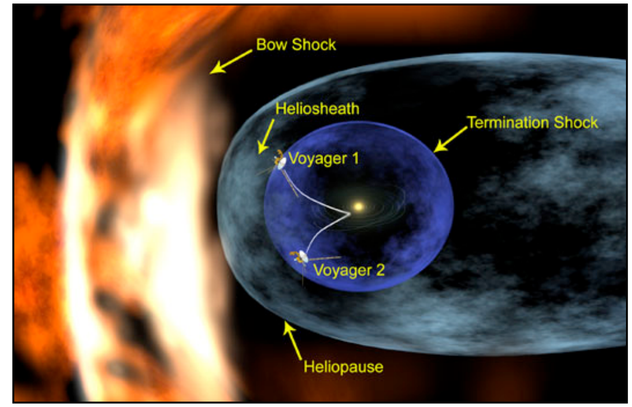
- Our society needs space weather knowledge to function efficiently
- Human beings require space weather predictions to work safely and productively in space
- **We are poised to provide knowledge and predictive understanding of the system**

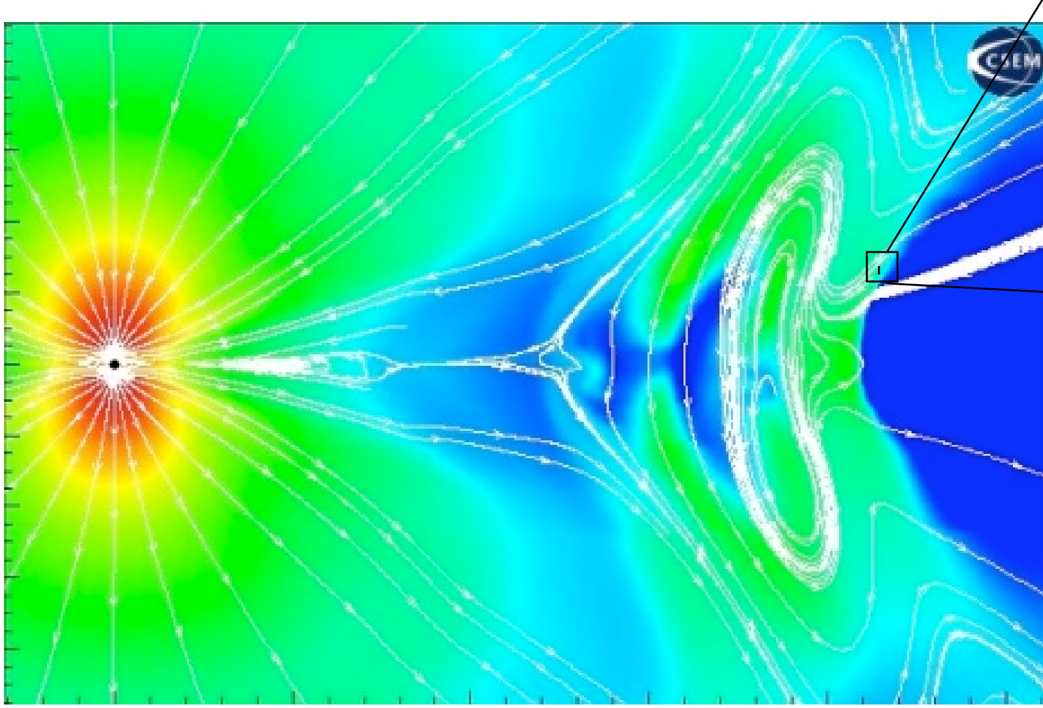


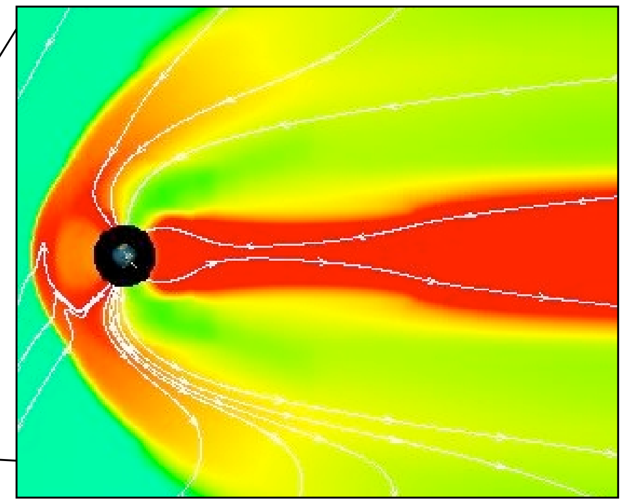
Nature of the Challenge

- A quantitative, predictive understanding of a complex "system of systems"
- Microphysical processes regulate global & interplanetary structures
- Multi-constituent plasmas and complex photochemistry
- Non-linear dynamic responses





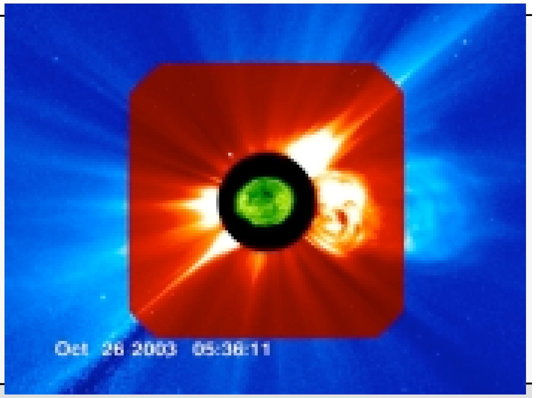




- Integration and synthesis of multi-point observations
- Data assimilative models & theory
- Interdisciplinary communities and tools

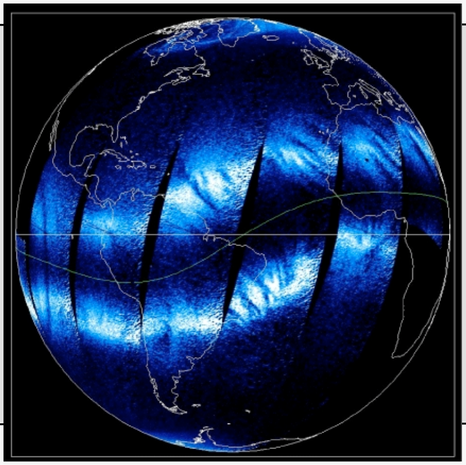
Sun-Solar System Connection Objectives

Agency Strategic Objective: Explore the Sun-Earth system to understand the Sun and its effects on the Earth, the solar system, and the space environmental conditions that will be experienced by human explorers, and demonstrate technologies that can improve future operational systems



