

# End-to-end System Test and Optical Performance Evaluation for the Solar and Heliospheric Observatory (SOHO) Ultraviolet Coronagraph Spectrometer (UVCS)<sup>1</sup>

Paolo A. Carosso  
Swales and Associates, Inc.  
Beltsville MD 20705

Larry D. Gardner  
Harvard Smithsonian Center for Astrophysics  
Cambridge MD 02138

Murzy Jhabvala  
NASA Goddard Space Flight Center  
Greenbelt, MD 20771

P. Nicolosi  
Universita' di Padova  
I-35131 Padova, Italy

## 1. ABSTRACT

The UVCS is one of the instruments carried by the Solar and Heliospheric Observatory (SOHO), a joint NASA/ESA Spacecraft launched in November 1995. It is designed to perform ultraviolet spectroscopy and visible light polarimetry of the extended solar corona. The primary scientific objectives of the UVCS investigation are to study the physical processes occurring in the extended solar corona, such as:

- the mechanism of acceleration of the solar wind,
- the mechanism of coronal plasma heating,
- the identification of solar wind sources, and
- the investigation of the plasma properties of the solar wind.

The UVCS End-to-End test activities included a comprehensive set of system level functional and optical tests. Although performed under severe schedule constraints, the End-to-End System Test was very successful and served to fully validate the UVCS optical design. All test results showed that the primary scientific objectives of the UVCS Mission were achievable.

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Following an introductory description of the UVCS Instrument, this paper describes the preliminary UVCS AIV activities, and the rationale for performing the end-to-end system test. The process for the selection of the most appropriate facility for the test is then summarized. The SAO laboratory is then described, as well as the preliminary work that was necessary to be performed to enhance the laboratory test environment. This includes the design, fabrication and installation of a special cryogenically cooled shroud for the vacuum chamber, and upgraded cleanroom facilities.

The test philosophy, performance goals, and a summary of the test results are also given.

## 2. INTRODUCTION

The Ultraviolet Coronagraph Spectrometer<sup>1</sup> (UVCS) is one of the instruments carried by the Solar and Heliospheric Observatory (SOHO)<sup>2</sup>, a joint NASA/ESA Spacecraft, currently in orbit and fully functioning. The SOHO spacecraft and its complement of payloads, including the UVCS, is shown in Figure 1.

The UVCS is an instrument designed to perform ultraviolet spectroscopy and visible light polarimetry of the extended solar corona. The primary scientific objectives of the UVCS investigation are to study the physical processes occurring in the extended solar corona, such as:

- the mechanism of acceleration of the solar wind,
- the mechanism of coronal plasma heating,
- the identification of solar wind sources, and
- the investigation of the plasma properties of the solar wind.

## 3. INSTRUMENT DESCRIPTION

The UVCS consists of a Telescope / Spectrometer Unit (TSU), and a Remote Electronics Unit (REU). The TSU is a telescope in which each of the three channels is optimized for observations respectively at the Lyman- $\alpha$ , O VI, and Visible Light wavelengths. The telescope has external and internal occultation, and includes a high resolution Spectrometer Assembly (SPA).

The Lyman- $\alpha$  section of the SPA is a toric grating spectrograph with an entrance slit mechanism, a neutral density filter inserter, a grating mechanism, and a windowed XDL detector<sup>6</sup>. The spectral range 1100 to 1361 Å is achieved by the detector size and by grating motions, and includes the primary H I line at 1216Å.

The O VI section is a toric grating spectrograph with an entrance slit mechanism, a neutral density filter inserter, a grating mechanism, and an open XDL detector. This detector is optimized for measurements of the O VI lines at 1032 and 1037 Å, plus additional lines in the 937 to 1126 Å (first order), and 469 to 563 Å (second order) range. The OVI section includes a mirror to focus the first order diffracted H I Lyman-α line on the O VI detector, thereby providing a redundant capability to detect that spectral line.

The White Light Channel (WLC) is designed to perform measurements of the polarized radiance of the corona. It consists of an entrance aperture, a polarimeter assembly, and a photomultiplier tube. The polarimeter assembly includes a rotatable half-wave plate, a fixed linear polarizer, a bandpass filter and a lens.

A schematic diagram of the UVCS is reported in Figure 2, and its optical path is shown in Figure 3. The internal occultation and telescope mirror motion is provided by the Mirror Occulter Mechanism (MOM) Assembly, illustrated in Figure 4.

