PROGRAM-LEVEL REQUIREMENTS FOR THE SOLAR DYNAMICS OBSERVATORY PROJECT

Appendix A

-DRAFT-

March 2003

Appendix A

-DRAFT-

Program-Level Requirements for the Solar Dynamics Observatory Project

A-1.0 INTRODUCTION

A-1.1 SCOPE

This appendix to the Living With a Star (LWS) Program Plan defines the Level 1 Requirements for the development and operation of the Solar Dynamics Observatory (SDO) project of the LWS Program at the Goddard Space Flight Center (GSFC). The specific requirements are presented in Section A-2.0.

This document serves as the basis for project assessments conducted by NASA Headquarters during the SDO development period and provides the baseline for the determination of the science mission success following the completion of the operational phase. Changes to information and requirements contained in this document require approval by the Enterprise Program Management Council in the Office of Space Science at NASA Headquarters.

The SDO is a follow-on mission to the very successful Solar and Heliospheric (SOHO) mission. It will obtain high temporal cadence measurements of the Sun over a substantial portion of a solar cycle to improve the scientific understanding that will lead to the development of an operational space weather capability. The SDO's five-year prime life is designed to provide measurements over a substantial portion of the solar cycle.

A-1.2 STRATEGIC IMPORTANCE

The NASA Strategic Plan contains two mission statements that frame the interests of OSS, LWS and, consequently, SDO:

1. To understand and protect our home planet and

2. To explore the universe and search for life.

These key mission statements are used to further define the goals, science objectives, and research focus areas in the OSS Strategic Plan. Those applicable to the OSS's strategic

Sun Earth Connection (SEC) program are given in Table A-1.2. The LWS Program is an essential element of the SEC Program and derives its goals and objectives from the OSS Strategic Plan, and the SDO project derives its requirements from two of the SEC objectives:

1. To understand solar variability and its effects on the space and Earth environments with an ultimate goal of a reliable predictive capability of solar variability; and

2. To obtain scientific knowledge relevant to mitigation or accommodation of undesirable effects of solar variability on humans and human technology on the ground and in space.

The SDO mission addresses these requirements in two ways, by performing science investigations alone, and by participating with other missions in performing system investigations to address the Sun's activity and the Earth's response. As a stand-alone mission, the SDO responds to SEC research focus area 1A in Mission Statement 1 and focus areas 1A, 1B, and 2A in Mission Statement 2. The other SEC focus areas are research goals that can only be addressed when the SDO participates in specific system investigations. Because the system investigations depend upon the availability, locations, and accuracy of other missions, the SDO Level I requirements address only SDO investigations as a stand-alone mission.

Mission Statement 1: To Understand and Protect Our Home Planet		
Goal	**Science Objectives**	**Research Focus Areas**
Understand the Earth system and apply Earth system science to improve prediction of climate, weather, and natural hazards.	1. Define the origins and societal impacts of variability in the Sun-Earth Connection.	(a) Develop the capability to predict solar activity and the evolution of solar disturbances as they propagate in the heliosphere and affect the Earth. (b) Specify and enable prediction of changes to the Earth's radiation environment, ionosphere, and upper atmosphere. (c) Understand the role of solar variability in driving space climate and global change in the Earth's atmosphere.
Mission Statement 2: To Explore the Universe and Search for Life		
Goal	**Science Objectives**	**Research Focus Areas**
Explore the solar system and the universe beyond, understand the origin and evolution of life, and search for evidence of life elsewhere.	1. Understand the changing flow of energy and matter throughout the Sun, heliosphere, and planetary environments	(a) Understand the structure and dynamics of the Sun and solar wind and the origins of magnetic variability. (b) Determine the evolution of the heliosphere and its interaction with the galaxy. (c) Understand the response of magnetospheres and atmospheres to external and internal drivers
	2. Explore the fundamental physical processes of space plasma systems.	(a) Discover how magnetic fields are created and evolve and how charged particles are accelerated. (b) Understand the coupling across multiple scale lengths and its generality in plasma systems.

Table A-1.2. The goals, science objectives, and research focus areas for the Sun Earth Connection in the OSS Strategic Plan that respond to two mission statements in the NASA Strategic Plan.

