Living With a Star Science Architecture Team Review

(as presented to: Geospace Mission Definition Team Meeting; Paul Kintner, chair; Greenbelt Marriott; Greenbelt, MD   September 10, 2001)

Glenn Mason, former SAT chair

LWS MOWG Meeting

Holiday Inn Capitol, Washington, DC

September 20-21, 2007

SAT report: http://lws.gsfc.nasa.gov/documents/sat/sat_report2.pdf

LWS SAT Members

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Janet Barth	GSFC
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Gary Heckman	NOAA Space Environment Center
Rod Heelis	U. Texas, Dallas
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Bob Robinson	NSF - Upper Atm.
Karel Schrijver	Lockheed Martin
Dick Wolf	Rice U
Human Space Flight representative	TBD
LWS Project Scientists	
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LWS SAT Subgroup Leaders

Gary Heckman	NOAA Space Environment Center
Rod Heelis	U. Texas, Dallas
Judith Lean	NRL
Richard Mewaldt	Caltech
Karel Schrijver	Lockheed Martin

SAT Guidance --

- NASA HQ Charter
- SECAS Science Goals & Science Flowdown from March 2000 SECAS meeting
- Notional missions set aside per SECAS guidance Oct 2000
- Requirements organized to address priorities list from George Withbroe

Charter for the
Living With a Star (LWS) Science Architecture Team (SAT)
(9/15/00)

The goal of the LWS program is to develop the scientific understanding necessary to effectively address those aspects of the connected Sun–Earth system that directly affect life and society. The SAT will function as a top-level science working group for LWS and report to the Sun Earth Connection (SEC) Science Program Director and the Sun Earth Connection Advisory Subcommittee (SECAS). The main role of the SAT is to examine the LWS program requirements and architecture from an overall systems point of view. The SAT is composed of solar-terrestrial scientists and representatives from the applications community. The members will be selected by the SEC Science Program Director at NASA HQ. It is expected that there will be a periodic rotation in the membership of the SAT as the LWS program evolves.

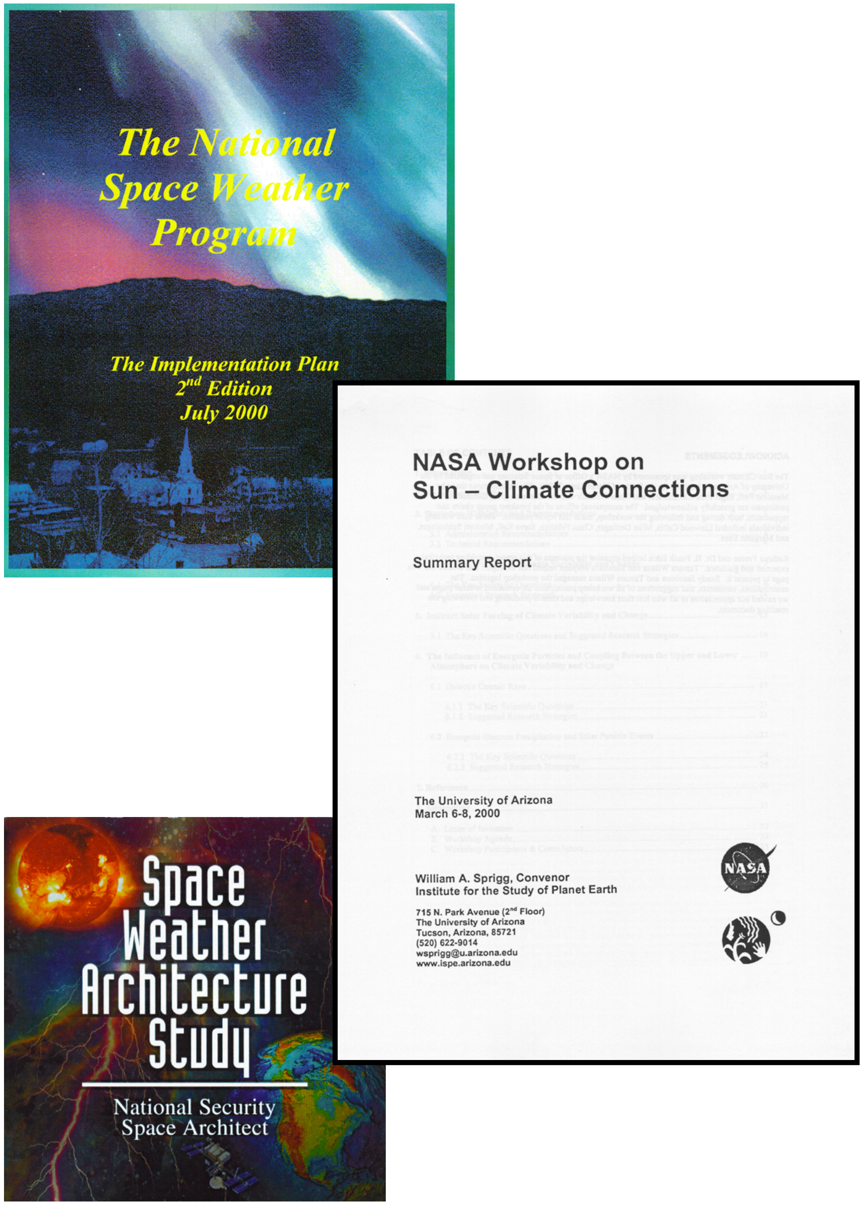
Table 1 -- LWS Goals and Objectives from SECAS

LWS Goal
Develop the scientific understanding necessary to enable the US to effectively address those aspects of the Connected Sun-Earth system that directly affect life and society.
LWS Objectives
• Identify and understand variable sources of mass and energy coming from our Star that cause changes in our environment with <u>societal</u> consequences, including the habitability of Earth, use of technology and the exploration of space. • Identify and understand the reactions of Geospace regions whose variability has <u>societal</u> consequences (impacts). • Quantitatively connect and model variations in the energy sources and reactions to enable an ultimate US forecasting capability on multiple time scales. • Extend our knowledge and understanding gained in this program to explore extreme solar-terrestrial environments and implications for life and habitability beyond Earth. March 2000 SECAS meeting