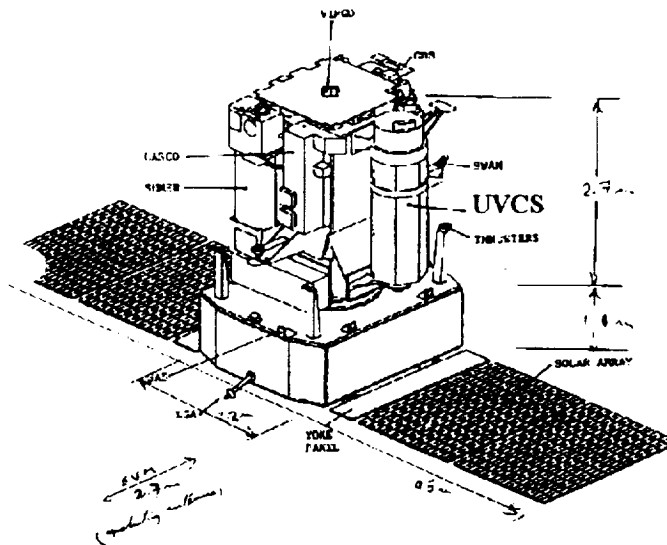
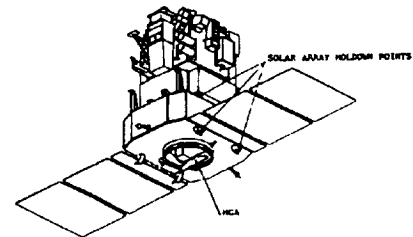
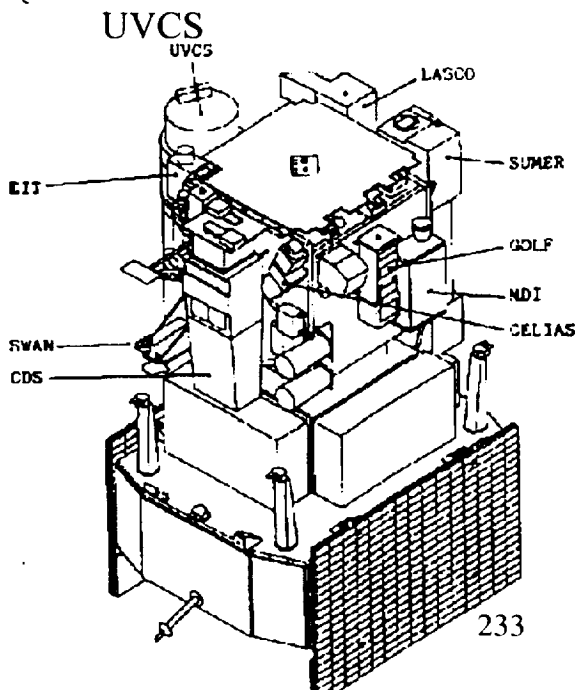