A-1.3 SCIENTIFIC GOALS, INSTRUMENT SCIENCE OBJECTIVES AND MEASUREMENT OBJECTIVES

In preparation for the SDO Announcement of Opportunity (AO), the SDO Science Definition Team identified seven essential science questions that needed to be addressed by SDO. These are:

1. What mechanisms drive the quasi-periodic 11-year cycle of solar activity?

2. How is active region magnetic flux synthesized, concentrated, and dispersed across the solar surface?

3. How does magnetic reconnection on small scales reorganize the large-scale field topology and current systems? How significant is it in heating the corona and accelerating the solar wind?

4. Where do the observed variations in the Sun's EUV spectral irradiance arise, and how do they relate to the magnetic activity cycles?

5. What magnetic field configurations lead to the CMEs, filament eruptions, and flares that produce energetic particles and radiation?

6. Can the structure and dynamics of the solar wind near Earth be determined from the magnetic field configuration and atmospheric structure near the solar surface?

7. When will activity occur, and is it possible to make accurate and reliable forecasts of space weather and climate?

The PI Teams, in response to the AO, have devised investigations designed to answer all seven of these questions. Each investigation in turn has defined a supplemental set of Instrument Science Objectives which form and integrated set of SDO science goals and objectives consistent with the seven SDO mission objectives:

EVE

E-1. Specify the solar EUV spectral irradiance and its variability on multiple time scales

E-2. Advance current understanding of how and why the solar EUV spectral irradiance varies. (Connections to other measurements)

E-3. Improve the capability to predict the EUV spectral irradiance variability.

E-4. Understand the response of the geospace environment to variations in the solar EUV spectral irradiance and the impact on human endeavors.

HMI

H-1. Convection Zone dynamics and solar dynamo

H-2. Origin and Evolution of sunspots, active regions and complexes of activity

H-3. Sources and drivers of solar activity and disturbances

H-4. Links between the internal processes and dynamics of the corona and heliosphere

H-5.Precursors of solar disturbances for space weather forecasts

SHARPP

S-1. Link solar magnetic features to irradiance variability at earth

S-2. Link observed/derived plasma characteristics to the associated magnetic structures throughout the photosphere, chromosphere, transition region, and corona, as they evolve over the solar cycle

S-3. Determine the nature of the coronal heating mechanism(s)

S-4. Understand the origin of flares and their relation to CMEs

S-5. Detect and measure reconnection signatures (e.g., Jets) characteristic of competing CME initiation models

S-6. Understand the origin and nature of global waves and dimmings that accompany many fast CMEs

S-7a. Determine the effects of ambient magnetic field topology and complexity will have on the initiation and propagation of CMEs

S-7b. Determine the factors associated with geoeffectiveness of CMEs over the solar cycle

S-8. Understand the heating and initiation of the fast wind in coronal holes

S-9. Understand active region expansion, streamer formation, and the nature of the slow wind

Table A-1.3.1. shows the mapping between the Instrument Science Objectives and how the Science Goals of SDO are met ("X" denotes an Objective that directly addresses a Science Goal, while "S" indicates an Objective which supports the goal.)

Instrument Science Objective

Science Question	E-1	E-2	E-3	E-4	H-1	H-2	H-3	H-4	H-5	S-1	S-2	S-3	S-4	S-5	S-	S-7a	S-7b	S-8	S-9
What mechanisms drive the quasi-periodic 11-year cycle of solar activity?	S				X	X					S								
How is active region magnetic flux synthesized, concentrated, and dispersed across the solar surface?		S			X	X		X		S	X								
How does magnetic reconnection on small scales reorganize the large-scale field topology and current systems? How significant is it in heating the corona and accelerating the solar wind?		S				X		X	X		X	X	S	S				X	X

Where do the observed variations in the Sun's EUV spectral irradiance arise, and how do they relate to the magnetic activity cycles?	X	X	X	X		X	X		S	X	S								
What magnetic field configurations lead to the CMEs, filament eruptions, and flares that produce energetic particles and radiation?						S	X	S	X				X	X	X	X	X		
Can the structure and dynamics of the solar wind near Earth be determined from the magnetic field configuration and atmospheric structure near the solar surface?						S		X	S		X					X	X	X	X
When will activity occur, and is it possible to make accurate and reliable forecasts of space weather and climate?	S	S	X	X	S	X	X	S	X	S			X	X	S	X	X	S	S