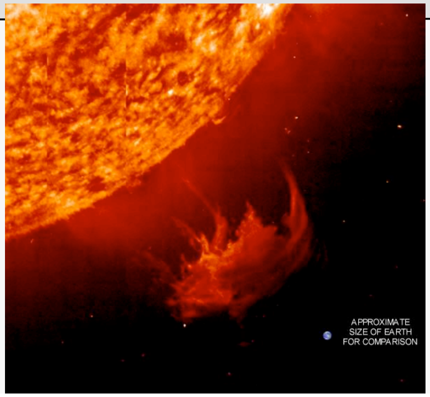
Open the Frontier to Space Environment Prediction

Understand the fundamental physical processes of the space environment – from the Sun to Earth, to other planets, and beyond to the interstellar medium



Understand the Nature of Our Home in Space

Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields



Safeguard Our Outward Journey

Maximize the safety and productivity of human and robotic explorers by developing the capability to predict the extreme and dynamic conditions in space

Sun-Solar System Mission Recommendations

Phase 1	Phase 2	Phase 3
Sun-Earth-Moon System	Sun - Terrestrial Planets	Sun-Solar System
Characterization of System	**Modeling of System Elements**	**System Forecasting**

Future Mission Recommendations

Solar:
SDO, Solar-B

CMEs & Heliosphere:
SDO, STEREO, IHSentinels, Solar Sail Demo

Radiation:
RBSP, IHSentinels

Geospace Impacts:
MMS, RBSP, THEMIS, ITSP/ITImager

Climate Impacts:
SDO, AIM

Moon, Mars Awareness:
LRO, MSL, ADAM

Interstellar Boundary: IBEX

Inner Boundary:
Solar Probe

Solar Processes:
Solar Orbiter

Geospace System Impacts:
GEC, GEMINI, MagCon

Climate Impacts:
L1 Earth-Sun, SECEP

Mars Atmosphere:
Mars Atmospheric Reconnaissance Satellite

Space Weather Stations:
Heliostorm

Solar System Space Weather:
SEPM, SWBuoys

Planetary Orbiters:
Pluto/Kuiper, JPO/JUNO

Solar Processes:
MTRAP, RAM

Heliospheric Structure & Disturbances:
HIGO, SPI/Telemachus

Geospace System Impacts:
AAMP, IMC, ITMC, ITMW

Solar System Space Weather:
DBC, FS/Shields

Planetary Orbiters:
IoE, SCOPE, NO, TE, VAP

Interstellar Medium:
Interstellar Probe

Habitability:
Stellar Imager

Already In Development or Formulation
Explorer
Partnership
Recommended

Characterize Environments

Model Systems

Forecast Hazards

2005 2015 2025 2035

Distributed small assets that form an evolving sensor web to sample the vast connection from the Sun to planetary environments and beyond

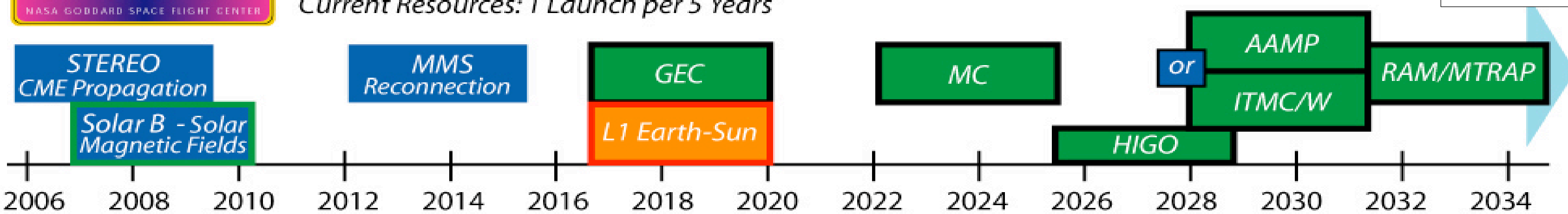
Sun-Solar System Mission Recommendations

Current Constrained Budget Lines

- In Development
- Recommended
- New Initiative
- Partnership

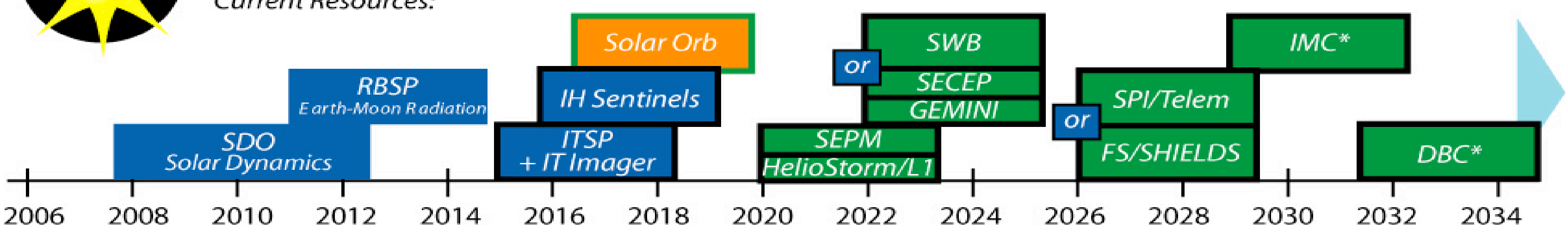
Low- to mid-cost missions strategically planned to solve fundamental questions in space physics that have broad impact

Current Resources: 1 Launch per 5 Years

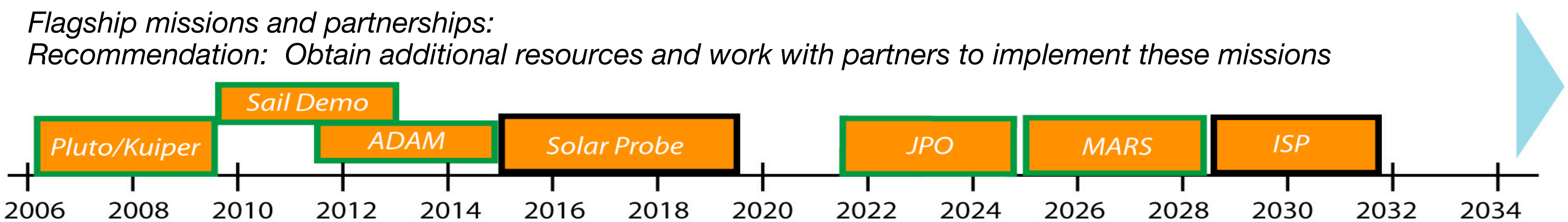


Low- to mid-cost missions strategically planned to understand the linked physical systems that affect life and society

