Heliospheric EUV/Radiometric Observer
HERO
For the International Space Station

C. SCIENCE INVESTIGATION

Introduction

Measurements of the solar energy throughout the solar spectrum and understanding its variability as a function of wavelengths provide important information about the physical processes and structural changes in the solar atmosphere. Understanding the terrestrial implication of the changes in the solar electromagnetic flux is essential, since the solar energy is deposited in various parts of the Earth's atmosphere, oceans, and lands. Therefore, it controls the heating, ionization, radiative, chemical, and dynamical processes characterizing the terrestrial atmosphere and climate system.

Since 1978 the Total Solar Irradiance (TSI) has been measured by various satellite experiments (fig XX). Unfortunately, the absolute accuracy of the measurements and degradation of the instruments make direct evaluation of the TSI and its variability impossible. While it is possible to use cross calibration techniques to estimate irradiance variations up to timescales of the order of the solar cycle, longer term trends, that may be important in climate change, can not be judged due to calibration and degradation uncertainty and gaps in the data set.

In order to over come this degradation and calibration problem we propose to fly a radiometer and EUV spectrometer on an International Space Station (ISS) Express palette, so that, for the first time, the instrument can be returned and the degradation mechanism studied and the instrument calibrated post-flight.

Figure XX. Time series of daily TSI values in Wm^{-2} as observed by NIMBUS7, ACRIM I & II, ERBS, SOVA2 and VIRGO.

1. Scientific Goals and Objectives

The specific scientific objectives listed below address the effect of Total Solar Irradiance (TSI) an X-ray/EUV/FUV variations in the space environment and their effect on the terrestrial atmosphere. The goals of the Heliospheric EUV/Radiometric Observer (HERO) mission and their relation to the goals of NASA's Sun–Earth Connection Program are listed below:

Tabulate:

- Compare various total irradiance data, including the DBSIM measurements, with high-energy radiations from X-ray to far UV to test their effect on the degradation of various types of radiometers.

- Perform space pyrheliometric intercomparison using the advantage of several and various type of radiometers in space in order to establish a new and advanced “Space Irradiance Reference Scale”. Since the current absolute accuracy of total irradiance measurements is ±0.2%, to reduce the various data sets to a well-established reference scale is essential to compile a long-term composite total irradiance to study the climate effect of irradiance changes.

- Provide simultaneous rapid (less than one minute time scale) measurements of TSI and absolute solar soft X-ray to far ultraviolet flux to investigate the relationship in variability and to provide the appropriately weighted flux input into the Earth’s atmosphere.

- Establish with high time resolution the temporal and spectral dependence of transient solar events in the X-ray to far ultraviolet spectral region.

- Relate the characteristics of solar flares and other such transient events to the characteristics of established Coronal Mass Ejection (CME) events. The objective is to find an electromagnetic signature associated with a CMEs.

- Provide an early warning of possible CME events. This will allow time for spacecraft systems to be put in a safe mode, astronauts time to abort space walks, and Earth bound power plants time to prepare for power surges.

- Test DBSIM in space and compare the DBSIM total irradiance data with other measurements, such as provided by the SOVA1 and SOVA2 radiometers on the ESA/ISS platform; the EOS/ACRIM III and SORCE/TSIM.

- Maintain a high precision irradiance database, validate measurements with in the comparison of DBSIM with other TSI measurements, and to integrate the results into NASA’s long-term Total irradiance database.

- Carry out research to better understand the underlying physical mechanisms of total solar irradiance variations.

- Compare data with high-resolution solar images available from various ground-based and space-based sources.

- Study of the contribution of the various solar activity features to the changes can solar total irradiance as a function of solar cycle and interpret the observed irradiance changes.

It is important to note that all of the above goals and objectives will be met with an instrument package which will have very low impact on spacecraft and mission resources, as may be seen in the instrument description and budget sections.

1. Total Solar Irradiance

The first space observations of total irradiance started in late 1978, and now for more than two decades total irradiance has been monitored from several space platforms (Fig. xx). These observations have established conclusively that total irradiance varies during the course of the solar cycle with an amplitude of 0.1%, being higher during solar maximum (Willson and Hudson, 1991). Short-term changes from days to months are superposed on this longer term trend which are related to the effect of active regions sunspots and facuale (Hudson et al., 1982). In the range of 5-min, the granulation and p-modes are the main drivers of the irradiance variations (Frohlich *et al.,* 1997).

Although it has been shown that a considerable part of irradiance variations are caused by the effect of the surface manifestations of solar activity (Foukal and Lean, 1988), there is a significant residual variability which cannot be explained by a simple effect of sunspot darkening and facular enhancements (Frohlich and Pap, 1989; Frohlich *et al.*, 1997). One of the most suprising results is the behavior of total irradiace during the rising portion of solar cycle 23, when it started to rise about 10 months sooner than other solar indices (Pap et al., 1999) and the current irradiance models underestimate the measured total irradiance (Frohlich, 1999). The fundamental question, however, is whether effects other than surface magnetic activity, like temperature and radius changes contribute to the long-term variations of total irradiance (Kuhn, 1998), or part or all of the residual variability is related to the insufficient accuracy and long-term precision of the current irradiance measurements (Frohlich, 1998; Pap and Frohlich, 1999).