Table A-1.3.1. By satisfying the Instrument Science Objectives, the Science Goals of SDO are met ("X" denotes an Objective that directly addresses a Science Goal, while "S" indicates an Objective which supports the goal in a secondary manner)

The goals can be satisfied by four measurement objectives provided that those measurements are made over a significant percentage of a solar cycle to permit characterization of internal solar variations that may exist in different time periods of a solar cycle. In addition, the measurements should be complementary in location, spatial resolution, wavelength coverage, and time cadence so that rapidly evolving features such as flares can be characterized. The measurement objectives are to:

1. Provide data for near-surface diagnostics of the dynamics of the solar interior that are sufficient for both global and local helioseismology.

2. Provide information about the global solar magnetic field, the active region evolution, small-scale features, and sources of irradiance variations.

3. Characterize the rapid evolution of plasma in the chromosphere and lower corona with a field of view and spectral coverage sufficient to facilitate linkage with the coronagraph images and to help interpret the EUV spectral irradiance measurements

4. Characterize the solar extreme ultraviolet (EUV) irradiance on timescales ranging from seconds to years to understand the solar variation caused by solar magnetic field evolution, and to study the solar induced variations of the Earth's ionosphere and thermosphere.

Table A-1.3.2. shows how the Measurement Objectives, and the instruments that meet those objectives, map to progress on each of the Science Questions.

Science Question	Measurement Objective	Instrument
What mechanisms drive the quasi-periodic 11-year cycle of solar activity?	1 (2, 3, 4 are secondary)	EVE, HMI, SHARPP
How is active region magnetic flux	1, 2, 3 (4 is secondary)	EVE, HMI, SHARPP

synthesized, concentrated, and dispersed across the solar surface?		
How does magnetic reconnection on small scales reorganize the large-scale field topology and current systems? How significant is it in heating the corona and accelerating the solar wind?	2, 3 (4 is secondary)	EVE, HMI, SHARPP
Where do the observed variations in the Sun's EUV spectral irradiance arise, and how do they relate to the magnetic activity cycles?	2, 3, 4	EVE, SHARPP, HMI
What magnetic field configurations lead to the CMEs, filament eruptions, and flares that produce energetic particles and radiation?	2, 3	HMI, SHARPP
Can the structure and dynamics of the solar wind near Earth be determined from the magnetic field configuration and atmospheric structure near the solar surface?	2, 3	HMI, SHARPP
When will activity occur, and is it possible to make accurate and reliable forecasts of space weather and climate?	2, 3, 4 (1 is secondary)	EVE, SHARPP,HMI

Table A-1.3.2. This table shows the mapping between the Measurement Objectives and the Science Questions.

A-1.4 PROJECT ORGANIZATION AND MANAGEMENT

The OSS has delegated responsibility for managing the implementation of the SDO Project to the GSFC. This responsibility includes managing the implementation approach and the resources for the project during formulation and implementation, science investigations, space flight systems, and ground systems contracts, staffing, facilities, and funding that coincide with available resources. The OSS has approved the development, assembly, integration and test of the SDO spacecraft at the GSFC.

The authority for the Governing Program Management Council (GPMC) for the LWS Program evolves as a function of time. Before the SDO is confirmed to enter Phase B, the GPMC is the Program Management Council (PMC) at the GSFC. At the Initial Confirmation Review (ICR), the transition from Phase A to Phase B, the GPMC changes to the Agency PMC, since the Administrator must approve all new programs for Implementation. After the SDO mission completes a successful Non-Advocate Review (because it is the first mission in the LWS Program) and is confirmed for Implementation, the GPMC changes to the OSS's Enterprise PMC (EPMC).

Regardless of the presiding authority of the GPMC for the SDO, the OSS shall hold the GSFC Center Director responsible for the content, quality, and success of the SDO project. The GSFC PMC shall review the SDO Project and its independent assessment products before they are forwarded to the OSS, and the OSS shall review the SDO Project and its independent assessment products before they are presented to the Agency PMC.