LIVING WITH A STAR
A PERSPECTIVE ON PRIORITIES 4/4/01

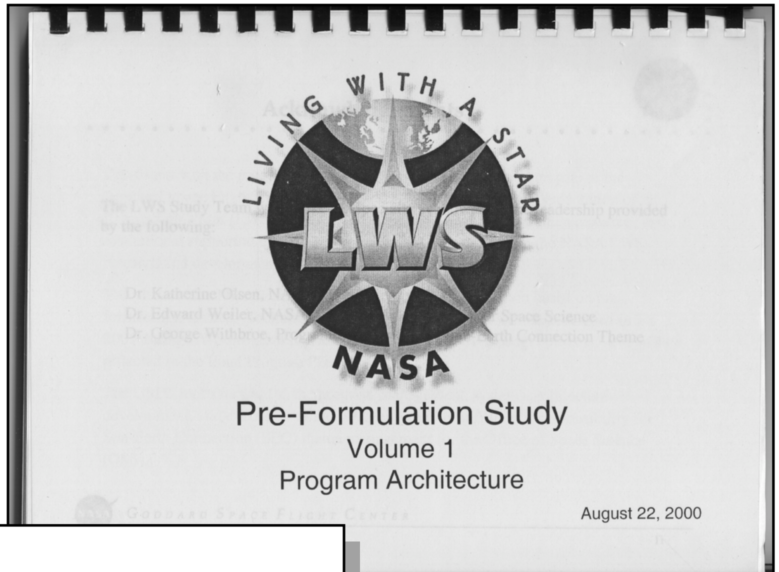
Priority

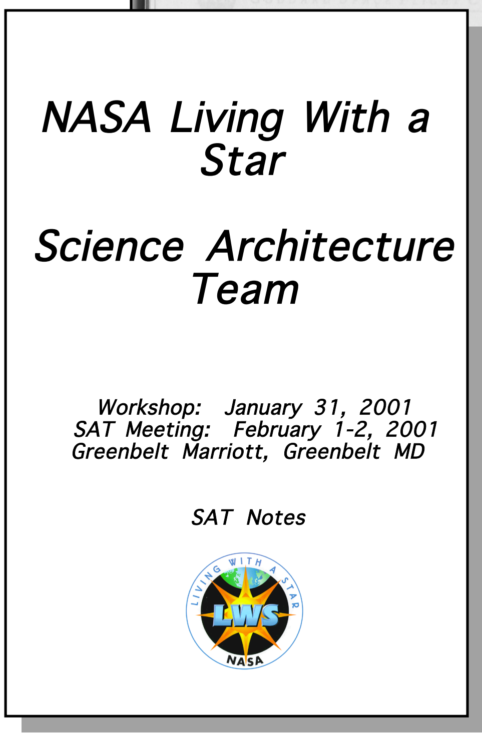
1. Solar Influences on Global Change.
2. Space Environmental “climate” data (e.g., specification models)
2. Nowcasting Space Environment
3. Prediction of:
    a) Solar Proton Events (astronaut safety, especially for deep space)
    b) Geomagnetic Storms for applications where effective mitigation is possible (e.g. electric power grid).
    c) Space Environment for operation and utilization of space systems.



Important Prior Studies--

- National Space Weather Program Reports
- NASA Workshop on Sun-Climate Connections
- DOD Space Weather Architecture Study

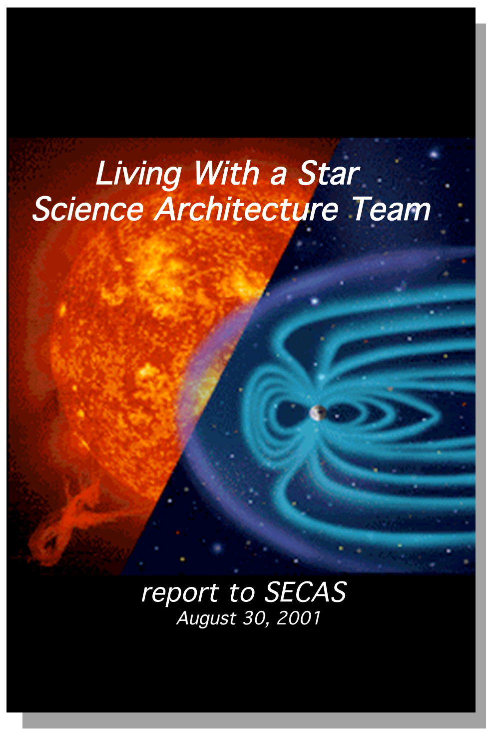



NASA Living With a Star

Science Architecture Team

Workshop: January 31, 2001
SAT Meeting: February 1-2, 2001
Greenbelt Marriott, Greenbelt MD

SAT Notes



LWS Documents --

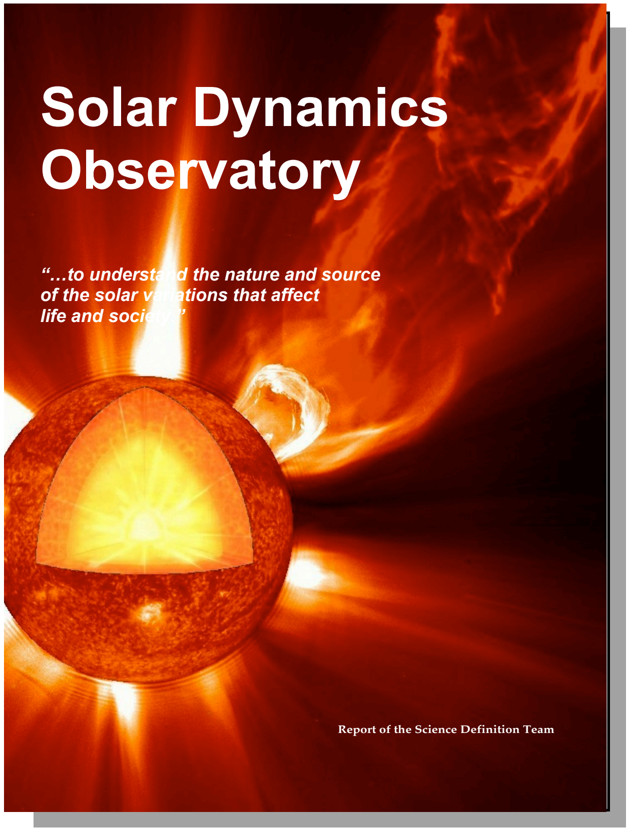
- LWS Pre-Formulation Study Vol. 1
- Notes from the LWS SAT Workshop Jan. 31, 2001
- Report to SECAS August 30, 2001

Other LWS SAT ground rules --

- LWS program must show clear progress in 5-10 year time scale to preserve robustness
  - higher risk, basic research for longer term improvements
  - SAT emphasis on near term activities
- Sparse data sampling -- ultimate product is physics-based models
  - observations to feed models
  - large scale linked model development required
    - well beyond scale of individual PI
- require a multi-year period of simultaneous observations of the whole system to understand the linkages

Practical considerations --

- SDO Mission Definition Team formed prior to SAT
  - cross membership of SAT members, LWS Project Scientist enables linkage with SAT
  - SAT effort emphasized other areas of LWS
- Initial mission sequencing (SDO followed by "Geospace") determined by NASA HQ
  - SAT did not investigate alternate sequencing scenarios