Current Resources:



Flagship missions and partnerships:
Recommendation: Obtain additional resources and work with partners to implement these missions



Optimized program will require more resources …

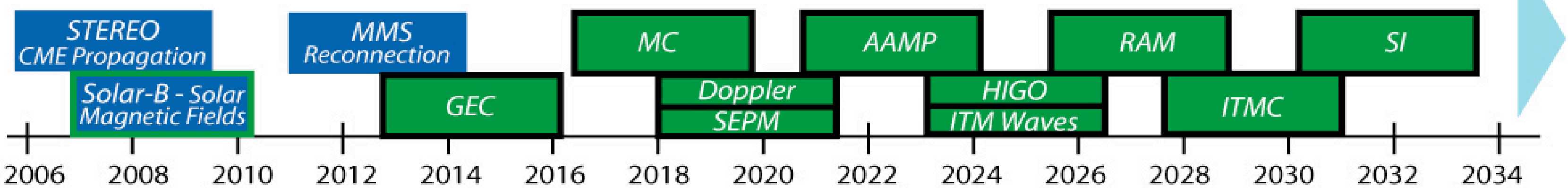
Sun-Solar System Mission Recommendations

Optimized Program

- In Development
- Recommended
- New Initiative
- Partnership

Low- to mid-cost missions strategically planned to solve fundamental questions in space physics that have broad impact

Recommendation: 1 Launch per 2-3 Years



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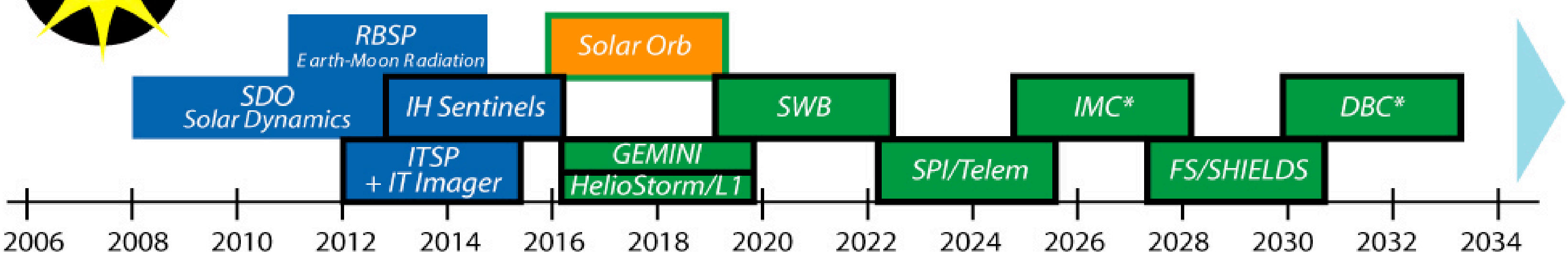

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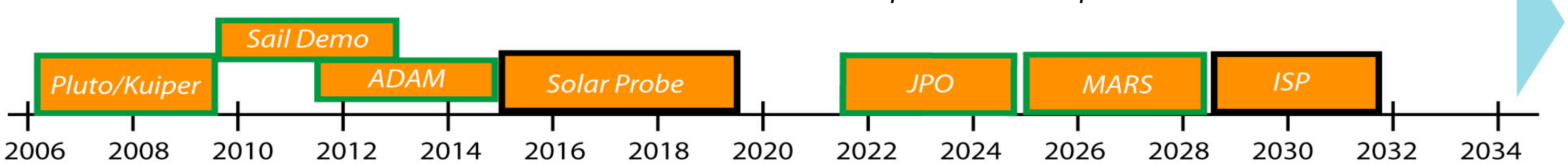
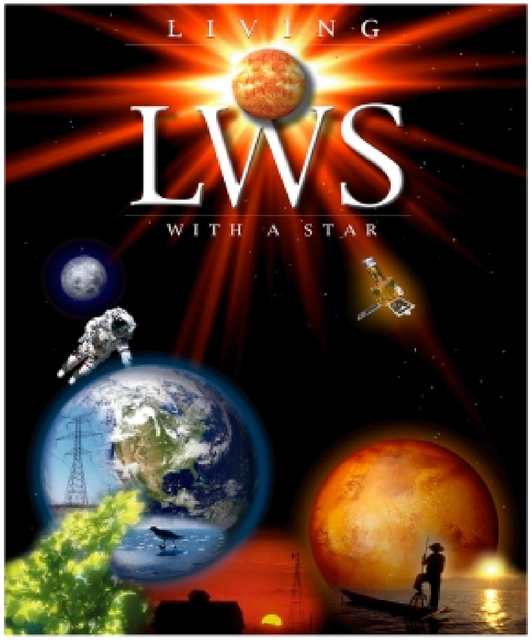


Human Capital and Infrastructure

So that we may develop/maintain U.S. space plasma and space weather prediction / mitigation expertise, it is vital to provide a broad range of competed funding opportunities for the scientific community



Science Investigations:
- Solar Terrestrial Probes (STP)
- Living with a Star (LWS)
- Explorer Program
- Discovery Program
- Sun-Solar System Great Observatory

Research Programs:
- Research and Analysis Grants
- Guest Investigator
- Theory Program
- Targeted Research & Technology
- Project Columbia

Enabling Capabilities:
Sounding Rocket/Balloon Program
Space Environment Testbeds (SET)
Advanced Technology Program
Education and Public Outreach

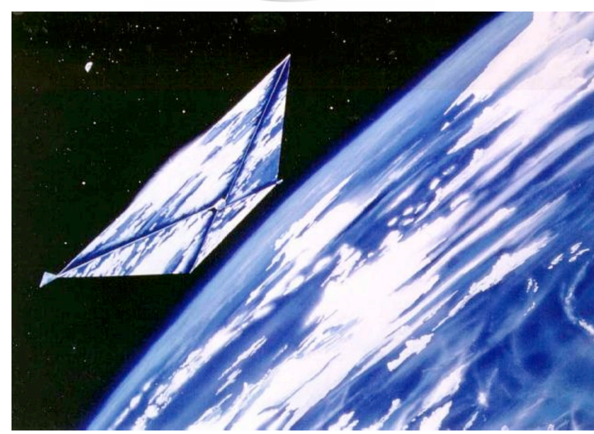
Develop IT, Computing, Modeling and Analysis Infrastructure
- Virtual Observatories