A-1.4.1 TEAMING ARRANGEMENTS

The primary SDO teaming arrangements for the mission implementation and flight operations are between the GSFC, the University of Colorado in Boulder, Colorado, Stanford University, and the Naval Research Laboratory (NRL). GSFC's three institutional partners are under contract to the GSFC and are key to the scientific success of the SDO mission. They have the following investigation responsibilities:

- University of Colorado – Extreme Ultraviolet (EUV) Variability Experiment (EVE);
- Stanford University – Helioseismic and Magnetic Imager (HMI); and,
- NRL – Solar Heliospheric Activity Research and Prediction Program (SHARPP).

The SHARPP instrument has three international contributors, from Belgium, France and Italy.

A-1.4.2 PROJECT ACQUISITION STRATEGY

The SDO science investigations are procured through the Announcement of Opportunity (AO) process. No acquisition competition occurred prior to the decision by the OSS to approve the GSFC proposed approach to develop and build the SDO spacecraft at the GSFC. The Kennedy Space Center (KSC) launch services contract is used to acquire the launch vehicle.

A-2.0 PROGRAMMATIC REQUIREMENTS

The development of the scientific understanding needed to enable the development of an operational capability for space weather prediction (the purpose of the LWS Program) requires an understanding of a 22-year time period of solar activity comprised of two solar cycles. The SDO's investigations to develop the capability to predict solar activity, its consequences in space, and the long-term climate of space require that it transmit large quantities of data for 24 hours a day, 7 days a week, for long time periods without significant interruptions. The ground system for the acquisition and distribution of these data is provided within the scope of the SDO project.

A-2.1 SCIENCE REQUIREMENTS

The science requirements for the SDO mission are described below.

A-2.1.1 MISSION SUCCESS CRITERIA

Full and minimum success criteria have been defined for SDO to set the boundaries for the SDO mission design space. The SDO baseline mission is being designed to meet the full mission success requirements, while reliability analysis is applied to ensure the achievement of the minimum mission.

A-2.1.1.1 FULL MISSION SUCCESS CRITERIA

The following measurements shall be obtained over the prime mission life of five years to obtain full mission success:

All three investigations operating 80% of the time over the course of 5 years

Instrument performance commensurate with the Science Instrument Full Performance Requirements listed in Section A-2.1.2.

A-2.1.1.2 MINIMUM MISSION SUCCESS CRITERIA

Tables A-1 and A-2 indicate that the majority of the Science Goals can be addressed despite the failure to meet a Measurement Objective. Therefore, the minimum success criteria for the SDO are as follows:

Two out of the three investigations operating 40% (60%?) over the course of 5 years.

Instrument performance commensurate with the Science Instrument Minimum Performance Requirements listed in Section A-2.1.2.

A-2.1.2 SCIENCE INSTRUMENT PERFORMANCE REQUIREMENTS

2.1.2.1 EVE INSTRUMENT REQUIREMENTS

EVE is a suite of spectral measuring instruments consisting of a Multiple EUV Grating Spectrograph (MEGS), MEGS A and MEGS B, that provides spectral irradiance measurements at high time cadence, an Optics-Free Spectrometer (OFS) for overlapping measurements and calibration, and an EUV Spectrophotometer (ESP) that provides extended spectral coverage and additional MEGS calibration.

A-2.1.2.1.1. EVE shall perform solar spectral irradiance measurements covering the 0.1 to 105 nm range. These measurements should be obtained at a cadence of no slower than 20 seconds.

A-2.1.2.1.2. EVE shall measure at least 18 emission lines at a spectral resolution of 0.1 nm. The absolute accuracy of these emissions should be 25% or better for the duration of the prime mission. These 18 emission lines have been chosen to adequately characterize the solar EUV spectrum variations for LWS/Geospace applications.

Add EVE minimum performance requirements when finalized

A-2.1.2.2 HMI INSTRUMENT REQUIREMENTS

HMI makes measurements of the Sun's vector and longitudinal magnetic fields and doppler velocity by obtaining filtergrams over a range of wavelengths in different polarizations.

A-2.1.2.2.1. The HMI shall obtain full-disk, 1.5-arcsec resolution photospheric velocity measurements every 50 seconds with an accuracy of TBD m/sec.

A-2.1.2.2.2. The HMI shall obtain full-disk, 1.5-arcsec resolution longitudinal magnetic field measurements every 50 seconds with a dynamic range of 3 kG.