SDO --

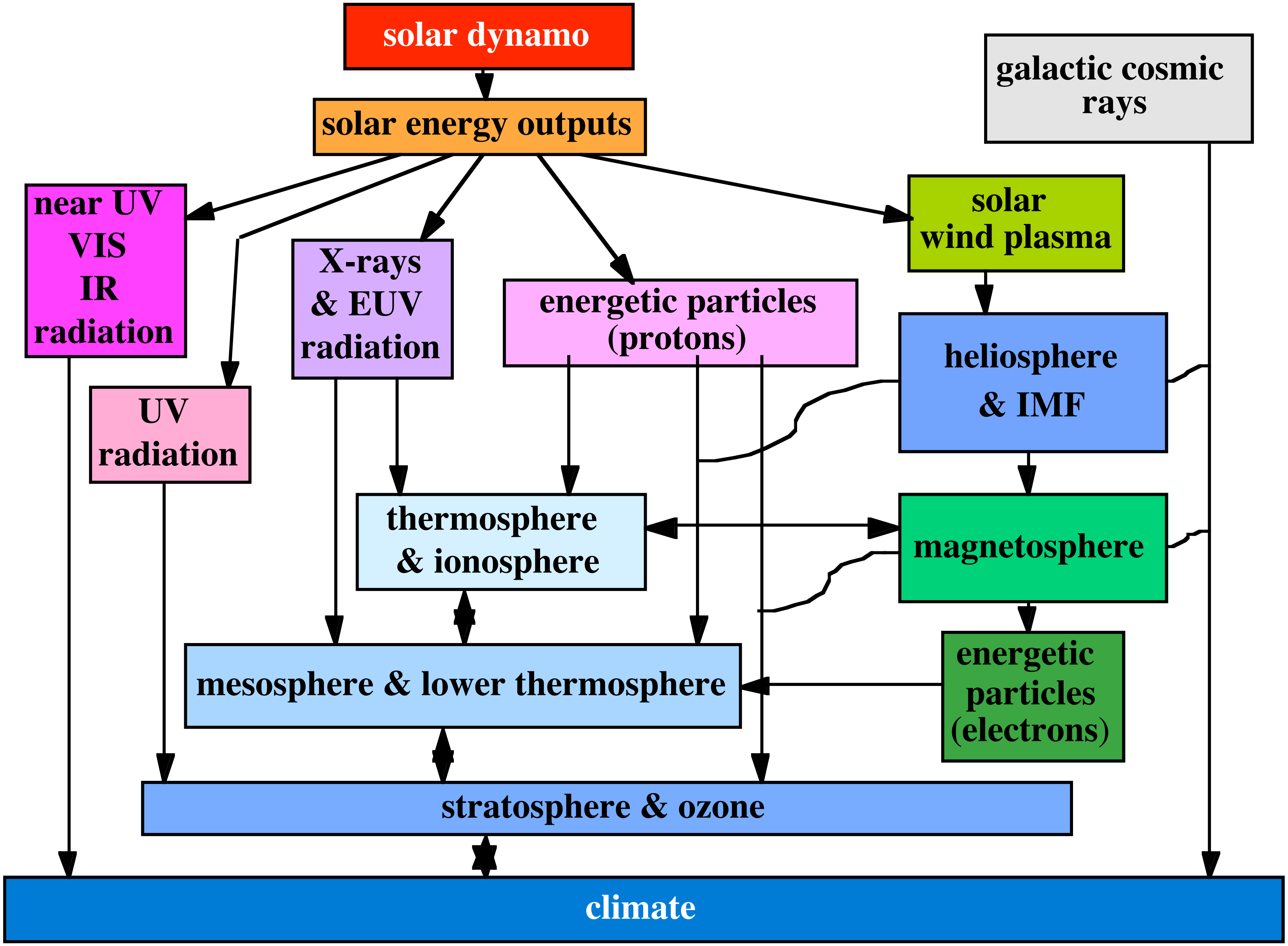
Report of the Science Definition Team

Available at:

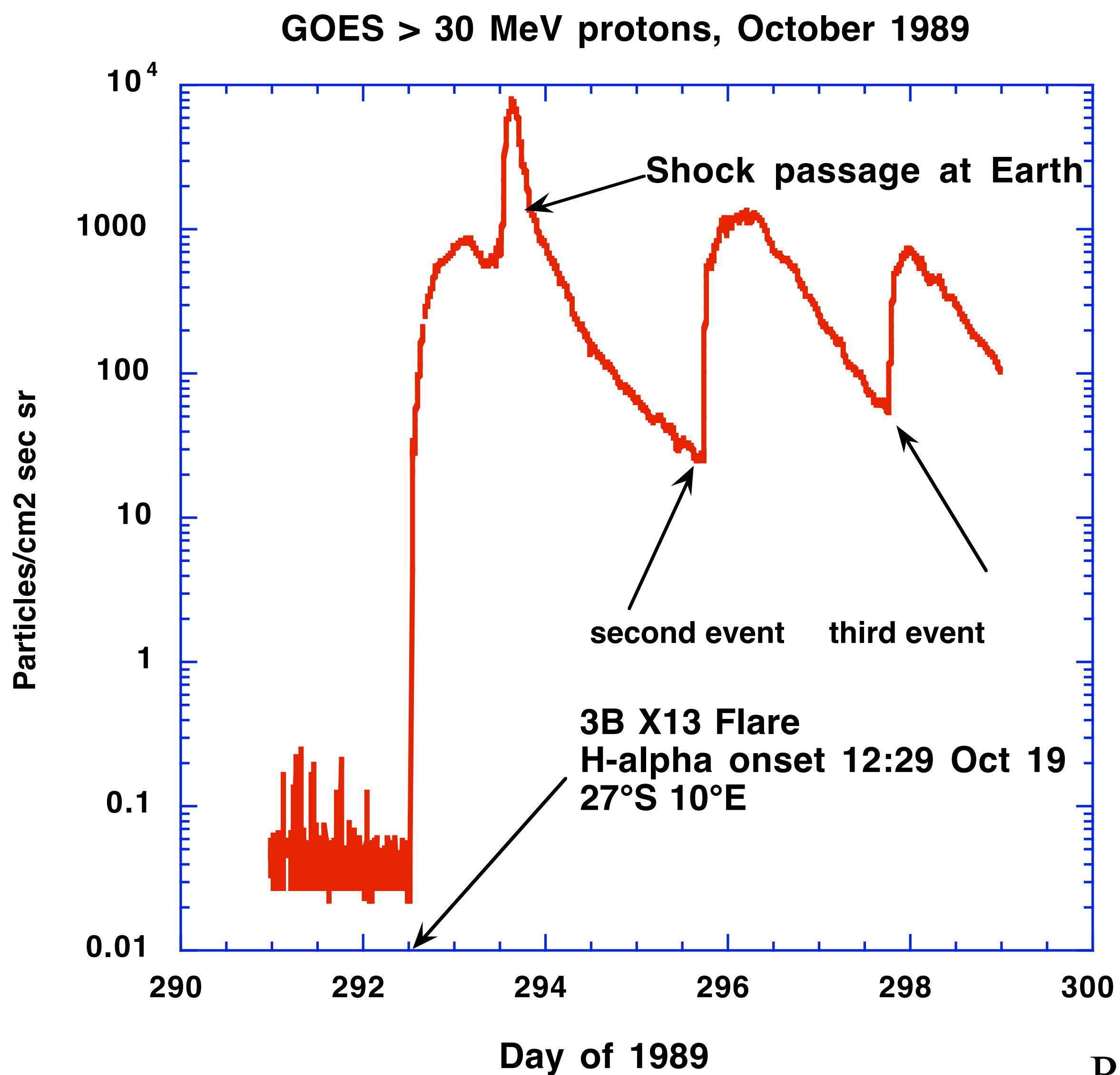
http://lws.gsfc.nasa.gov/lws_sdo_sdt_report.pdf