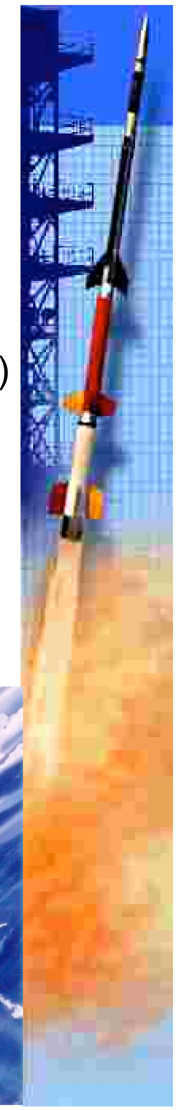
Low Cost Access to Space
- Science, Training, & Instrument Development

E/PO to Attract Workers to Earth-Sun Systems Science

Maintain Multiple Hardware & Modeling Groups
- Strengthen University Involvement in Space Hardware Development
- Facilitate and Exploit Partnerships
- Interagency and International

Upgrade DSN to Collect More Data Throughout the Solar System





External Partnerships

Partnership Forums:

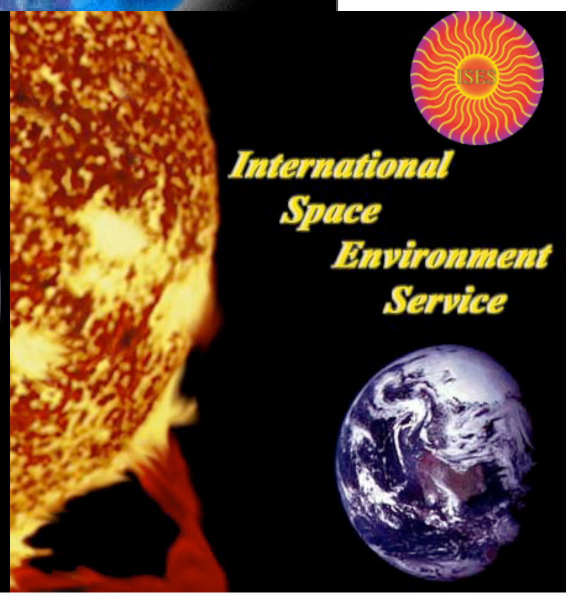
- International Living With a Star
- International Heliophysical Year
- Enabling Space Weather Predictions for the International Space Environment Service
- National Space Weather Program

Current Partnership Missions:

- Ulysses (ESA)
- SoHO (ESA)
- Cluster (ESA)
- Geotail (JAXA)
- Solar-B (JAXA)

Future Partnership Missions:

- Solar Orbiter (ESA)



National Partners:

- National Science Foundation
- National Oceanic and Atmospheric Administration
- Department of Commerce
- Department of Defense
- Department of Transportation
- Department of Energy
- Department of the Interior

END

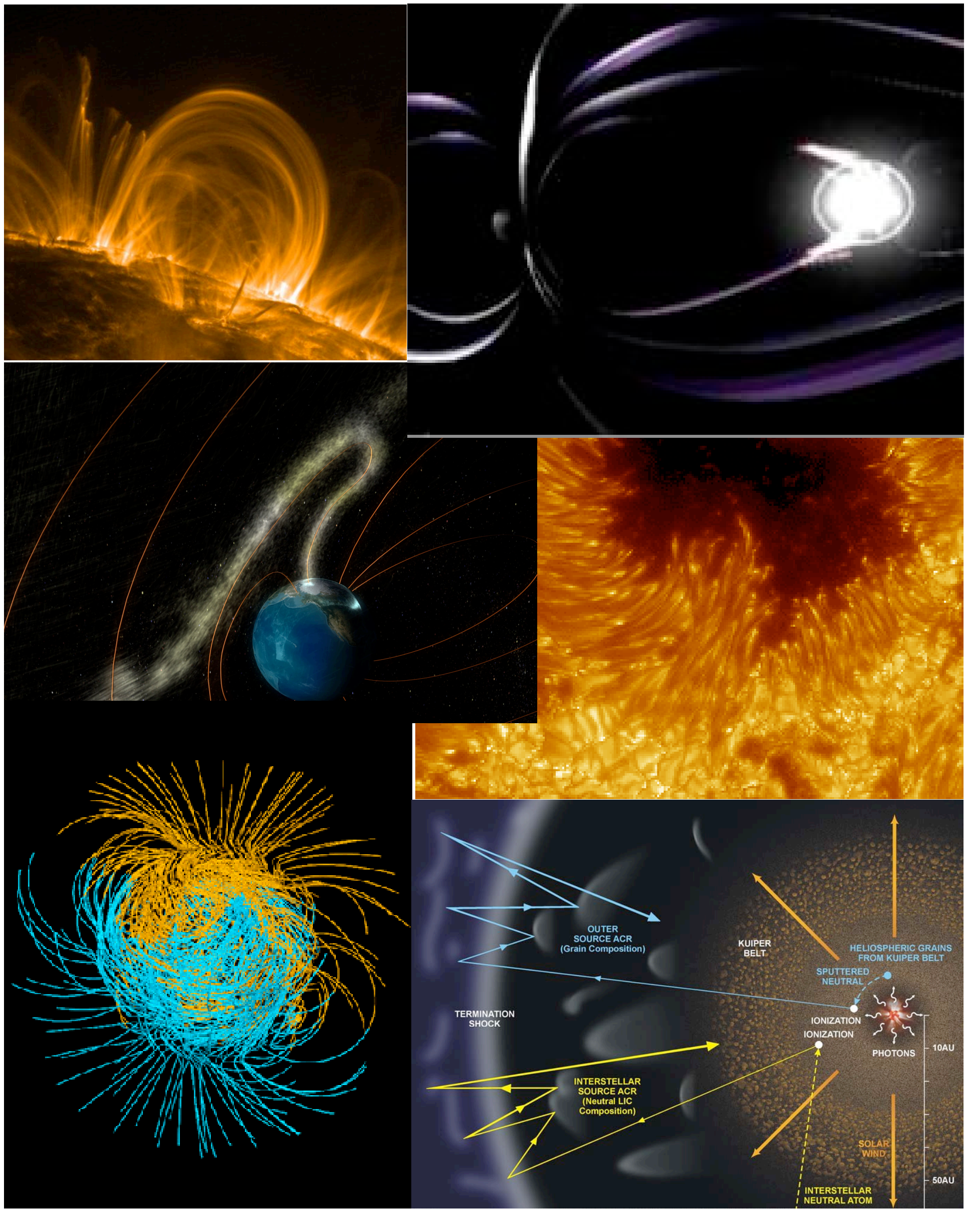
Open the Frontier to Space Weather Prediction

1) Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, and geospace storms

2) Understand the plasma processes that accelerate and transport particles throughout the solar system

3) Understand how nonlinear interactions transfer energy and momentum within planetary upper atmospheres.