One of the largest obstacles in studying long-term variations in total irradiance is the limited absolute accuracy (±0.2%) of the calibration of the radiometers. This limited absolute accuracy, as shown in Fig.XX, leads to the different scale of the various irradiance measurements. The problem is further complicated since the measurements have been made with different types of instrument, operational modes and data reduction techniques. In order to compile a homogeneous long-term total irradiance data sets we have to (1) better understand the characteristics of the instruments and (2) to establish a Space Irradiance Reference Scale to which the various data sets can be reduced. These efforts are necessary to clarify whether the residual variability of total irradiance is a real solar effect related to global changes inside the Sun. This is an important issue in solar physics since it can help us to clarify the origin of solar variability and it is equally important to understand the role of solar variability in climate changes.

Various attempts have been made to establish an irradiance reference scale, the first, the so-called “Angstrom scale”, was introduced as early as 1905. After several unsuccessful attempts, the World Radiation Reference (WRR) was introduced in 1980 which is defined by five different types of radiometers located at the World Radiation Center, Davos, Switzerland. Most recently, Crommelynck *et al.* (1995) defined the Space Absolute Radiometer Reference (SAAR) scale based on comparison of various flight experiments in 1992 and 1993. However, these flights occurred in consecutive years during the declining phase of solar cycle 22. Optimally, such a radiometric scale should be established under the same solar activity conditions by comparing the irradiance measurements of various instruments. In addition, the effect of high-energy solar radiation, considered to be one of the major sources of the degradation of radiometers, should be studied at the same time.

Flying HERO on the International Space Station concurrently with the SOVA experiment on the ESA/ISS platform would provide the comparison of various radiometers at the same time. In addition, other radiometers, such as the EOS/ACRIM III and TSIM will also perform parallel irradiance measurements. Therefore, intercomparison of these radiometers will help to establish a more reliable "real" irradiance level to which all the measurements can be scaled.

The impact of long mission life is that, without exception, all TSI instruments degrade with time and exposure due to the high intensity of solar radiation. The highest level of degradation is on the detectors. Other factors to consider in the degradation are the effects of age on the electronic components and the general optical quality of the instrument, such as shutter and collimator surfaces. Though we have devised schemes to mitigate this problem by flying 'backup' detectors that are not exposed as often as the operational detector, this approach cannot account the degradation due to aging in the electronics and general instrument optical quality. Furthermore, this scheme assumes that the detector degradation is totally due to solar exposure and that the backup detectors have no aging characteristics. This is a risky assumption. Data from the two radiometers in the VIRGO experiment on SoHO (PM06 and DIARAD) demonstrate different spectral sensitivity and degradation profiles, indicating that the cavities degrade differently with EUV exposure, making it difficult to asses the actual TSI variability. One should keep in mind and that the average time between the calibration of a typical laboratory instrument in a benign environment is six months. One can also see that maintaining absolute radiometry on these time scales are impossible without re calibration.

Concurrent comparison of the various total irradiance data with the HERO/EUV measurements will help to better correct for the degradation of the different types of radiometers related to the high-energy radiation. The return of the HERO instruments for post-flight calibration will provide the means to understand the absolute degradation, and apply corrections to other data sets.

In addition to space pyrheliometric intercomparison, DBSIM will also provide high time resolution and precision irradiance measurements. These irradiance data will be compared to groundbased solar images available from several sources (e.g. PSPT in Hawaii, BBSO, Kitt Peak). These intercomparisons will make it possible to follow the emergence, evolution, and decay of active regions and to study their effect on total irradiance. Although there are hints in the literature that the evolution of active regions plays a prominent role in the changes of total irradiance (Frohlich and Pap, 1989; Pap, 1997), the high cadance of the DBSIM observations will allow us to closely monitor the effect of the movement and the change of the characteristics of active regions on total irradiance.

2. Relevance to NASA Themes and Missions

Analyses based on the results of the two-decade long irradiance measurements, both bolometric and at various wavelengths, have established conclusively that the Earth's climate, radiative environment, and upper atmospheric chemistry are influenced by the varying solar energy flux, and understanding and predicting the various forms of interactions in the Sun–Earth system are imperative for assessing the impact of future human activities. Therefore, it has become one of the major future plans of NASA to understand how to Live with a Star — with our changing Sun. There are two major concerns:

- how the changing solar radiation influences the atmospheric chemistry and the Earth's climate.
- how the changing Sun influences our space environment and human activities in space.

Sun—Earth Connection and Solar Physics

The Earth's climate is the result of a complex and incompletely understood system of external inputs and interacting internal parts. Climate change can occur over a range of time scales, may be driven by natural variability — including solar variability — and/or anthropogenic. Global climate change in response to human influences is one of the most pressing questions facing science today. Predictions of climate change in response to greenhouse-gas emissions by the current generation of climate models roughly agree on prospects for globally warmer climates and more vigorous hydrologic cycles.

The major portion of the entire solar spectrum is fairly well represented by a blackbody with a temperature of 5770 K. This mostly continuum radiation originates in the solar photosphere. Its major part reaches the troposphere and the Earth's surface and oceans, and long-term changes in this energy output may be responsible for slow climatic changes such as produced the Little Ice Ages (Hansen et al., 1993). Short-term changes over days, weeks and a few years appear to have little climatic effect, but the Earth's upper atmosphere is very responsive to solar activity variations in general via the effect of energetic solar radiations and particles.