Figure 1 - The SOHO Spacecraft



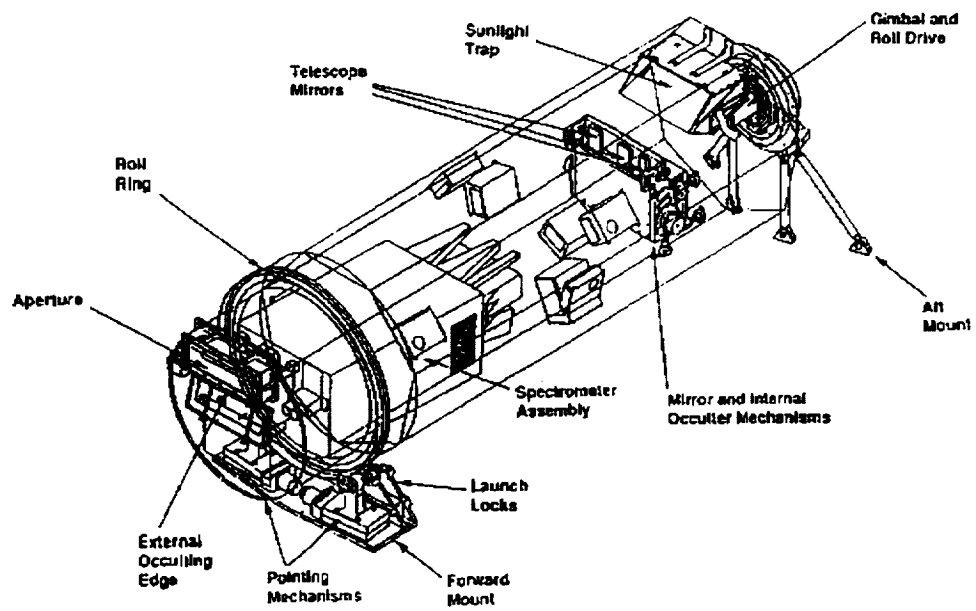


Figure 2 - The UVCS Instrument

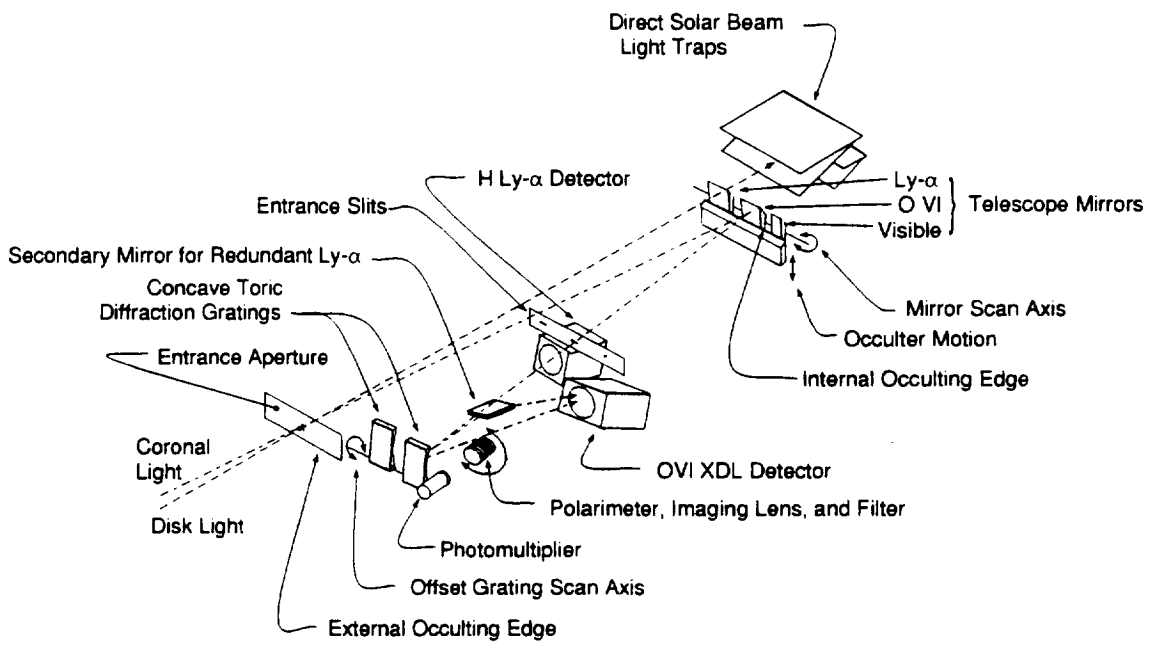


Figure 3 - The UVCS Optical Path

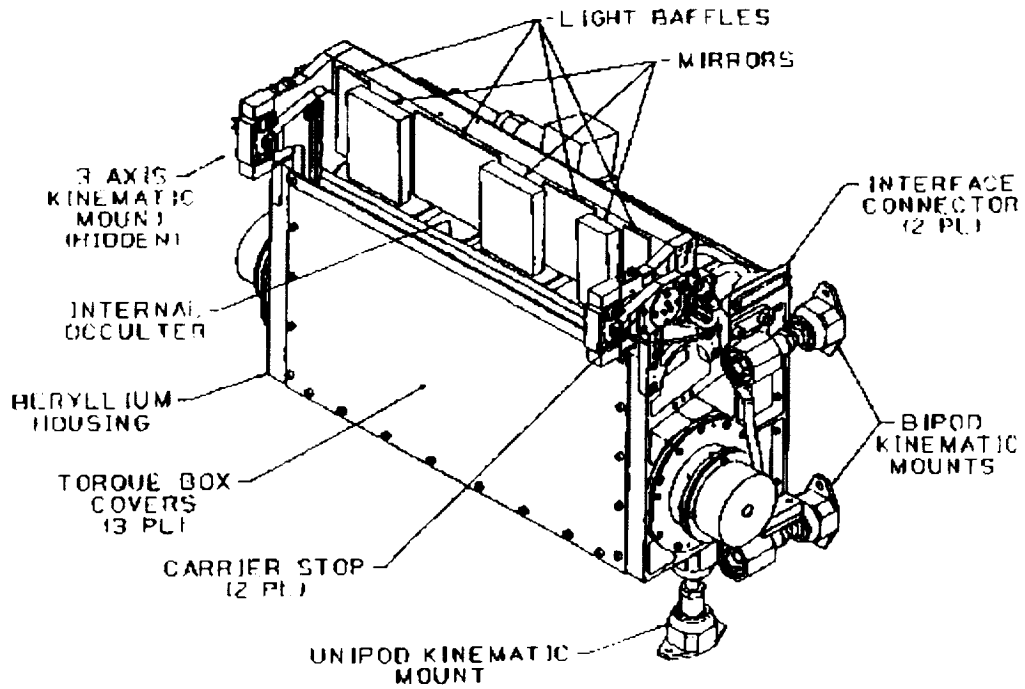


Figure 4 - The Mirror Occulter Mechanism (MOM) Assembly

## 4. UVCS END-TO-END TEST BACKGROUND

The International Solar Terrestrial Project (ISTP) planned for and performed an End-to-end System Test on the Ultraviolet Coronagraph Spectrometer<sup>1</sup> (UVCS) in the June-July 1995 time frame.

The major goals of the test were:

- to verify the UVCS Instrument functionality at system level, and
- to measure key optical performance parameters of the Instrument in its flight configuration.

All the UVCS subsystems had previously undergone qualification testing at various facilities, per the UVCS Product Assurance Plan<sup>3</sup>, and the integrated Instrument had undergone a verification program, including vibration test, functional, EMC, etc.

The performance of some flight-like models of the major UVCS optical components had been measured by SAO.

Some of the optical performance properties had been measured on the Spectrometer Assembly (SPA), in vacuum, in November 1994, at Alenia Spazio, Torino, Italy. That test program utilized non-flight optical components to simulate the telescope, and provided an initial evaluation of the Spectrometer spectral and spatial resolution<sup>5</sup>.

Although this preliminary testing and characterization work provided valuable information, a system level test was required to verify the functionality of the Instrument in its full flight configuration, its end-to-end optical performance, and to validate the optical design. The decision to actually perform such a test was not straightforward, however, due to severe schedule constraints. The SOHO AIV and launch processing schedule did not allow for extended periods of time to be dedicated to Instrument activities.