A-2.1.2.2.3. Full-disk, 1.5-arcsec resolution vector photospheric magnetic field measurements every 10 minutes with a polarization accuracy of .3%.

Add HMI minimum performance requirements when finalized

A-2.1.2.3 SHARPP INSTRUMENT REQUIREMENTS

SHARPP has two components: **KCOR (**K-coronagraph)**,** a white light coronagraph imager capable of making polarization and white light measurements of the corona; and, **AIA** (Atmospheric Imaging Assembly), a suite of high-resolution Ultraviolet/EUV telescopes and a guide telescope that provides the AIA with a pointing error signal of 0.25 arc-seconds over a 50 arc-second range of motion.

A-2.1.2.3.1. SHARPP shall obtain full-disk, 1.32-arcsec resolution images of the solar atmosphere out to 1.2 solar radii in seven wavelengths spanning the temperature range 20,000 to 3 million Kelvin (K) with a cadence of at least one set every 10 seconds.

A-2.1.2.3.2. SHARPP shall obtain white light coronagraphic polarization and brightness images with a time cadence of no higher than 60 seconds, with a pixel size of 15 arcsec from 2 to 15 R_{sun} with an accuracy of 10%.

Add SHARPP minimum performance requirements when finalized

A-2.2 MISSION AND SPACECRAFT PERFORMANCE

A-2.2.1 The mission design life shall be five years that starts after the spacecraft is in geosynchronous orbit and the instruments have successfully completed check-out.

A-2.2.2 The mission shall contain consumables to support instrument operations for ten years.

A-2.2.3 Data analysis shall be provided for the five-year prime mission lifetime and for one additional year after completion of the prime mission.

A-2.2.4 The end-to-end system of the SDO instrument, spacecraft, and ground system shall obtain and deliver solar observations to the Principal Investigator's Science Operating Centers (SOC) of sufficient quality to achieve the mission science requirements.

A-2.2.5 The SDO shall maintain near-continuous science data downlink contact with the ground in order to capture the science data within the capture budget.

A-2.2.6 The SDO shall employ the use of a dedicated ground station to meet science data downlink completeness requirements.

A-2.2.7 The SDO shall be designed to support Orbit Circularization.

A-2.2.8 All mission and time critical activities shall be performed within ground contact to allow telemetry monitoring.

A-2.2.9 The SDO shall be designed to support controlled end-of-life disposal.

A-2.2.10 The SDO shall support the system studies of the LWS science community.

A-2.3 LAUNCH REQUIREMENTS

A-2.3.1 The launch vehicle shall deliver the Observatory to a transfer trajectory from which the Observatory-supplied propulsion system shall modify the orbit to its desire final profile.

A-2.3.2 The launch vehicle shall be capable of delivering a secondary payload to a transfer trajectory when it delivers the SDO primary payload to its transfer trajectory.

A-2.3.3 The launch vehicle shall provide mechanical and electrical interfaces to the SDO and the ground system for testing, verification, and flight operations.

A-2.4 GROUND SYSTEM REQUIREMENTS

A-2.4.1 The ground system shall support a science data downlink rate of up to 150 Megabits per second for 24 hours per day and 7 days per week. (Add 95%?)

A-2.4.2 The Ground Stations shall route the science data directly to the Instrument Science Operations Centers after receiving the data and accounting for the data latency requirements.

A-2.4.3 Each ground station shall provide S-band frequency command, telemetry and tracking functions in support of SDO mission operations.

A-2.4.4 Each ground station shall provide local Ka-band frequency telemetry storage in support of SDO science operations.

A-2.5 MISSION DATA REQUIREMENTS

A-2.5.1 The PI teams shall provide a data archive of their instrument science and science data products for the life of the mission in accordance with the requirements in the LWS Data Management Plan.

The PI teams shall formulate all primary science data products and provide for their distribution in accordance with the requirements in the LWS Data Management Plan.