Although the solar radiation below 300 nm represents only 1% of the Sun's total electromagnetic output, variations in this part of the spectrum are especially important since it is totally absorbed in various layers of the Earth's atmosphere. Consequently, it plays a significant role in heating the Earth's atmosphere and establishing its chemical composition through photodissociation and photoionization processes. Especially below 200 nm, the solar energy represents only a small fraction (less than 0.01%) of the total solar flux. This part of the spectrum involves emission lines and continua emitted from the chromosphere, chromosphere—corona transition layer, and the solar corona. The set of emission features starts with the SI II lines near 182 nm. The Lyman-α line at 121.6 nm is the first major emission line for which the intensity exceeds the neighboring continuum by orders of a magnitude (Rottman, 1988). The 125 – 170 nm spectral range is aeronomically important since it heats the lower thermosphere (below about 200 km) through the production of O by O_2 absorption in the Schumann-Runge continuum. The importance of the strong Lyman- α emission line for terrestrial research is well established. In the mesosphere it photodissociates water vapor, which contributes to the destruction of ozone at about 70 km altitude. Between 60 and 90 km of the Earth's atmosphere, the ionization of NO by Lyman- α is responsible for the formation of the ionospheric D region. The Lyman- α line is usually considered as a dividing line between the solar UV and EUV spectrum.

The various EUV emissions at wavelengths shorter than Lyman- α and down to X-ray are entirely absorbed above 90 km in the Earth's atmosphere by the major neutral constituents of O, N_2, and O_2. These emissions are also responsible for the ionization of the E and F regions. The E region is formed by the absorption of the solar EUV flux between 80 and 102.7 nm. The F region is the most heavily ionized part of the ionosphere by the 20 – 90 nm EUV radiation, which includes an intense solar emission line at 30.4 nm.

The most variable part of the solar spectrum is the X-ray in the 1 – 8 Å band. It arises principally from coronal regions of closed magnetic flux loops. It has been shown that 98% of the disk-integrated 1 – 8 Å X-ray flux is associated with active regions. The X-ray spectrum is a combination of continuum and line contributions. The mix of line and continuum varies from quiescent active region to flare conditions — the amplitude of the flare-related rapid changes can be as large as 10^5 (Wagner, 1988). Although the amount of the energy in the X-ray band is negligible in the solar electromagnetic spectrum, the large temporal variations have significant effect on the terrestrial atmosphere, especially on the ionosphere. The X-ray radiation penetrates deeper to the Earth's atmosphere, and it plays an important part in the ionization of the D region below 68 km and between 81 and 85 km. In principle, it ionizes all the atmospheric constituents, but it is most effective in ionizing O_2 and N_2. Rapid changes in X-ray related to solar flares have been identified as primary causes of the sudden ionospheric disturbances which cause fadeouts in high-frequency radio propagation.

A precise knowledge of the structure and variability of the neutral and ionized upper and middle atmospheres thus requires knowledge of the solar variability in the EUV and soft X-ray spectral regions. Unfortunately, the variation of the solar EUV irradiances over the solar cycle is poorly known since observations of this radiation cannot be made from the ground. Direct space based absolute EUV and soft X-ray absolute solar irradiance measurements using pre SoHO spectrometers were, unfortunately, extremely difficult to interpret because of optical surface instabilities, changes in detector sensitivity and calibration uncertainties, and have often led to large errors in the measured solar flux. These difficulties have long been recognized by the space science community and have resulted in many attempts to characterize the solar EUV irradiance using models based primarily on empirically constructed EUV reference spectra along with solar

EUV flux proxies such as the daily F10.7 radio flux and its 81-day average (Hinteregger, 1981; Richards et al., 1994). Some models make use of both the ground-based F10.7 and space-based hydrogen Lyman-α data (Tobiska and Barth, 1990; Tobiska, 1991; Tobiska and Eparvier, 1998). Inconsistencies between the EUV solar irradiance models and the actual measured absolute fluxes they attempt to reproduce are well known and have been addressed by Lean (1990) and Richards *et al.* (1994).

Figure XX Time series of daily EUV flux values as 10^9 photons cm^{-2} s^{-1} as observed by SEM on SoHO.

Absolute Solar Hydrogen Ly-α Observations

Nearly all estimates of the thermodynamic parameters such as density, bulk velocity and temperature of heliospheric hydrogen in the very local interstellar medium (VLISM), which include the interplanetary medium, have been derived through observations of resonantly scattered (line of sight) solar emissions by H Ly-α (121.6 nm); however, significant disparities have been reported (Chassefière *et al*., 1986, and Ajello *et al*., 1987). Furthermore, one important input parameter that is essential in interpreting and characterizing the physical and thermodynamic state of the heliosphere and/or its dynamics is the absolute solar flux at H Ly-α. Recently, the absolute solar H Ly-α flux database from Earth orbit has been recalibrated to the UARS satellite (SOLSTICE Ly-α) by Tobiska and Eparvier 1998, emphasizing the importance of absolute solar HI Ly-a flux. In the proposed work we will measure the absolute flux at H Ly-a using the same techniques which we have demonstrated in the solar EUV i.e. we will provide continuous observations of superb quality, high stability transmission grating “filters” and photodiodes.

Hydrogen Ly-α observations also provide an important FUV spectral window into the physics of active solar regions. The way in which solar transient electromagnetic events develop in the X-ray to FUV spectral region is a largely unexplored science, hence, the observations of emissions over a broad range of photon energies is required to fully characterize these events in the highly time variable spectral region.

Finally, not only is the absolute solar H Ly-α flux required as an input source function for interpreting backscattered H Ly-α from the atomic hydrogen gas in which the Earth is imbedded, it is also required as an input into the photochemistry of the Earth’s atmosphere, as discussed in the Section entitled Sun—Earth Connection. Thus, it is an important input into understanding the dynamics and coupling of the Sun-Earth system and should therefore be continuously observed from well outside the Earth’s hydrogen corona.