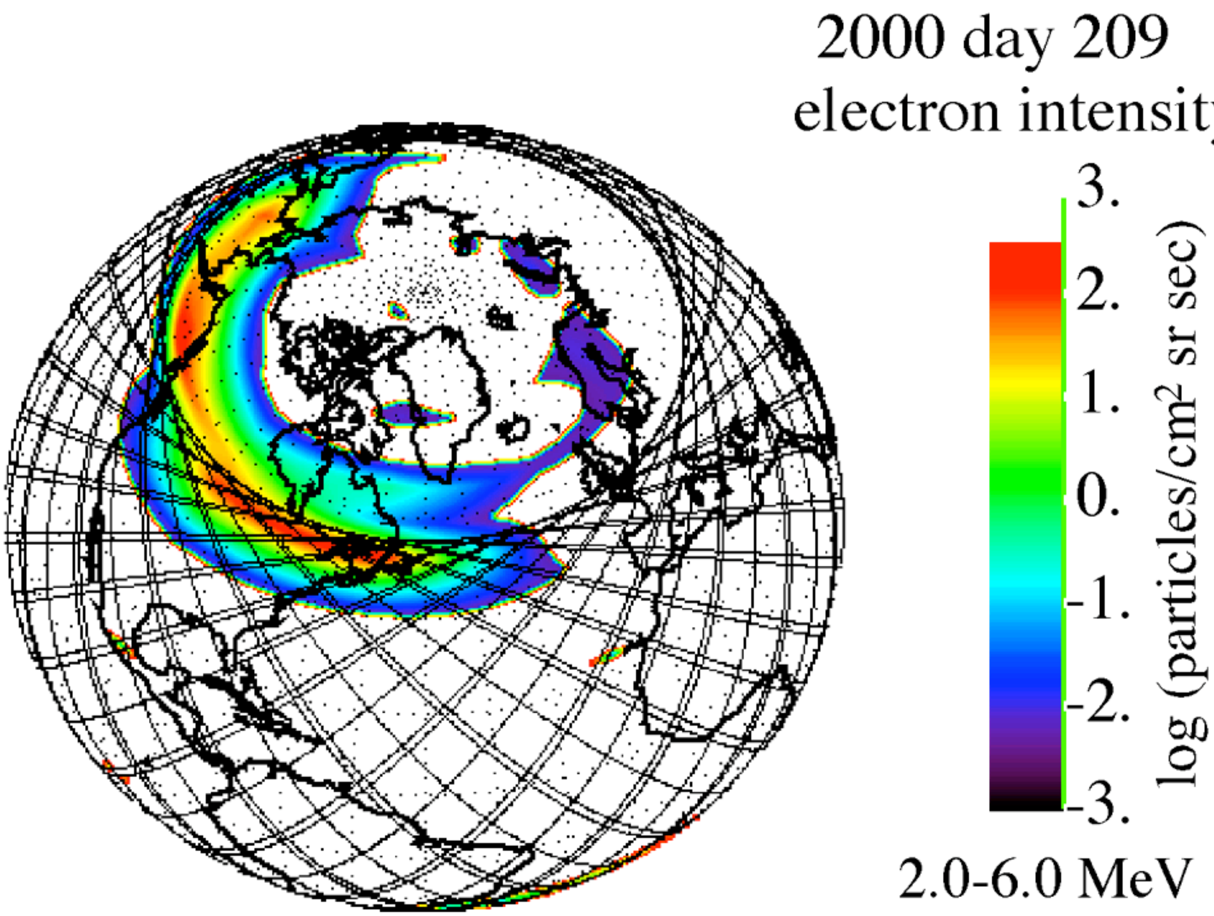
SAT Approach --

- organize LWS program areas defined in terms of linked sequences of events in order to
  - follow physical processes from start to finish (e.g. sun to upper atmosphere)
  - ensure that *all* significant links in the chain are identified
  - enable a global theory & modeling effort to achieve predictive goals



courtesy of Judith Lean


GOES > 30 MeV protons, October 1989
Particles/cm2 sec sr
10 4
1000
100
10
1
0.1
0.01
290
292
294
296
298
300
Day of 1989
Shock passage at Earth
second event
third event
3B X13 Flare
H-alpha onset 12:29 Oct 19
27°S 10°E



SAMPEX data courtesy S. Kanekal

Table 2 -- LWS Priorities

	Priority	Area
Space Environment	1	Solar Influences on Global Change
Space Environment	2	Space Environmental "climate" data (e.g., specification models)
Space Storms	2	Nowcasting Space Environment
Space Storms	3	Prediction of: a) Solar Proton Events (astronaut safety, especially for deep space) b) Geomagnetic Storms for applications where effective mitigation is possible (e.g. electric power grid). c) Space Environment for operation and utilization of space systems.

LWS Science Architecture

Implementation Group / (Pre) Science Definition Teams (SAT subgroups)	Theory and Modeling /Data Analysis	Sun	Heliosphere	Geospace	Space Environment Testbeds
Space Environment • Climate forcing • Specification models	Specification modeling	Irradiance	Secular solar wind model	Solar cycle radiation specification	Radiation tolerance (degradation)
Space Storms • Nowcasting/anomaly • Prediction (events, environment)	Dynamic Models, Analysis	Flares CMEs SPEs	Solar/storm warning CME propagation	Shocks Storm process	Mitigation (SEUs, charging)

courtesy Larry Zanetti

Space Storm Problem Areas

Solar Impacts on Communications, Navigation and Radar

1) Forecast the effects of variations in the electron density distribution in the ionosphere
2) Discover the cause of plasma density irregularities that cause radio scintillation

Tracking and Identification of Objects in Space

3) Understand and predict solar influences on satellite drag

Geomagnetic Induced Currents

4) Develop the capability to forecast induced currents due to ionospheric-geomagnetic current systems

Dynamics of the Near-Earth Radiation Environment

5) Discover the processes that accelerate, transport, and distribute energetic particles during geomagnetic storms
6) Understand and predict the intensity of outer-zone electrons due to high-speed solar wind streams

Particle Radiation Associated with Explosive Events on the Sun

7) Develop the capability to forecast solar particles accelerated by flares and CMEs
8) Predict the intensity of particles accelerated by traveling interplanetary shocks
9) Understand how solar/interplanetary variability governs the entry of energetic particles into the magnetosphere

Space Environment Problem Areas

Solar Impacts on Communications, Navigation and Radar

1) Determine the effects of long and short term variability of the Sun on the global-scale behavior of the ionospheric density from 100 to 1000 km.
2) Discover the influence of solar variability on the intensity and location of plasma irregularities in the 100 km to 1000 km altitude region.

Tracking and Identification of Objects in Space

3) Determine the effects of long and short term variability of the Sun on the mass density of the atmosphere between 120 and 600 km altitude and describe them with accuracy better than 5%.

Dynamics of the Near-Earth Particle Radiation Environmen t

4) Understand the processes responsible for the acceleration, loss, and transport of radiation belt electrons and ions responsible for radiation dose and bulk charging effects.
5) Understand the geospace response to geomagnetic storms such as the development and trapping of the ring current, Joule heating of the ionosphere, ground induced currents, severe spacecraft surface charging environments, etc.
6) Reveal and characterize the effects of solar energetic particles at low Earth orbit and in the atmosphere/ionosphere

Climate variability due to solar variations

7) Identify and quantify the Earth's near-surface temperature changes attributable to solar variability (from both direct and indirect solar energy forcings).
8) Identify and quantify the changes in ozone distribution attributable to solar variability (in the form of electromagnetic radiation and energetic particles).

Deep space probe / Astronaut safety on Mars mission

9) Develop the capability to specify and predict solar activity (on time scales of active regions to the solar cycle) and heliospheric modulation of energy inflow from the Sun and the galaxies to the Earth’s space environment.

Sample problem area treatment

Since observational sampling of the Sun, heliosphere, and geospace is extremely sparse, the SAT adopted the view that the ultimate product of the program would be in physics-based models of the various regions of importance. In this approach, the role of observations is to understand the physical processes so that theory and models can be developed, and, eventually, to drive the models so that nowcasting and predictions can be made. In the words of one attendee at the SAT workshop, "the observations should be made to feed the models."

Implications --

1) The LWS program will need to develop large scale global models well beyond the scale undertaken by individual Principal Investigators, and involving interfaces among traditional SEC regimes that are not the focus of existing research.

2) A broad community of researchers will need to have ready access to data sets from many spacecraft covering broad areas of the Sun-Earth system.

3) It will be necessary to have a multi-year period of simultaneous observations of the whole system in order to understand, and convincingly demonstrate that we understand all the linkages.

4) The importance of observations in the program can be quantitatively linked to their role in improving models, and/or reducing the uncertainties in nowcasting or forecasting.

Implications --

The first three points above have a critical role in the management and organization of the LWS program.

The 4th point provides a clear mechanism for evaluating and prioritizing measurement objectives.