4) Determine how solar, stellar, and planetary magnetic dynamos are created and why they vary.



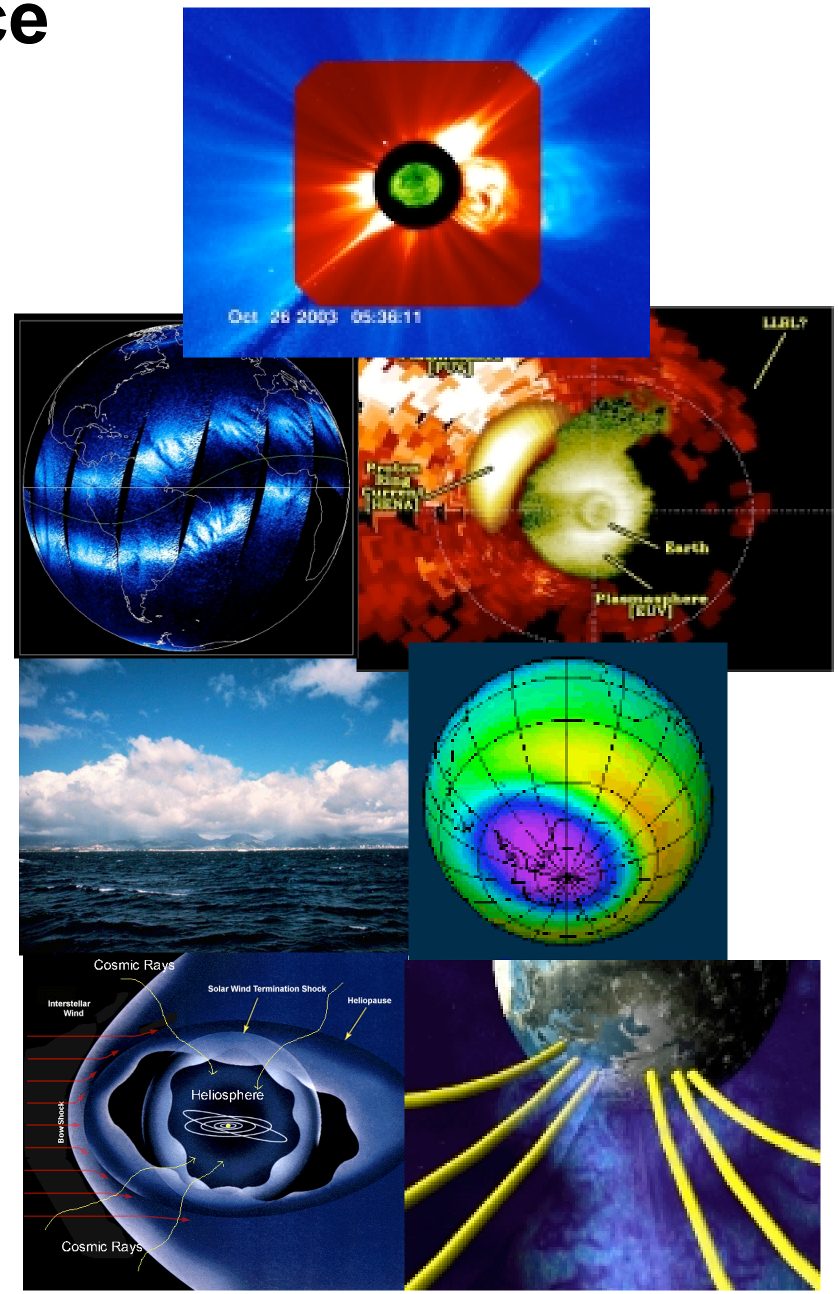
Understand the Nature of our Home in Space

1) Understand the causes and subsequent evolution of activity that affects Earth's space climate and environment

2) Understand changes in the Earth's magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects

3) Understand the Sun's role as an energy source to the Earth's atmosphere, particularly the role of solar variability in driving climate change

4) Apply our understanding of space plasma physics to the role of stellar activity and magnetic shielding in planetary system evolution and habitability