Space Weather

Space weather is in its broadest sense a science dedicated to understanding the full range of external physical phenomena which affect the Earth and its environment. By far the most important driver of the “local” day to day space weather is the Sun and its highly variable short wavelength electromagnetic and particle emissions.

The HERO/EUV instrument provides high temporal resolution (0.25 s) observations of solar soft X-ray and EUV. Such data will be invaluable to the scientific community and to the general public since particle ejections associated with solar dynamics often lead to magnetic storms which can disrupt power plant operations and communications. Particularly strong enhancements of solar X-rays, EUV, and FUV radiation accompany large solar flares and highly active solar regions. The magnetic storms are driven by energetic particles associated with CMEs directed toward Earth. In addition to disrupting power distribution systems over large geographic regions such storms can dramatically affect radio communications through severe ionospheric disturbances. Forewarning is particularly important for astronauts as space weather can adversely affect their health unless they are inside their space habitat. It is therefore imperative that an early warning storm watch system be available that is simple, and highly reliable. The HERO/EUV instrument meets these requirements and will provide real time continuous observations of solar weather.

It is very important to manned space exploration to develop an early warning system of imminent arrival of CME event particles. For example, Figure XX shows a CME event that ooccurred on April 7 1999. Figure XXa (from the the the Report of the NASA Science Definition Team for the STEREO mission) shows the response of the SoHO EIT, LASCO, and COSTEP instruments and the WIND spcecraft. Figure XXb shows the SoHO/ CELIAS/ SEM 15 s data for the CME event. Both CELIAS/SEM central and the first order data indicate the onset of the CME occurring at 13:53 UT. *Thus, the high time resolution of HERO/EUV instrumentation will clearly measure the beginning of major solar events coupled to the eruption of CME events.* Indeed, The SoHO data have been identified by the National Space Weather Program as a space weather metric in its executive summary document entitled, “Study of Metrics for the National Space Weather Program”.

Figure XXa SoHO EIT, LASCO, COSTEP, & WIND observations of the 7 April 1997 CME event data for the CME event described in Figure 9 of the Report of the NASA Science Definition Team for the STEREO mission.

Figure XXb The time evolution of the same 7 April 1997 X-ray event shown in Figure XXa, as seen by SoHO CELIAS/SEM. Note the time scale here is in hours rather than days for XXa

3. Relevance to the Space Station Program

Flying HERO experiment on the International Space Station will provide a sensitive, independent evaluation of the contamination environment near the ISS.

Provide a warning of proton events and radiation dangers to ISS personel.

2. Science Implementation

a. Instrumentation

The Heliosphere EUV/Radiometer Observer (HERO) consists of two sets of hardware components: the science detector head assembly and a two-axis scan platform on which it is mounted. The experiment is designed to take full advantage of ISS facilities with no impact on the flight crew. The science assembly is primarily two Sun viewing instruments making full solar disk measurements simultaneously from the same platform. They are the Differentially Balanced Solar Irradiance Monitor (DBSIM) and an Extreme Ultraviolet (EUV) spectrometer.

2.a.1 The DBSIM

Overview and Heritage

We derive the pedigree of the DBSIM from two instruments that span the 20-year history of total irradiance study from space, namely, the ACRIM I, ACRIM II, and SOLCON and DIARAD. The DBSIM borrowed the highly efficient conical cavity design used by the ACRIM I and ACRIM II instruments and combined them with the differential geometry of the SOLCON and DIARAD instruments. The inclusion of a Neural Fuzzy process controller further enhances the performance of DBSIM that triples the sampling rate of these older designs. Improvement in speed, precision and accuracy are the result of this heritage merging.

The fundamental component of DBSIM is the highly efficient conical cavity absorber. The absorber is a thirty-degree right circular cone mounted into cylindrical thermal impedance. Specular black paint is applied to the inner area of the cone. This arrangement provides six absorption paths in the cavity. Typically, the coefficient of absorption of this type of cavity is 0.99998.   On the outer area and near the apex of the cone is placed a stable ohm heater winding used to convert electrical energy into heat energy. Near the top and bottom of the cylindrical impedance, are placed resistive temperature sensors that transduce heat flux. Solar power is transduced by what is called electrical power substitution.

DBSIM Data Acquisition and Telemetry

The basic shutter operation mode of the DBSIM is the differential mode. A shutter alternately blocks solar radiation from, and admits it to, the primary cavity. The DBSIM time constant of less that 0.5 seconds provides measurements settled to within 1 ppm of the final value in 10 seconds following a shutter operation. The shutters are opened or closed every 24 seconds, providing symmetrical reference and observation phases. In the shutter closed (reference) phase all three cavities view the heat sink and electrical heating provides the necessary power to balance the primary cavity's conductive and radiative losses and maintaining the constant primary cavity-to-heat sink temperature difference. In the shutter open (observation) phase the primary cavity is irradiated by the sun and the remaining two cavities continue to view the heat sink. The electrical heating power supplied to the primary cavity is automatically decreased by the Fuzzy Logic PID servosystem in proportion to its absorption of solar irradiant power.

Solar irradiance in the International System of units (SI) is derived from the electrical power supplied to maintain the constant primary cavity-to-heat sink temperature balance in the two phases.

$$\text{Solarpower} = k/\alpha A\,(P_{ref} - P_{irr})$$

α = coefficient of absorption
P = electrical power
A = detector area
k = lumped errors (cavity radiation loss × heating non-equivalence × scattered light × diffraction losses...)