SAT Approach --

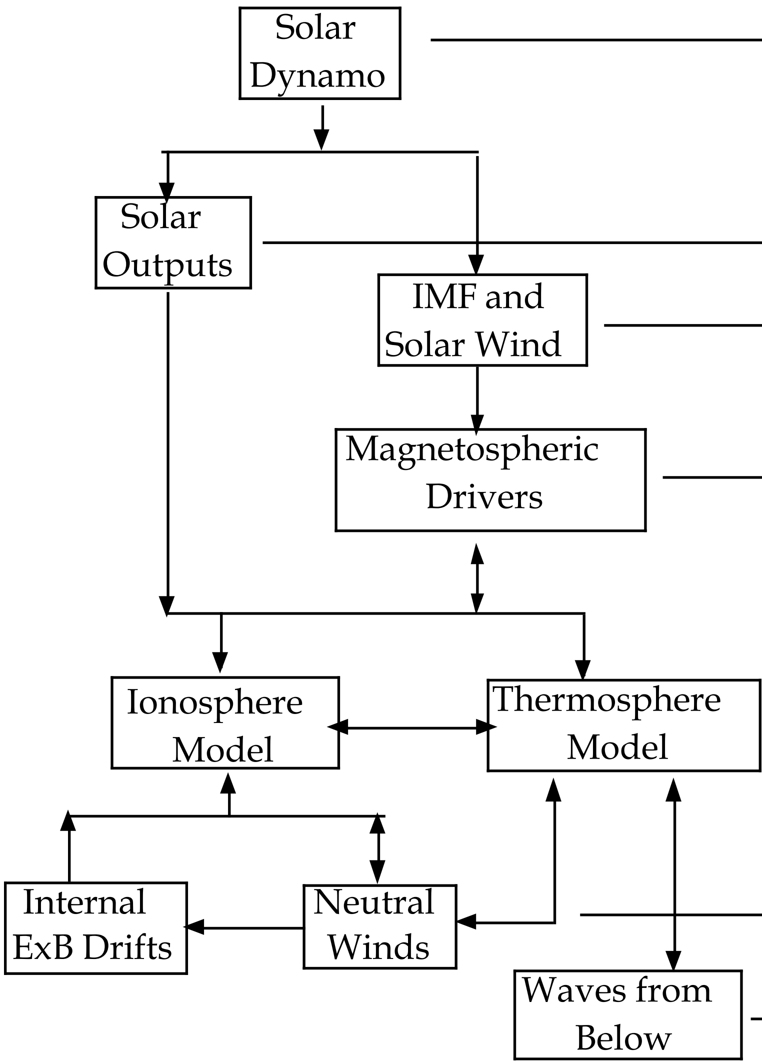
- for each problem area (e.g. S/C drag), identify
  - physical processes from start to finish (e.g. sun to upper atmosphere)
  - current state of theory and modeling, including accuracy
  - establish ~5-10 year goals for required improvements
    - model refinement; data assimilation; new models
    - observations required
      - existing missions that can provide needed data
      - missing observations required to meet LWS goals

<u>Produce the capability to specify and predict the mass density of the atmosphere between 120 and 600 km altitude with accuracy better than 5%.</u>

- **Societal impact:**
  Satellite orbits are perturbed by atmospheric drag.
  Atmospheric conductivity is critical parameter for determination of induced ground-currents, and ionospheric radio scintillation.
- **Primary Current Limitations:**
  Empirical model with 20% long term accuracy.
  Poor altitude specification below 350 km.
  Computational models driven by proxies for solar EUV radiation and electromagnetic drivers.
  Sensitive to poorly specified small scale motions at lower boundary.
- **5-10 yr LWS goal:**
  Refine empirical model of winds and density with new data & inputs.
  Validation of physics-based models with variations in measured input drivers.
  Establish data assimilation processes to accommodate sparse data sets
- **> 10 yr LWS goal:**
  Validated physics-based assimilation model.

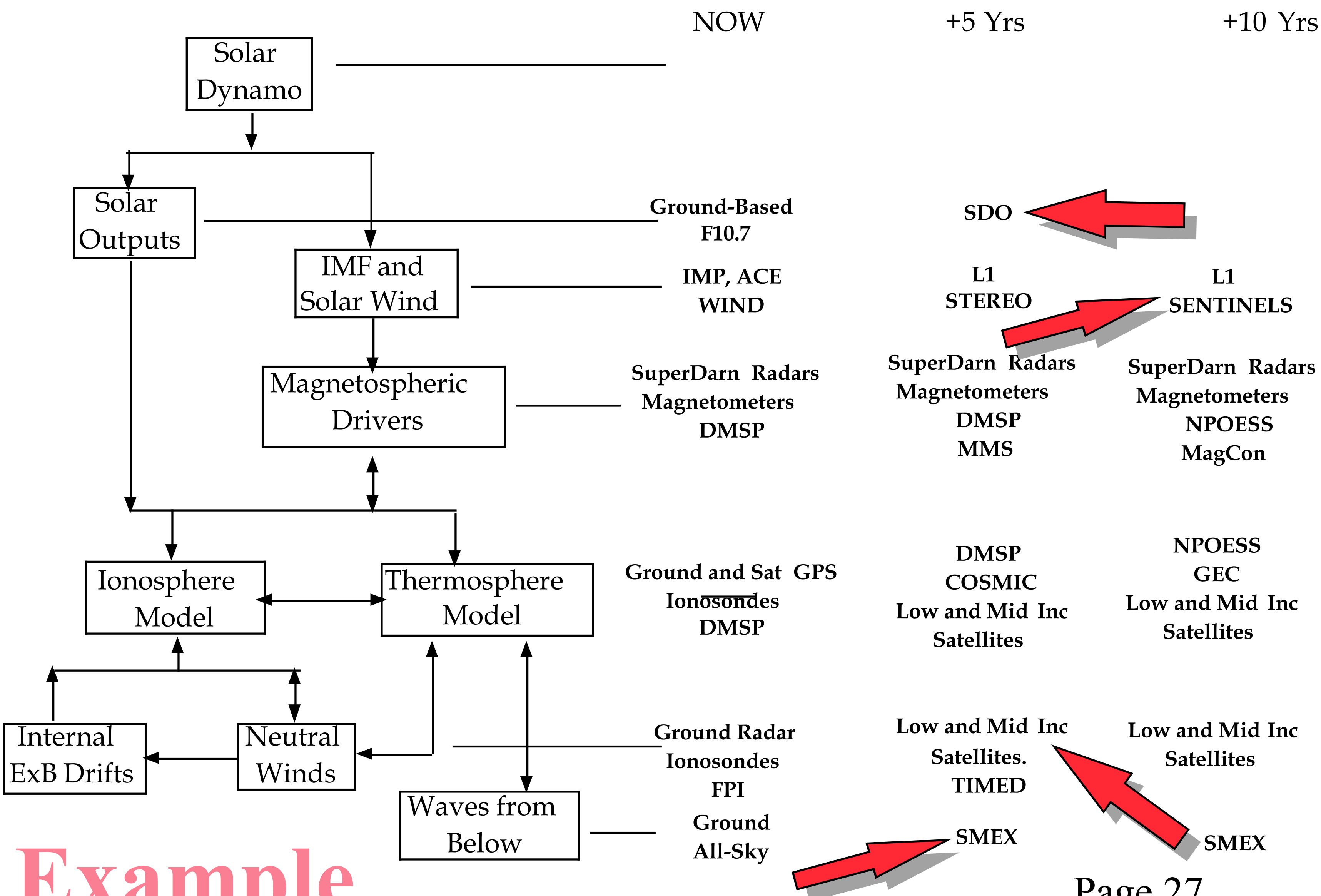
Example of LWS problem area

Atmosphere Ionosphere Magnetosphere Research Agenda



	Now	+ 5 yrs	+ 10 yrs
Solar Outputs	Proxies eg F10.7	Measured eg euv spectrum	Data Assimilation Models
IMF and Solar Wind	L1 Observations	L1 Observations	L1 Observations
Magnetospheric Drivers	Empirical and Data Assimilation Models	Data Assimilation and MHD Simulations	
Thermosphere Model	Empirical and Physics Models	Coupled Physics Models with Data Assimilation	Coupled Physics Models with Data Assimilation
Neutral Winds	Empirical Models	Empirical and Data Driven Models	Coupled Physics Models with Data Assimilation
Waves from Below	Empirical Models	Data Assimilation Models	

Atmosphere Ionosphere Magnetosphere Measurements Agenda



Example

LWS SAT findings for --

1) new missions to fill the gaps in observational picture

2) system to make required data from non LWS missions easily available to LWS researchers