The UVCS test schedule had therefore to be optimized such that it would ensure achievement of the desired results in the limited time available, and under safe conditions.

The ISTP Project negotiated with the SOHO Project the release of the UVCS from the Spacecraft to allow for transportation of the UVCS to the U.S.A. from France. A period of approximately 49 days was allocated to this test.

## 5. TEST FACILITY SELECTION

Several options were considered in the process of selecting the facility for the execution of the UVCS End-to-end test:

- the Goddard Space Flight Center (GSFC) in Greenbelt, MD,
- the Smithsonian Astrophysical Observatory in Cambridge, MA, and
- the Intespace Facility in Toulouse, France.

The factors that had to be traded against each other included:

- Risks during transportation
- Logistics support
- Suitability
- Optical environment
- Management complexity

Transportation risks are always a significant factor, especially when moving from an overseas location is required.

Logistics support, such as mechanical and electrical support facilities capable of fast turn around are required for any unplanned rework or fix.

Suitability of the facility, in terms of facility layout, space available, support equipment (e.g. lifting equipment), and cleanliness control, were an extremely important consideration in the decision process. Familiarity with and knowledge of the facility was also important. Factors such as facility certification and utilization history were considered in the trade study.

The optical properties of the vacuum facility were obviously an important factor, due to the need to minimize any adverse optical background during the optical measurements in vacuum.

Management complexity factors were also considered, e.g., for instance, the establishment and implementation of contractual arrangements with foreign organizations.