The absorption cavities are placed one-hundred and twenty degrees apart along equal radii on a high thermally conducive low heat capacity common thermal reference shown in Figure XX. Just above each of the absorption cavities are focusing precision apertures that accurately define the sensing area (A) and reflect excess sun light back to the view limiting apertures.

DBSIM Calibration

The Table Mountain Solar Test Facility (TMO/STF) will be used for instrument radiometric comparisons. It is situated at an altitude of 2316 meters in the Angeles National Forest, 60 miles NE of Los Angeles. The large solar tracker supports a one-meter environmental testing chamber and directs its three 25 cm diameter quartz windows at the sun. Up to three separate flight instruments can be tested in the chamber at a time. High vacuum ($1\text{x}10^{-6}$ Torr) can be reached from ambient atmospheric pressure in less that 10 minutes. The chamber has a temperature controlled mounting surfaces for operation and testing of flight instruments over -55 to +85 degrees Centigrade.

This program will allow a pre-flight and post-flight measurement to be obtained with the highest level possible after return from flight. This program is an efficient means to maintain the TSI observations in the Space Absolute Radiometric Reference (SARR) database.

The DBSIM instrument has been designed and a prototype instrument has been fabricated by JPL. The prototype DBSIM is being made available to the HERO mission at a significant cost savings to the HERO program. The HERO program will be responsible for modifications to the DBSIM for flight, analysis for safety, and the extensive pre and post flight calibrations.

The EUV Spectrometer

Overview and Heritage

The EUV spectrometer is a lightweight instrument based on the successful design of the SoHO CELIAS/SEM spectrometer (Ogawa et al. 1998), with enhanced capabilities. The EUV spectrometer will add a FUV (Lyman α) science channel. The EUV instrument package consists of two thin shells that bolt together for easy access to the optical components. The electronics resides below the optic axis and are located very close to the output of the silicon diodes to reduce effects of electromagnetic interference. The optical section of the EUV sensor can be considered in two sections:

1) X-ray EUV Spectrometer

A highly stable (150 nm thick) Al filter limits the radiation that enters the spectrometer to the Al transmission bandpass, blocking visible radiation. The transmission grating (5000 l/mm) spectrometer is configured to isolate and directly detect the prominent full disk solar He II 30.4 nm line and the Fe IX - Fe X complex (17.1 nm) in 1st order. The extended source of the Sun (~1/2°) and entrance slit (2 mm × 10 mm) give the spectrometer a bandwidth of ±5.0 nm at the first order position of these important lines. Detection of the X-ray and EUV emissions is realized using SoHO type Al coated Si photodiodes placed at the central order, which includes the X-ray spectral region of interest, and at the 30.4 and 17.1 nm 1st order positions. For moderate solar activity (Judge et al. 1999), and zero order detector will register ~180 pA, and each of the 1st order detectors ~15 pA, based on our experience with SoHO. The size of the detector (active area 6 mm × 16 mm) is selected to minimize signal loss due to any pointing errors up to 15 arc min., and to minimize losses due to the small dispersion produced by the horizontal grating support grids (4 μm period). The silicon photodiodes are unbiased and therefore only Johnson noise is expected. At a temperature of 0˚ C and with a shunt resistance of 100 MΩ, the thermal noise will only amount to 1.2×10^{-14} A/Hz$^{1/2}$.

2) FUV (Ly-α) Double Monochromator

The Lyman-α channel is a double monochromator using two 1000 l/mm free standing transmission gratings in series. The 121.6 nm band transmitted in 1st order by the 1st grating is then further dispersed by the second grating (-1st order) so that the visible light rejection is high (better than 10^{-10}). An uncoated, highly stable (Korde et al. 1993), photodiode detector produces and expected current is ~80 pA for a 1 mm x 10 mm entrance aperture. The bandpass of ±25 nm, will isolate the solar Ly-α line. The gratings are of the type flown on the highly successful ROSAT mission and the photodiodes and electronics are of the type flown by us on the equally successful SoHO mission.

Data Acquisition and Telemetry

The data acquisition and analog to digital conversion of the photodiode currents is similar for all channels. The diode output is amplified using a very low noise, stable integrated circuit electrometer, and then voltage to frequency converter/counter combinations used for digitization. The counters are read and data processed to a form suitable for the ICU by a Field Programmable

Gate Array (FPGA). A statistic will also be calculated based o the 1-20 nm data to provide a solar event ‘beacon’. Time averaged data (say 15 s averages) can also be computed and transmitted over the beacon mode at a combined data rate of < 4bps as input for space weather predictions or as a solar event flag.

EUV Calibration

The HERO X-ray/EUV instrument will be calibrated pre-flight at the Synchrotron Ultraviolet Radiation Facility (SURF III) of the National Institute of Standards and Technology (NIST) in Gaithersburg (MD) and/or the synchrotron facility Brookhaven National Lab (BNL) in New York.

The aluminum coated diodes, aluminum filter and the gold gratings are separately calibrated throughout the wavelength regions of interest. The component calibration data provides the quantum yield of the photodiode detectors, the absolute transmission of the aluminum filters and the grating transmission at the zero and first order channels positions (30.4 nm and 17.1 nm). After the component calibration, and end to end instrument efficiency will be measured and a consistency check will be made to validate the calibration. The absolute uncertainty of the on-orbit instrument is expected to be ~ 8% at these short wavelengths based on our prior experience with our SoHO CELIAS/SEM, the predecessor of the proposed HERO EUV spectrometer. The expected flight precision is 0.5% or less.