3) coordinated theory, modeling, and data analysis program

<u>All 3 components are required for achieving LWS goals</u>

LWS SAT--
recommended set of initial missions

Name	Launch	Description
SDO	2006	Solar seismology and magnetic field studies; EUV radiation; radiation belt studies
Geospace -Radiation Belt 1/2 and 3/4	2008 & ~2013	Radiation belts over a range of L shells; two launches in order to cover full solar cycle
Geospace-LEO	2009	*in-situ* measurement of ionosphere and thermosphere dynamics and structure; solar energetic particles & polar cap size; SAA
Geospace-EPO	2009	global auroral imaging and O/N2 perturbations; energetic neutral atom imaging for ring current dynamics
Inner Heliosphere Mappers	2009	~4 identical spacecraft in inner heliosphere orbits; structure, dynamics, & radial evolution of CMEs, solar particles, and geo-effective disturbances

LWS Geospace Missions -- Radiation Belts

Mission Concept: dedicated S/C & missions of opportunity

GTO-like: 2/3 satellites per launch in two launches phased for solar cycle coverage - core + opportunity; measure B, energetic particles, plasma incl. ion composition on first launch. Second launch spacecraft include above measurements plus waves and E

Geo mission of opportunity: measure B and energetic particles, plasma incl. ion composition, ENA, E

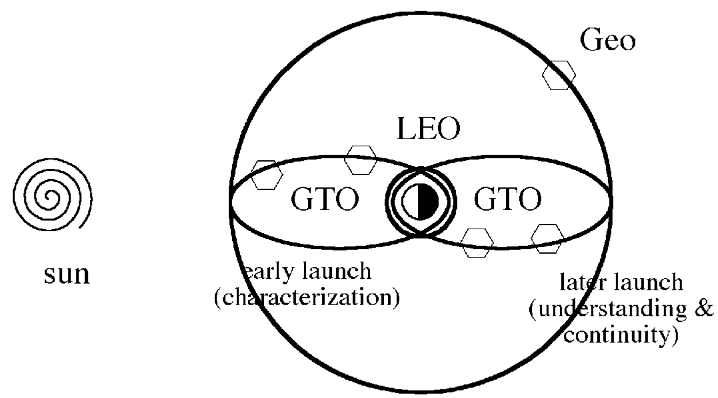
LEO: SEP and SAA measurements for ionospheric, atmospheric, climate, & human radiation exposure similar to SAMPEX or DMSP

Science Questions:

- *What processes control the acceleration, loss, and transport of radiation belt electrons and ions?*
- *What is the geospace response to geomagnetic storms, e.g., development and trapping of ring current, Joule heating of the ionosphere, ground induced currents, and severe S/C charging?*
- *What are the effects of solar energetic particles at low Earth orbit and in the atmosphere/ionosphere?*
- *What is the radial and longitudinal distribution and dynamics of particles in CME and flare-associated solar particle events?*

LWS Target Areas

- *S/C radiation dose and bulk charging*
- *S/C drag*
- *Magnetospheric induced currents*
- *communication, navigation, and radar*
- *upper atmospheric chemistry / ozone*
- *ground induced currents*



Other contributing measurements:

L1: ACE, Wind, Triana

NASA missions: SDO, GEC, ISS, MagCon, MMS, TWINS, Image?, Polar?, Cluster?, SAMPEX? non-NASA missions: GOES, LANL-GEO, GPS, HEO, DMSP, NPOESS, GMS (Japan), ICO, commercial-satellites

LWS Geospace Missions -- Ionosphere/Thermosphere

1. LEO Orbits below the exobase; inclination to maximize longitude and latitude coverage within seasonal variations (~70°); in-situ measurements of ionosphere and thermosphere dynamics and structure; solar energetic particles/polar cap access and size; SAA

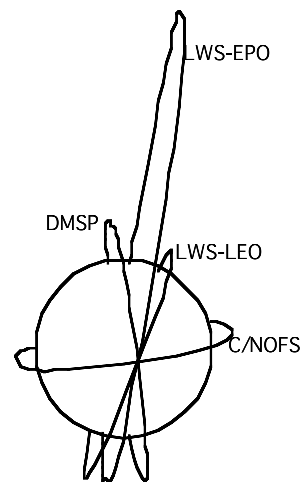
2. Elliptical Polar Orbit (EPO)

Inclination and eccentricity to maximize efficiency of global auroral imaging and O/N2 perturbations and other pertinent parameters; energetic neutral atom imaging for ring current global view

Science Questions:

Global Specification and Prediction of Neutral Upper Atmospheric Density and Dynamics; Ionosphere Density, Structure and Irregularities

- *Dynamics, latitude, longitude, and local time variations in: Thermospheric winds; Neutral mass composition and density E-field or ExB drift; Ionospheric mass composition and density; Scintillation and Density Irregularities*
- *Global Auroral Energy Deposition*
- *Global Neutral Density Perturbations*
- *Ring Current Dynamics*
- *LWS Target Areas*
- *Detection and tracking of space objects*
- *Communication, Navigation and Radar*
- *Geomagnetically Induced Currents*



Other contributing measurements:

C/NOFS: equatorial ionosphere dynamics & structure

DMSP/NPOESS: latitude profiles of neutral density at fixed local times; energetic particle input

Ground Based Observations: Electric Fields, Conductivities, Magnetic Perturbations

L1: ACE, Wind, Triana: specification of IMF and Solar Wind; SDO: EUV spectral irradiance; Geoeffective disturbances

Inner Heliospheric Mappers

Mission Concept: Four identical spacecraft in elliptical heliocentric orbits (0.5 –0.95 x 0.72 AU)

Objective: Continuous, in situ, inner-heliospheric observations to study the structure, dynamics, & radial evolution of CMEs, solar particles, and geo-effective disturbances

Strategy: Multi-point observations distributed in radius & longitude

Instruments: Magnetometer, Solar wind analyzer, Energetic particles, & Radio waves

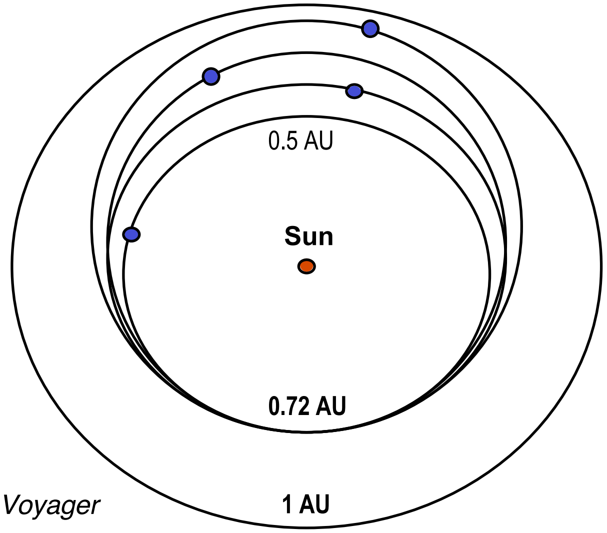
Launch Vehicle: Single Delta-II launch

Science Questions:

- *What is the ambient structure of the inner heliosphere?*
- *How do large-scale structures evolve during transit to Earth? (CMEs, shocks, fast streams)*
- *What dynamic processes in the corona can be determined from heliospheric observations?*
- *What is the radial and longitudinal distribution and dynamics of particles in CME and flare-associated solar particle events?*

LWS Target Areas

- *Solar impacts on communications, navigation, and radar*
- *Dynamics of the near-Earth radiation environment*
- *Magnetospheric induced currents*
- *Radiation from explosive solar events*