A-2.5.2 The SDO Principal Investigators shall provide the calibrated, full-resolution data obtained as part of the SDO mission including the engineering data and ancillary information necessary to validate and calibrate the science data to the public as soon as possible after collection. This data shall be accessible to all SDO Investigators, to the general science community, and to the public in accordance with the requirements in the LWS Data Management Plan**.**

A-2.5.3 The SDO Principal Investigators shall be responsible for the initial assessment of the data, the subsequent delivery of the data products and analysis software to the data repository in accordance with the requirements in the LWS Data Management Plan and with funding provided by the SDO project**.**

A-2.5.4 The SDO Principal Investigators shall be responsible for scientific analysis necessary to meet the instrument science objectives.

A-3.0 MISSION, SCHEDULE, AND COST REQUIREMENTS

A-3.1 SCHEDULE REQUIREMENTS

The SDO Project Plan shall include provisions for the development and regular update of detailed, logic-based schedules for the spacecraft and individual instrument providers. These schedules shall include all major activities, interdependencies between major items, deliveries of end items, critical paths, schedule margins, and long-lead procurement needs. Major milestones reflected in the Program Commitment Agreement and this document shall be held under Headquarters control, a set of milestones that expand upon and support the Headquarters-controlled milestones are controlled by the LWS Program Office, and the detailed schedules that support the Headquarters-controlled milestones are controlled by the SDO Project Office.

A-3.2 COST REQUIREMENTS

The SDO shall be cost capped at $450 million in real year dollars *(this number will need to be modified for full-cost accounting and worded in such a way that the Headquarters and GSFC institutional numbers are allowed to vary depending upon the agreements negotiated yearly as part of the POP)* for the total life cycle cost (LCC) including the launch vehicle, five years of operations, and six years of data analysis. Provided that Program-Level Requirements are preserved and that due consideration has been given to the use of budgeted contingency and planned schedule contingency, the SDO project shall pursue scope reduction and risk management as means to control cost. The SDO Project Plan shall include potential scope reductions and the time frame in which they could be implemented. If other methods of cost containment are not practical, the reductions identified in the Project Plan may be exercised. However, the SEC Director shall approve any reduction in scientific capability, including those reductions specifically identified in the Project Plan, before they are implemented by the Project. The signers of this document shall agree to any potential scope reductions affecting these Program Requirements.

A-4.0 EXTERNAL AGREEMENTS

The SDO Project shall be conducted in consideration of the following letters of agreement (LOAs):

LOA with Belgium regarding the provision of their contribution to the SHARRP AIA….

LOA with Italy regarding the provision of their contribution to….

LOA with CNES regarding the provision of their contribution to….

Any future agreement with another US government organization would go here.

A-5.0 INTERNAL AGREEMENTS

The SDO Project shall be conducted in consideration of the following LOA:

LOA with White Sands?

LOA with KSC needed?

A-6.0 EDUCATION AND PUBLIC OUTREACH

The SDO Project shall develop and execute an Education and Public Outreach Plan that is consistent with the information provided in the approved Solar Terrestrial Probes-LWS Education and Public Outreach Plan, a document approved as part of the approval of the LWS Program Plan.

A-7.0 TAILORING

No tailoring of the requirements in the LWS Program Commitment Agreement or the LWS Program Plan is planned.

APPROVALS AND CONCURRENCES

NASA Headquarters:

Edward J. Weiler Associate Administrator for Space Science	Date
Richard R. Fisher Director, Sun-Earth Connection Division	Date
Kenneth W. Ledbetter Executive Director for Flight Programs	Date
Dana A. Brewer Program Executive, LWS Program	Date
Madhulika Guhathakurta Program Scientist, LWS Program	Date
William ? Wagner Program Scientist, SDO Project	Date

APPROVALS AND CONCURRENCES (Continued)

Goddard Space Flight Center:

O. Christopher St.Cyr Senior Project Scientist, LWS Program Goddard Space Flight Center	Date
Barbara J. Thompson Project Scientist, LWS Program Goddard Space Flight Center	Date
Kenneth O. Schwer SDO Project Manager Goddard Space Flight Center	Date
Nicholas ? Chrissotimos LWS Program Manager Goddard Space Flight Center	Date
Dorothea ? Perkins Director, Flight Programs and Projects Goddard Space Flight Center	Date

APPROVALS AND CONCURRENCES (Continued)

Goddard Space Flight Center (Continued):

William F. Townsend Deputy Director Goddard Space Flight Center	Date
A. V. Diaz Director Goddard Space Flight Center	Date