The DBSIM and EUV sensors are mounted on a two-axis scan platform which allows the experiment to operate continuously and autonomously throughout the mission. The supporting (reflown) hardware has been developed and flown on six space shuttle missions successfully by Dr. Broadfoot’s group at the University of Arizona and includes a single board computer which controls the experiment; it receives, stores and performs observing sequences autonomously. Full-time operation is guaranteed by a mass-memory board used if telemetry is not available, the data is recorded on board for playback when the downlink is re-established. A low rate command and monitor data channel is all that is necessary.

There is a large accumulated inventory of qualified flight hardware of which we plan to take advantage. The primary heritage is due to the USAF supported “Arizona Airglow Experiment” (GLO). The complete interface system from the experiment through the shuttle to the ground station will be made available to support the implementation of the HERO experiment.

The Scan Platform

The DBSIM's viewing axis is parallel to the EUV spectrometer axis. Both instruments can tolerate an offset between its optic axis and the center of the sun of up to 0.5 degrees. However, pointing knowledge need to be at least 0.1 degrees.

A scan platform built by University of Arizona for the USAF, will be supplied to the HERO mission. U of A will supervise completion of the analysis, fabrication, and testing to qualify it to support the HERO experiment. The materials have been approved and as well as the design techniques. The HERO experiment assembly can be pointed ± 135° in elevation and ± 170° in azimuth. Three electro-optical limit switches on each axis provide position and limit information to the software in the ICU. The center limit switch provides a zero or reference position for positioning calibration which is used as a commencing position after instrument powerup and a starting point for software stored observations Software limits are coded into the operational software for the two axes. In addition to the software limit, mechanical stops are provided to limit rotational motion. Both potentiometers and encoders provide positional information. The center of gravity of the HERO assembly will be placed on the rotational axis of the scan platform to prevent large torques on the gearing system during dynamic flight. Consequently, the scan platform will be safe for launch and landing in any orientation.

Instrument Control Unit (ICU)

The microprocessor and control circuitry which operate the experiment are housed in the ICU. The ICUconsists of an Intell 386-based microprocessor card, boot ROM, capacitor-backedup RAM, erasable programmable read only memory (EPROM), a 16 megabytes memory, digital input/output, housekeeping cards (analog I/O), communications interface, a tracking CPU boards, communications memory, and a motor-drive board. The ICU orchestrates overall instrument operation and will interface HERO to the ISS avionics unit. The system is fully autonomous. Experiment configurations are stored on board. The ICU initiates and controls the experiment through time-tagged commands. New configurations can be uploaded at any time. There is sufficient memory to save data from observations when run during LOS periods.

Low-Voltage Power Supplies (LVPS)

A single enclosure houses the nine individual power supplies needed to generate the low voltages required by the HERO experiment head. The input voltage of +28V DC is supplied by the HH avionics unit. The output voltages are +5, +12, ±15, and +30V DC. All supplies use DC/DC converters which provide isolation between the input 28V DC and the output voltage. The ICU controls the on/off switching of all LVPS/s. The LVPS provides input current limiting, short circuit protection, and fusing for equipment protection.

Command and Data Handling

Data from the HERO experiment and the sun tracker will be routed to the ICU and then to the memory for buffering or temporary storage. The data will be retrieved from memory and passed on to the Avionics for downlink. The POCC commands the ICU to downlink its real-time and playback data at appropriate times during the orbit. The downlink data rate is programmable with data rates selectable in factors of two 880, 440, 220, and 110 k bits per second.

b. Mission

The HERO mission has been designed from the start as a simple mission to implement using proven technology to achieve a high science return. Specifically, the HERO mission has been designed to take full advantage of the ISS opportunity as an Express Pallet payload. The Science Objectives of the HERO mission are best achieved from the ISS where observations can be carried out for the required long duration (2 years) and then be safely retrieved for the required post-flight analysis. The instrument operations are of low complexity and based on past, shuttle flight proven missions. Mission Operations will be managed remotely at the USC Remote Operations Center. Daily mission operation requirements are minimal and will require only routine monitoring. Since the HERO mission has only one target, the Sun, it has only one science operating mode. Data requirements are minimal and the capability for autonomous operation over a period of days is achievable.

The HERO Operations Center will be located on the USC campus. Since the HERO mission has been designed to be largely autonomous, and the data rate is relatively small, MO&DA can be achieved at a significant cost savings by locating the operations center on campus and linking the operations center to the MSFC Payload Operations and Integration Center (POIC) using the Telescience Resources Kit (TreK). TreK is the low cost PC based telemetry and command system developed by MSFC for just this type of application. The on campus location will also provide the unique opportunity for more intensive student involvement with the program and also additional opportunity for a coordinated EPO effort.

c. Data Collection, Analysis, and Archiving

Once data is received, telemetry formats will be converted to raw scientific formats using software developed by USC and JPL. Daily data dumps will be routed from the HERO Operations Center at USC to Co-investigators at GSFC, JPL, and UCLA. HERO Co-investigator Joseph Davila will oversee distribution of flight data to the archive at the Solar Data Analysis Center (SDAC) at GSFC. Level 0 data will be made available on the database server within 24 hours. For science operations and scheduling with outside members of the scientific community, the HERO program has identified two Co-investigators at GSFC and will place required data equipment with GSFC and the SDAC.