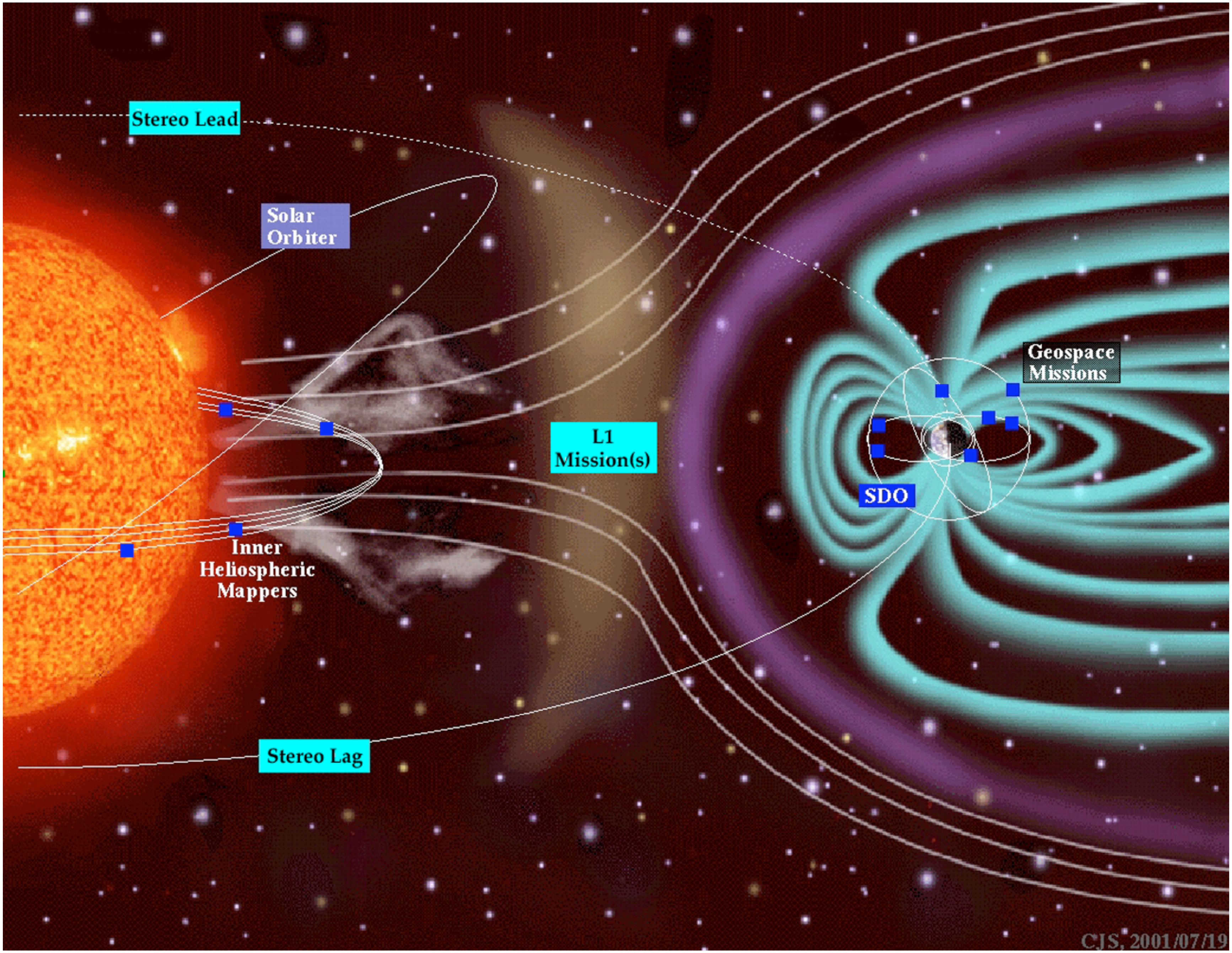
Other contributing measurements:

L1: ACE, Wind, Triana; STEREO:

Multi-pt imaging & in situ data on CMEs, SEPs

Inside 1 AU: SOLO?, Messenger?, Beppi-Columbo?;

Also upstream: SOHO, IMP, Geostorm?, Magtail Con.; Outside 1 AU: Ulysses, Voyager


Stereo Lead
Solar Orbiter
L1 Mission(s)
Geospace Missions
SDO
Inner Heliospheric Mappers
Stereo Lag
CJS, 2001/07/19

Solar Cycle & LWS Mission Observations

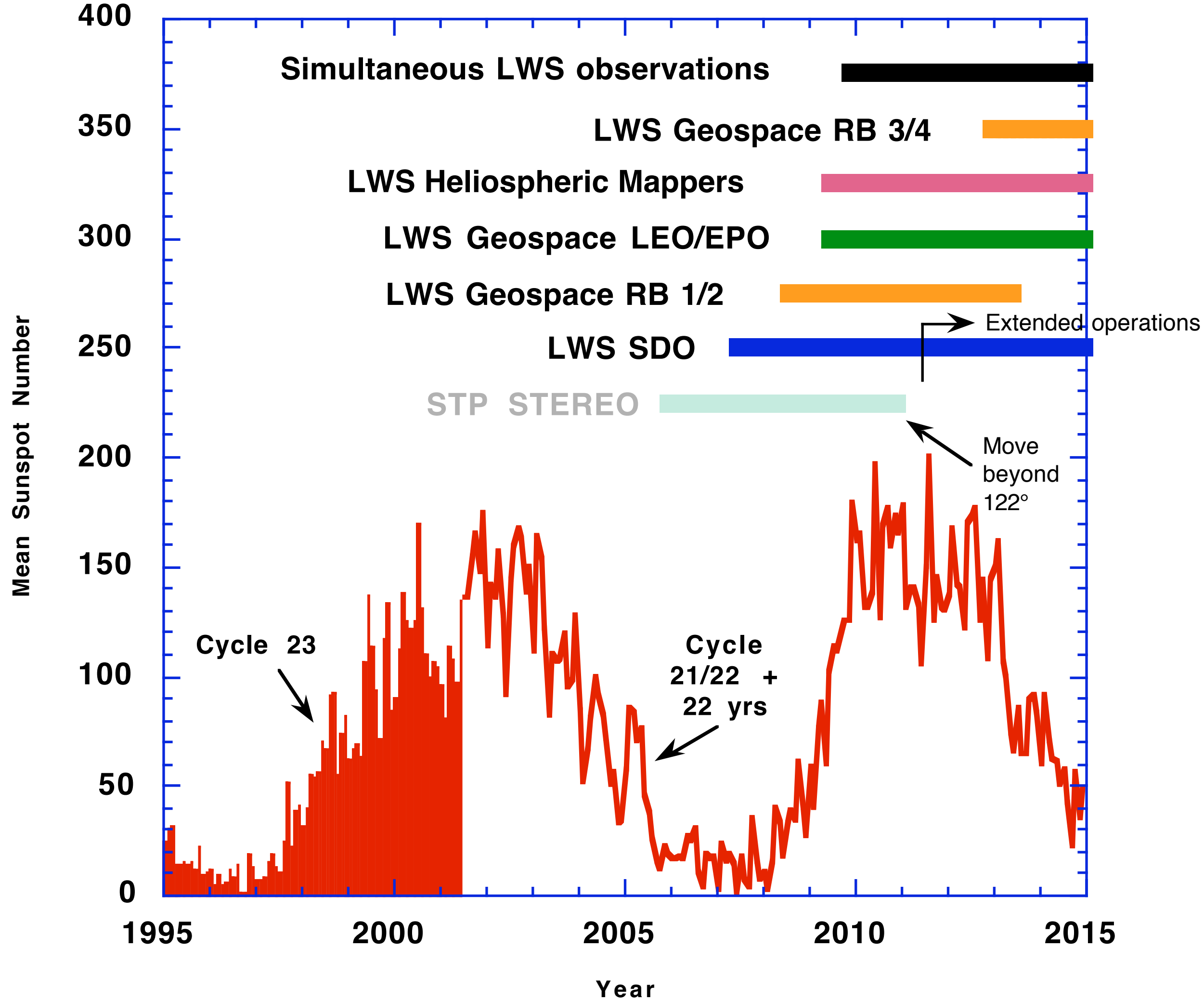


Table 8 -- LWS Supporting Missions

Spatial Region	LWS Supporting Missions
Outer Heliosphere	Voyager, Ulysses
Solar (remote)	SOHO, HESSI, TRACE, Solar-B
Inner Heliosphere	SOLO, Messenger, Beppi-Columbo, Solar Probe
Heliosphere at 1 AU	STEREO, IMP, Geostorm,
L1	ACE, Wind, Triana
Magnetosphere	MagCon, GEC, TWINS, Polar, Cluster, GOES, LANL-GEO, GPS, IMP-8
Low Earth Orbit	SORCE, TIMED, DMSP, TIROS, NPOESS, SAMPEX, C/NOFS