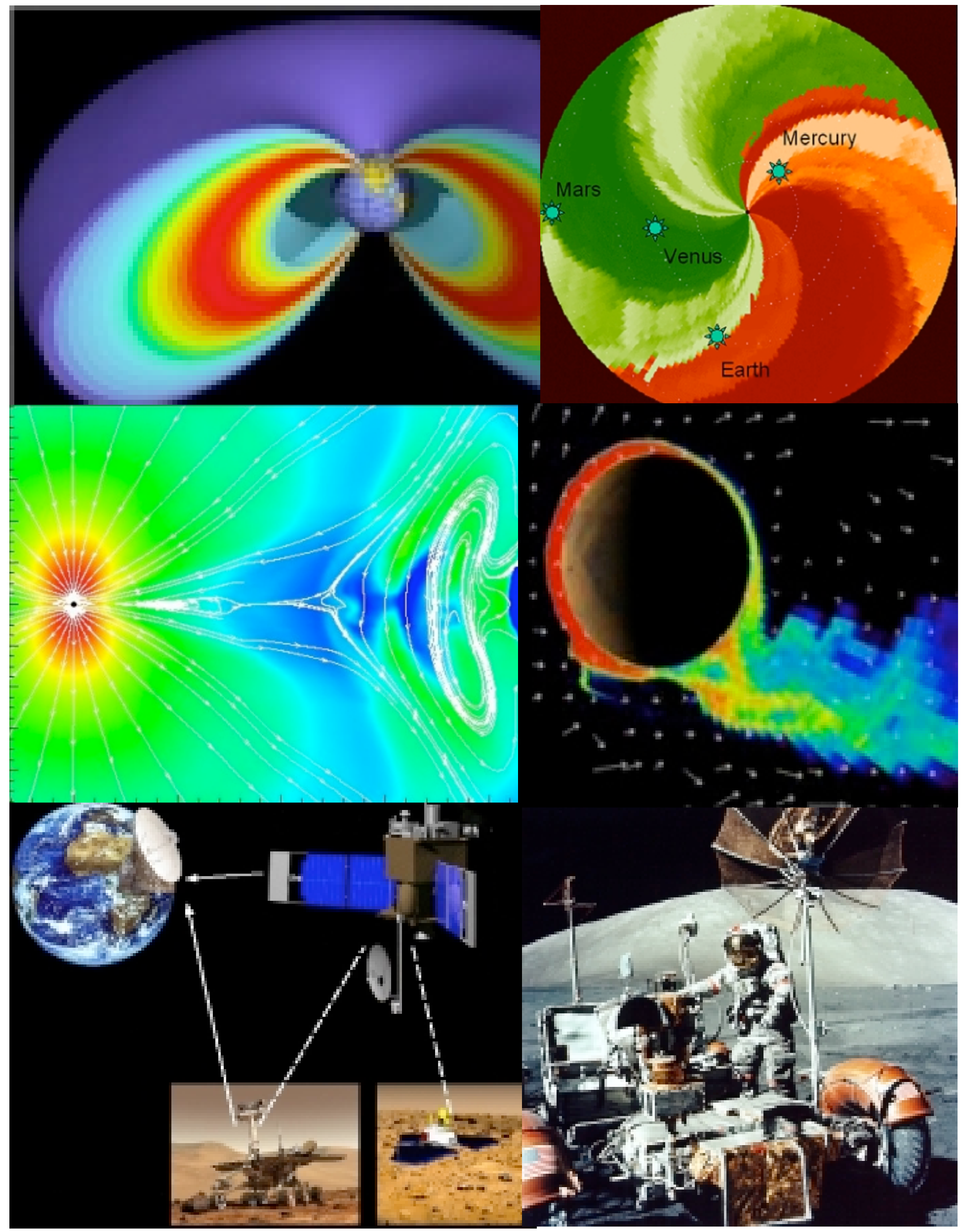
Safeguard our Outward Journey

1) Characterize the variability and extremes of the space environments that will be encountered by human and robotic explorers

2) Develop the capability to predict the origin of solar activity and disturbances associated with potentially hazardous space weather.

3) Develop the capability to predict the acceleration and propagation of energetic particles in order to enable safe travel for human and robotic explorers

4) Understand how space weather affects planetary environments to minimize risk in exploration activities.



The Plan Conforms to the Solar and Space Physics Decadal Survey in Detail

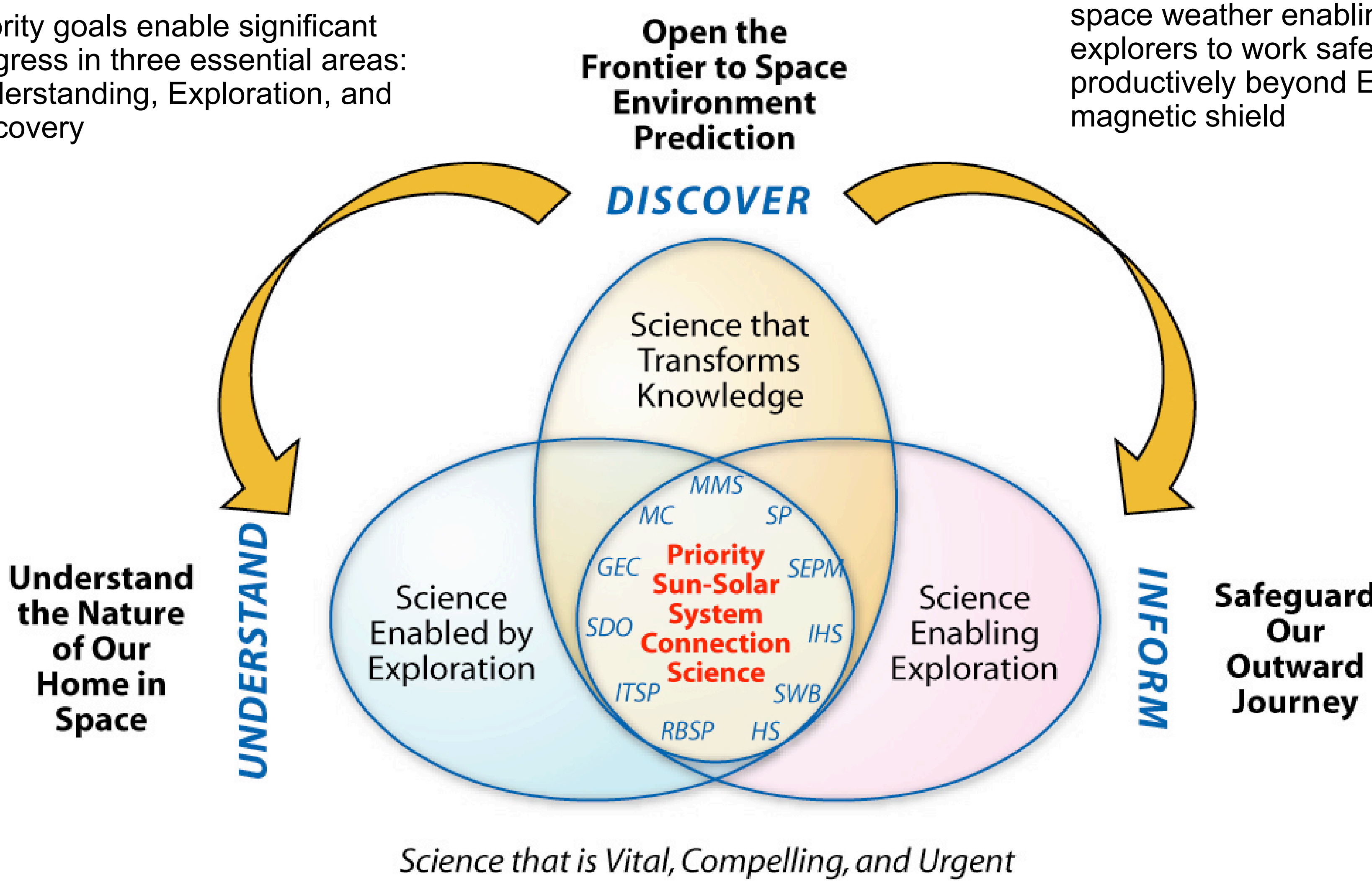
Comparison of the 2005 SSSC Strategic Roadmap Primary Science Objectives Research Focus Areas the 2002 Decadal Survey Science Challenges