The first three months of on-orbit operations will be devoted to instrument checkout and correlation studies for calibration purposes. Calibration products will include absolute flux conversion routines, dark current values, and temperature curves. Since the calibration data will require close examination to verify pre-flight calibration routines, access to calibrated values will be limited. For the first three months of operations, the calibrated database will be limited to pre-flight information.

The public database will include software algorithms to provide calibrated (level 1) data. It is anticipated that data products in a variety of temporal formats will be available through the HERO database. Comparison of observed data with models and subsequent interpretation of the data will be apportioned across the team by scientific interests.

Data Products
Level 0 data. (RAW DATA) Level 0 data are irradiance values (uncorrected to average sun earth distances), detector solar/electrical equivalence power, instrument temperatures, sun pointing measurements and instrument housekeeping data. Included at this level will be spacecraft time tags, geocentric coordinates and velocities.

Level 1 data products will be science and engineering data converted to the international system of units (SI). Data products are the average total solar and infra red irradiance in units of watts per square meter for each DBSIM measurement cycle, and absolute solar flux units for the EUV sensor. Results will be corrected to 1 Astronomical Unit. Every 30 days, degradation correction terms will be included so that the highest precession may be maintained.

Level 2 data will be solar irradiance results of level 1 data complied for a variety of average time periods and statistically analyzed data sets. Daily means will be calculated and available for climate and solar physics investigators.

D. MISSION DESIGN APPROACH

The HERO mission has been designed to provide maximum science return at minimum complexity. The HERO mission payload is designed to qualify as a Standard Express Pallet payload as defined in the Express Pallet payload Accommodations Handbook (draft). The HERO mission has no requirements for non-standard services and has no requirements for crew interaction. The primary science and mission requirements are listed in the Science-to Mission Traceability Matrix, Table B1.

Mission Design

The HERO mission will provide the opportunity to correlate the past 20 years of TSI measurements by establishing an absolute reference scale that all past measurements can be traced to. Because of the gaps in TSI measurements in time and technology, direct comparisons with the past instruments are difficult. Post flight analysis to remove the EUV degradation effects are impossible. The HERO mission has been designed to save the past 20 years of TSI measurements and to bridge the gap in time and technology for the next generation of TSI science and understanding.

To achieve this, the optimal HERO mission is two years on orbit. Additionally, the degradation studies proposed to meet the HERO objectives of understanding changes in TSI measurements require the HERO payload be returned for post-flight analysis. The most effective mission platform is the retrievable platform offered by the EXPRESS Pallet at this time. The two year mission life on orbit is designed to provide critical solar measurements at an important time in Solar Cycle 23, transitioning towards solar maximum, and provide enough exposure to the on-orbit environment and EUV induced degradation in the instrumentation.

Instrument Implementation:

The HERO payload fits within all EXPRESS Pallet interface requirements as a Standard Payload. The Payload mass, power, and data rates are listed in Table BXXXX.

In operation, science observations begin with the scan platform acquiring and tracking the sun as long as possible from sunrise through sunset. The Science Instruments require a minimum of 20 contiguous minutes of solar tracking to complete a valid observation. The optimal solar observation would be continuous tracking form sunrise through sunset, but may be limited due to violations of the Field of View (FOV) by ISS obstacles. The results of a preliminary FOV study is listed in Table B3, and indicates that even in the worst case for tracking attitude, the HERO scan platform will be able to track the Sun much more than the require minimum duration. The frequency of valid solar observations is also very high for HERO on the ISS.

During tracking, the HERO ICU collects instrument science data as well as performance data for analysis post-observation in the overall health and performance of the mission. During the mission, anomalies will be tracked and monitored as needed by the operations team at USC. Real-time data downlinks are not required during science operations or general maintenance. The HERO ICU is capable of storing up to 28 days of flight data before recorder dumps are necessary. Operationally, the HERO data recorders will be dumped daily or as often as needed.

In the event of emergency safing, the HERO payload can be powered off until safe conditions are met, without jeopardizing the HERO mission or damage to the instruments.

The HERO payload is designed to take advantage of existing developed hardware that has successful heritage in operation on the Space Shuttle. The Scan Platform design, provided by the University of Arizona, has past flight histories on STS-53, STS-69, STS-XX, STS-85, and STS-95. All required shuttle safety analysis and documentation has been previously approved for the scan platform design and materials. Designs and test procedures will be reviewed to assure an on-orbit operational lifetime of 3.0 years (1.5 times expected mission).

The HERO science instruments are within the design parameters for the Scan Platform. The Scan Platform can be launched on the shuttle in any orientation, as well as land.

Mission Operations:

The DBSIM may be placed in one of thirty-two operational modes. The most basic mode is a dual phase operational mode that alternately shades and irradiates one of the absorption cavities with a duty cycle of twenty-four seconds. In this mode, a measuring cycle begins with all cavities shaded, this is a reference phase. During the reference phase, all cavities measure the common thermal environment, which is, the upper instrument housing, shutter assembly, precision aperture assembly, and cavity thermal assembly. In this phase, all cavities are dissipating equal electrical power and are in balance. In the second phase, the selected observation cavity is irradiated. The added solar power increases the flux in this observation cavity above that of the other shaded reference cavities. This initiates action of the servo system to reduce power in the observing cavity in order to maintain the original balance determined during the reference phase. This process takes ten seconds. Once balanced, equation 1.0 is applied.