Missions shown in red are to be terminated prior to LWS new missions, per August 2001 SEC Senior Review Final Report

LWS Data System finding--

- *new LWS missions to fill the gaps in observational picture*
  - recommended missions take account of other assets
- *critical that NASA LWS management ensure that these other data are taken, and are easily available*
  - NASA operated non-LWS S/C: a factor in mission extensions, etc.
  - non NASA S/C: seek to obtain required data through partnering, etc.
  - require a data system (possibly a virtual system) that will serve an an archive that individual researchers and coordinated large-scale modeling teams can access to achieve required LWS theory & modeling goals.

LWS Data System --

- *LWS SAT finding:*
  - Data Systems Team (DST) should be formed to examine issues and make specific recommendations to LWS program management
    - need to examine cost/benefit of adding any particular data set to the system
    - should include archival data that can form the basis for many early studies and payoffs from the LWS program (e.g. radiation belt model updates) well before the first LWS mission is launched.
    - report activities of the DST to the Science Architecture Team

LWS Theory & Modeling Program finding --

- *LWS will be a success if and only if there are substantial improvements in theoretical understanding and modeling of each component of the Sun-heliosphere-geospace system*
- *Theory and modeling will embody the knowledge acquired by the LWS program*
- *It would be unwise to assume that the required theory and modeling program will arise through the natural instincts of the community*
- *The SAT believes that a comprehensive theory and modeling program needs to be embarked upon immediately --*

LWS Theory & Modeling Program finding --

- *A Theory, Modeling, and Data Analysis Definition Team (TMDADT) needs to be formed with the same status as a mission definition team. Its charge should include:*
  – definition of goals and objectives, including metrics
  – recommendations on management structure that will be in place through the LWS program and will ensure coordinated and unified development
  – recommendations on procedures to ensure that the program encourage and promotes new concepts, and provides for their speedy inclusion in the developing models
  – preliminary assessment of the data that will be needed for success that can provide useful guidance to the SDTs
  – as assessment of the utility and necessity of data for theory and model development that can be provided from existing and planned NASA and non-NASA sources

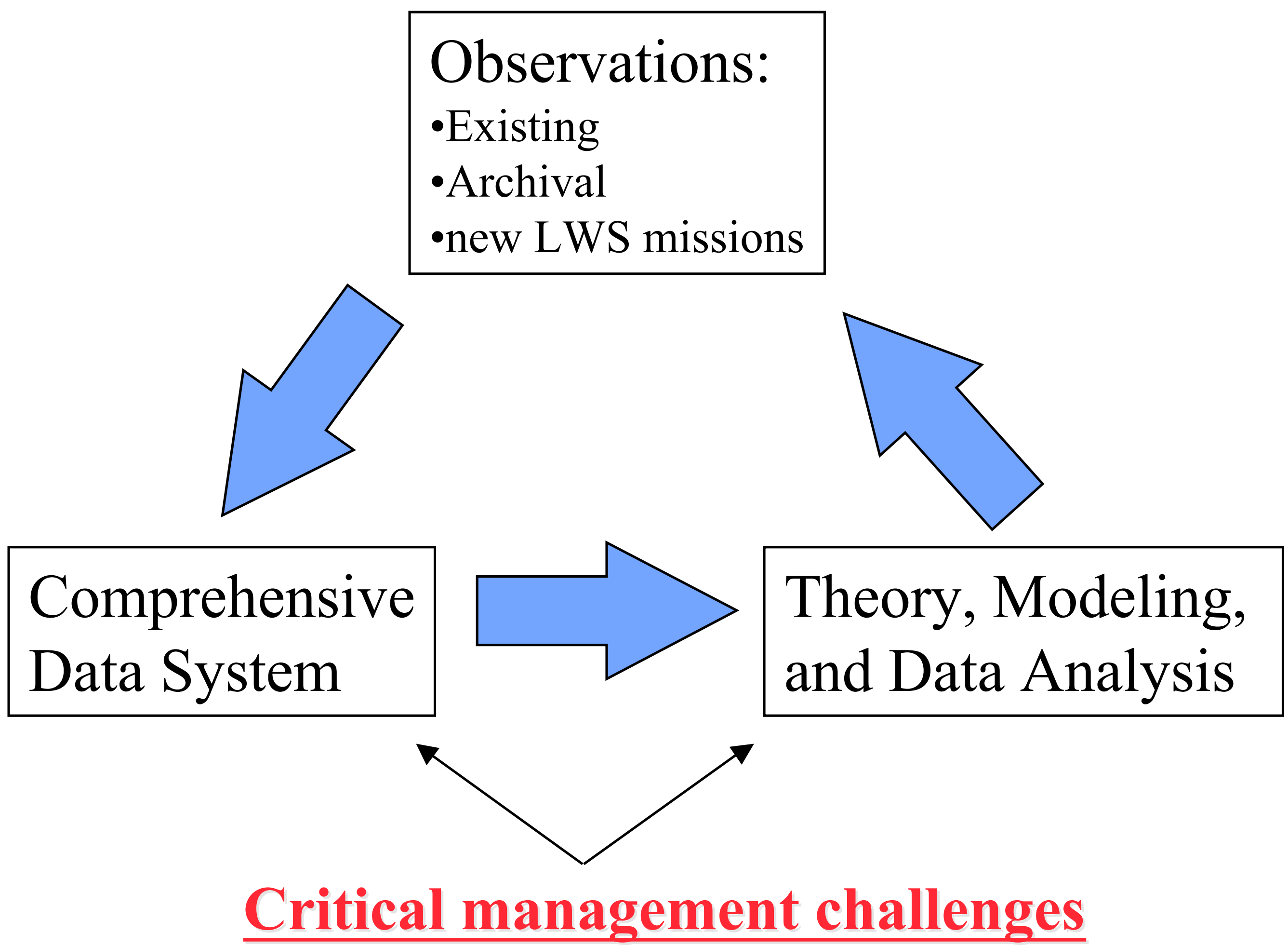
LWS Theory, Modeling, and Data Analysis Program finding (con't) --

- *Selected members of the TMDADT should also be appointed to the mission SDTs the ensure coordination.*
  - the converse should also occur: members of the SDTs should have joint appointments on the TMDADT.
- *The TMDADT should disband and replaced by a permanent management structure that will ensure success of the theory and modeling effort*

LWS Theory & Modeling Program finding (con't) --

The LWS program has accepted a daunting challenge -- to deliver comprehensive knowledge and improved predictability of how our changing Sun impacts our society. There are multiple spacecraft, coordinated measurements, and intertwining theories and models. The challenge is one of science and also one of management, and nowhere is the success in meeting the management challenge more crucial for the ultimate success of LWS that it is for theory and modeling.

LWS SAT picture



Conclusion: How to coordinate Mission Definition Teams with SAT approach?

- ***Identify the LWS problem areas best addressed by a mission or missions,***
- ***Determine significant model improvements achievable in the 5-10 year time frame,***
- ***Enumerate existing or planned missions whose measurements can be employed to support the model development and theory improvements, and identify critical missing measurements,***
- ***Identify targeted new measurements (partnerships or individual S/C) required to fill in the missing pieces,***
- ***Iterate the process to achieve closure with resources, the level of science understanding, and societal impact.***