2005 SSSC Strategic Roadmap Primary Science Objectives & Research Focus Areas		2002 Solar and Space Physics Decadal Survey Science Challenges: 1. Understanding the structure and dynamics of the Sun's interior, the generation of solar magnetic fields, the origin of solar cycle, the causes of solar activity, and the structure and dynamics of the corona	2. Understanding heliospheric structure, the distribution of magnetic fields and matter throughout the solar system, and the interaction of the solar atmosphere with the local interstellar medium	3. Understanding the space environments of Earth and other solar system bodies and their dynamical response to external and internal influences	4. Understanding the basic physical principles manifest to processes observed in solar and space plasmas	5. Developing near-real-time predictive capability for understanding and quantifying the impact on human activities of dynamical processes at the Sun, in the interplanetary medium, and in the Earth's magnetosphere
Objective F: Open the Frontier to Space Weather Prediction *Understand the fundamental physical processes of the space environment - from the Sun to Earth, to other planets, and beyond to the interstellar medium*						
RFA F1: Understand magnetic reconnection as revealed in solar flares, coronal mass ejections, and geospace storms	F1	x		x	x	
Research Focus Area F2: Understand the plasmas processes that accelerate and transport particles	F2	x			x	
RFA F3: Understand the role of plasmas and neutral interactions in nonlinear coupling of regions throughout the solar system	F3	x	x	x	x	
RFA F4: Understand the creation and variability of magnetic dynamos and how they drive the dynamics of solar, planetary and stellar environments	F4	x	x		x	
Objective H: Understand the Nature of Our Home in Space *Understand how human society, technological systems, and the habitability of planets are affected by solar variability and planetary magnetic fields*						
RFA H1: Understand the causes and subsequent evolution of solar activity that affects Earth's space climate and environment	H1	x		x	x	x
RFA H2: Determine changes in the Earth's magnetosphere, ionosphere, and upper atmosphere to enable specification, prediction, and mitigation of their effects	H2			x	x	x
RFA H3: Understand the role of the Sun as an energy source to Earth's atmosphere, and in particular the role of solar variability in driving atmospheric and climate change	H3	x				x
RFA H4: Apply our understanding of space plasmas physics to the role of stellar activity and magnetic shielding in planetary system evolution and habitability	H4	x	x	x	x	
Objective J: Safeguarding our Outward Journey *Maximize the safety and productivity of human and robotic explorers by developing the capability to predict the extreme and dynamic conditions in space*						
RFA J1: Characterize the variability, extremes, and boundary conditions of the space environments that will be encountered by human and robotic explorers	J1			x		x
RFA J2: Develop the capability to predict the origin and onset of solar activity and disturbances associated with potentially hazardous space weather	J2	x				x
RFA J3: Develop the capability to predict the propagation and evolution of space weather disturbances to enable safe travel for human and robotic explorers	J3		x			x
RFA J4: Understand how space weather affects planetary environments to minimize risk in exploration activities	J4		x	x		x

Approach to Identify Priority Science Targets

- Predictive capability for safe and productive exploration requires full understanding of a complex system of disparate systems
- Priority goals enable significant progress in three essential areas: Understanding, Exploration, and Discovery

- For example, discovery of near-Sun processes by Solar Probe provides transformational knowledge of the source of space weather enabling explorers to work safely and productively beyond Earth's magnetic shield



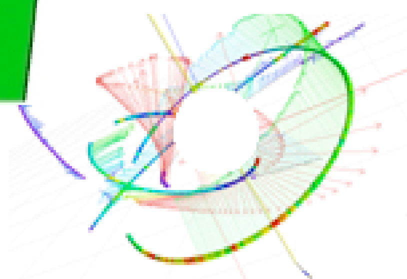
Program Implementation

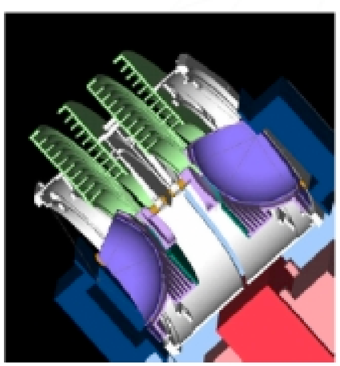
- The plan is designed to be *robust* - sufficiently flexible to facilitate adjustments as new knowledge is acquired, new discoveries are made, and transformational technologies are developed
- A “learn as you go” approach provides key decision points between development phases
- The development phases support similar program elements of the human flight Exploration Initiatives, with development phase (n-1) for SSSC informing development phase (n) for human exploration. Thus, for example, accomplishments of SSSC Phase 2 will inform human exploration Spiral 3
- First SSSC development phase is already underway, utilizing current program assets and near-term launches
- Subsequent development phases will develop the new knowledge base, new understanding, and the new predictive capability that will enable safe and productive exploration activities

2005 New/Updated Mission Studies

Mission Studies	Study Engineers	Study Scientists	Study Scientists
Heliostorm	**J. Daughters/JPL**	**T. VanSant/GSFC**	**St. Cyr/GSFC**
Mars Dynamics	**J. Chase/JPL**	**J. Forbes/CUB**	**J. Russell/UVA**
Mars Aeronomy	**J. Ayon/JPL**	**J. Slavin/GSFC**	**M. Liemohn/UM**
SIRA	**R. Howard/GSFC**	**N. Gopalswamy/GSFC**	**R. Macdowell/GSFC**
Doppler	**P. Cline/GSFC**	**D. Hassler/SwRI**	**P. Liewer/JPL**
SW Buoys	**R. Muller/QSS**	**E. Roelof/APL**	**N. Murphy/JPL**
Space Phys. Pkg.	**M. Johnson/GSFC**	**T. Moore/GSFC**	**C. Kletzing/UI**
ITM Waves	**R. Muller/QSS**	**J. Forbes/CUB**	**D. Fritts/CRA**
SEPP	**J. Daughters/JPL**	**L. Strachan/SAO**	**R. Lin/UCB**
MiLiMI	**P. Cline/GSFC**	**E. Roelof/APL**	**M. Liemohn/UM**
AMS	**R. Howard/GSFC**	**C. Cattell/UMN**	**C. Kletzing/UI**
1AU Observatory	**J. Daughters/JPL**	**P. Liewer/JPL**	**N. Gopalswamy/GSFC**