A benefit of differential measurements is the immunity of the DBSIM from temperature drifts in the spacecraft and instrument interface surfaces. This means that less stringent requirements need be placed on the spacecraft thermal control design, and makes the DBSIM an excellent choice for the Express Pallet on ISS.

The DBSIM measures total solar irradiance at a rate 0.04 Hz (a measurement every 24 seconds) and is adaptive to other temporal resolutions associated with space irradiance monitors such as the 2-minute ACRIM resolution and the 3-minute SOLCON and DIARAD/VIRGO resolution. The overall uncertainty is ± 0.01% of the SI measurement and a long term precision of 20 ppm/year or better.

DBSIM is completely autonomous when placed in automatic mode, so that minimum commanding is required. The only case that commanding of the instrument is required is at an initial start-up and every month for one orbit to perform degradation tests. Commanding may also be required if some unique experimentation is desired during the mission.

Three channels are incorporated into the instrument to provide comparison between the detectors as the instrument ages. The observing detector, "A", is alternately exposed to then shaded from the sun every 22 seconds. Detectors "B" and "C" remain shaded from sunlight and are used as thermal references for the detector "A". Then, for one orbit every thirty days, detector "A" will be used as a reference detector while detector "B" will be used as an observation detector. At the end of the orbit, the detectors will resume their original roles. This procedure allows for the determination degradation of the detector. This information is then used to correct the data acquired over the previous 30 days of the mission. Detector "C" would be used in a similar fashion to calibrate detectors "A" and "B" as required. The third detector has minimum surface change because it is the least exposed.

The science and engineering data from the instrument are bursted out every 1.024 seconds over its RS422 serial port to the spacecraft for storage in spacecraft memory.

The ancillary data required by the experiment to produce and interpret results are spacecraft geocentric position (X, Y, Z) in kilometers (+/- 1 km). Spacecraft geocentric velocities (Vx, Vy, Vz) in kilometers/second. Universal time of observations (+/- 1 ms).

E. MANAGEMENT, SCHEDULE, AND COST

Roles and Responsibilities of the PI, PM and Organization.

The USC management team for HERO consists of the Principal Investigator (PI), and the Project Manager (PM). As PI, Professor Darrell Judge is responsible for the overall scientific, engineering, and programmatic success of HERO for which he is answerable to NASA. Donald McMullin, as PM, is responsible for assuring that the budgetary allocations are not exceeded and has the authority to commit program resources, and is accountable to the PI for meeting cost, schedule and technical goals. The management team is assisted by the Science Team Members, and subcontractor leads.

Judit Pap’s responsibility will be to participate in processing, validate and analyzing the DBSIM total irradiance. This activity will include to compare the DBSIM total irradiance with other source of TSI data as well as the HERO/EUV measurements. She also will participate in comparing the HERO irradiance data with ground-based images.

Decision Marking Process

The HERO program will be managed by the USC Space Sciences Center, under the direction of Dr. Darrell L. Judge. The HERO management team brings t this program the successful experience of the very closely related SoHO SEM program, in addition to many sounding rocket and shuttle flights. The HERO PI was also PI on the Pioneer 10/11 UV photometer experiment for the 25 year lifetime of the mission. Direct and frequent communication between key individuals is assured through regular weekday meetings at USC and through e-mail and/or phone communication with our Co-investigators. Reciprocal visits between institutions and/or teleconferences will be scheduled as appropriate.

Teaming Arrangements

Critical to assisting the Science team members, is the successful heritage and support of each of the involved Science Team Member Institutions. Each Science Team Member brings with them the varied experiences of past accomplishments. USC is bringing to the project the past experiences of many successfully managed and flown missions (Pioneer 10 EUV Photometer, SoHO Solar EUV Monitor), shuttle flight and safety record (International EUV Hitchhiker Missions, IEH-1, IEH-2, and IEH-3). NASA’s Jet Propulsion Lab (providing DBSIM instrument), NASA's Goddard Space Flight Center (providing solar data analysis and SDAC support), University of Arizona (providing shuttle experienced solar pointing scan platform).

The Science Team Members have comparable experience from many NASA and ESA programs including: Pioneer 10, SoHO, TRACE, STEREO, IEH, VOYAGER, ACRIM, WIND and SOLCON.

Institutional Commitments

All team members and their affiliated institutions are committed to the HERO program. USC will establish the day to day remote operations Payload Operations Command Center (POCC) on campus for easy access to HERO investigators and students.

Schedule

A top level schedule for the HERO mission is shown in Fig. XX. A full 3 month reserve is planned for risk mitigation. Many of the scheduled activities have additional flexibility and built-in overlap.

Cost

Tables B2 and B3 list the total NASA OSS anticipated costs, as requested in the AO. Our budget estimate figures include a cost reserve for phases B through D. This budget estimate is based on our past experience with similar design issues and our continued relationship with the same vendors and sub-contractors that were selected for our earlier space shuttle programs. The cost estimating methodology used is estimating by similarity, and updating earlier cost data. During Phase A, our budget estimates will be reviewed, and a detailed budget for phases B through E will be developed.

Full Cost Accounting

HERO co-investigators from GSFC and JPL have provided USC with budget estimates using Full Cost Accounting procedures as required by each NASA center.

F. EDUCATION AND PUBLIC OUTREACH AND SMALL DISADVANTAGED BUSINESSES

USC is committed to meeting the NASA OSS goals and objectives for Education and Public Outreach and NASA OSS requirements for participation of Small Disadvantaged Businesses. The HERO mission EPO and SDB programs will be described fully in the Phase A study report.

G. APPENDICIES