Technology Development





- **Answering our science questions will sometimes require measurements at unique vantage points, within and outside the solar system**
  - Cost-effective, high-ΔV propulsion and deep space power
    - CRM-1: High energy power & propulsion—advanced RTGs
    - CRM-2: In-space transportation—solar sails
    - CRM-15: Nanotechnology—carbon nanotube membranes
  - Large area coverage and space-time ambiguity resolution require simultaneous in-situ measurements using clusters & constellations, combined with remote sensing (sensor webs);
  - Compact, affordable instruments & spacecraft; low-power hi-rad electronics
    - CRM-3: Advanced telescopes & observatories
  - Low-cost access to space (secondary payloads; sounding rockets)
    - CRM-10: Transformational spaceport
- **Return & ingest large data sets from throughout the solar system**
  - Next-generation or follow on to Deep Space Network
    - CRM-5: Communication and Navigation
- **Visualize, analyze and model space plasmas**
    - CRM-13: Advanced modeling/simulation/analysis

Education and Public Outreach

Education and Public Outreach is Essential to the Achievement of the Exploration Vision

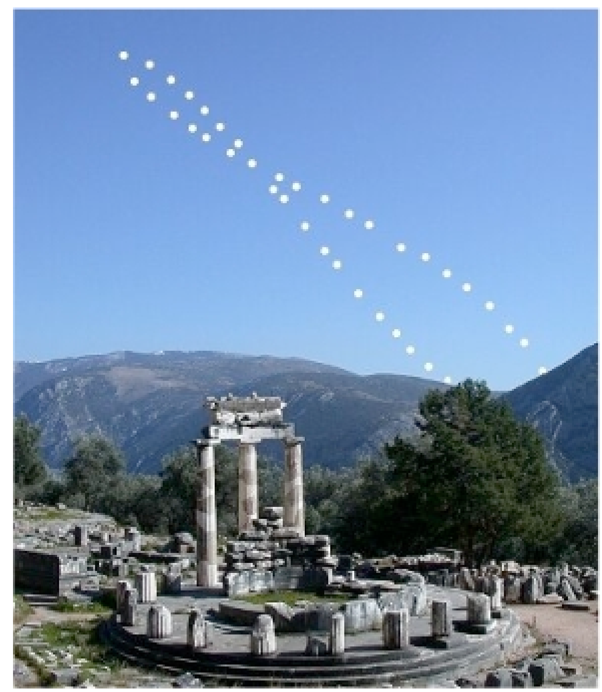
– Emphasis on workforce development
– Requires increase in the capacity of our nation's education systems (K-16)
– Entrain under-represented communities in STEM careers (demographic projections to 2025 underscore this need)

Roadmap committee #10 has focused on:

– Close up look at the role national science education standards play in effectively connecting NASA content to formal education
– Importance of E/PO to achievement of Exploration Vision
– Identification of unique E/PO opportunities
– Articulation of challenges and recommendations for effective E/PO

Unique E/PO opportunities associated with SSSC science

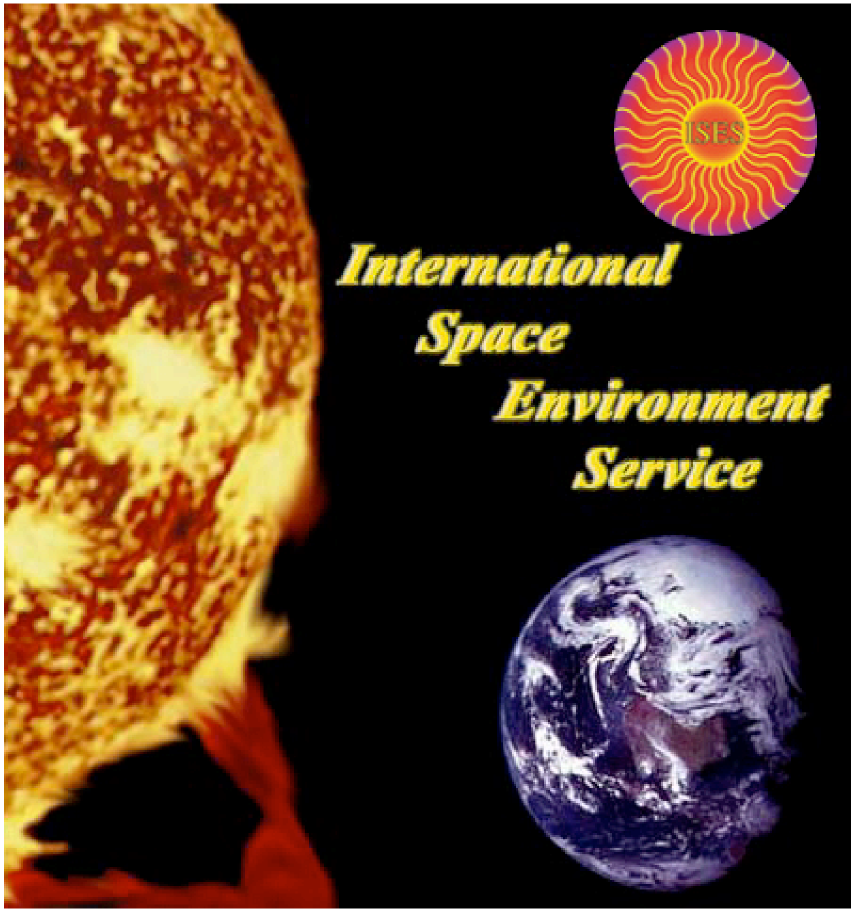
Living With a Star	• **Study the Sun to learn about stars** • **Role of Solar variability in Earth's climate**
Space Weather for Earth & Exploration	• **Analogy with terrestrial weather/climate** • **Conditions changing all the time** • **Need for situational awareness** • **Protecting space explorers**
Magnetism	• **Invisible force: "seeing the invisible"** • **Magnetism vs gravity; significance of magnetism in Solar System and Universe** • **Magnetic shields and planetary habitability** • **Electromagnetic Spectrum**
Plasma	• **State of matter depends on location**
Propulsion	• **Solar sails for space travel**




Sun-Solar System Connection
International Workshop

- International Living with a Star
- International Heliophysical Year

Opportunities for International Collaboration on Space Weather Research



New Challenges for International Collaboration on Space Weather Forecasting

The world's real-time space weather services are provided by the 10 Regional Warning Centers of the ISES.

These international centers monitor and predict solar-terrestrial activity and provide space weather forecasts and warnings for users who plan or conduct activities sensitive to solar terrestrial conditions

- **International Space Environment Service**
- **NOAA / World Warning Agency in Boulder, CO**