The Intespace facility was very attractive because it minimized transportation risks, as it is located very close to the Matra facilities in Toulouse. It also offered good supporting facilities. The vacuum facility, however was not sufficiently large to guarantee the desired optical environment, and certification data were unavailable.

Having decided that the move from France was necessary, the final selection was made by giving the highest priority to the fact that the primary goal of the test was to measure the



Instrument optical functionality, thus requiring the best optical environment. The SAO Ultraviolet Coronagraph Laboratory includes a unique vacuum facility that is optimized for stray light testing, and was therefore selected for the test.

A thorough evaluation of the SAO facilities was conducted and a number of facility improvement measures were identified. These upgrades were implemented prior to the test, to ensure that all environmental control and safety requirements were in place. The cleanrooms were upgraded. A low temperature shroud was designed, fabricated and installed in the existing vacuum chamber. Comprehensive contamination monitoring equipment was also installed. Strict contamination control procedures were enforced in the laboratories.

### ***5.1. THE SAO TEST FACILITY***

The test facility located in the Ultraviolet Coronagraph Laboratory of the SAO consists of a vacuum chamber fitted with a light source, a removable monochromator, an articulated collimating mirror, and an Instrument Support Fixture (ISF), plus various articulated stages for the insertion and removal of filters and light diodes in the incident beam.

Light sources are easily interchangeable, to accommodate the various wavelengths needed throughout the test. Colored and neutral density filters, and diffusers, can be inserted into the beam as needed.

The incident beam is reflected towards the instrument by an articulated collimating mirror (See Figure 5). To minimize the chamber background stray light, a light trap is located just behind the collimating mirror, the beam travels a distance of approximately 12 m prior to entering the instrument's entrance slit, and a baffling system is placed in the elongated section of the chamber.

When fitted with the appropriate light sources, the optical system provides the beam divergence required for proper solar simulation.

To measure the incident beam intensity, NIST calibrated diodes can be inserted and removed from the incident beam by means of motorized stages controlled from the exterior of the chamber. For the optical measurements in vacuum, the UVCS was placed on the ISF, located in the ~1.8 m diameter section of the chamber. The ISF itself was in effect a motorized optical table with capability for translation in two dimensions and pivot about one.

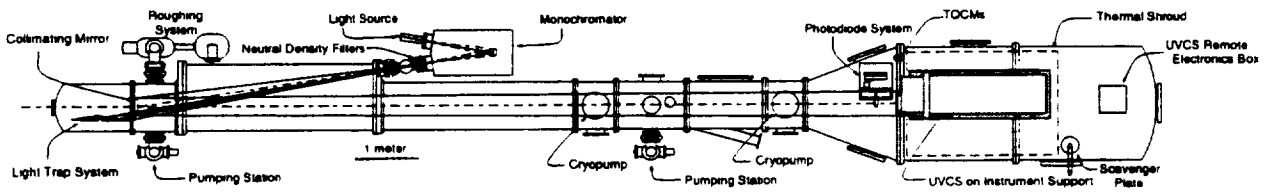


Figure 5 - The SAO Vacuum Chamber

## **6. TEST SCHEDULE**

The International Solar Terrestrial Physics (ISTP) Project negotiated the release of the UVCS from the Matra facility for the 27th of May, 1995. The Instrument was to be returned to KSC on July 27th.

The work to upgrade the facilities at SAO began at the end of March, and a facility walkthrough was held on May 10th to verify the facility readiness. The UVCS arrived at the GSFC early on May 30th, to allow for switching to a smaller shipping container, and arrived at SAO late on the same day.

The UVCS End-to-end System Test was initiated immediately thereafter. The Instrument Diagnostics and Characterization phase was performed first. This was followed by a Rework / Retest phase, during the last two weeks of the test period.

## **7. TEST PHILOSOPHY**

As previously mentioned, the 49 days allowed for the test were allocated to two test phases. During the initial Diagnostics phase, originally intended to last approximately two weeks, a series of functional and performance tests were planned, aimed at evaluating a broad spectrum of key instrument parameters. Should any malfunction or problem be identified at the end of this phase, of such a magnitude that work on the Instrument would be required, the test would be suspended to allow for such repairs.

A two week Rework phase was also included in the initial plan, to perform the repair work pertaining to a number of open items leftover from the Pre-ship Review.

Any additional time remaining after the Diagnostics and Rework phases was planned to be used for additional Instrument characterization.

No major malfunctions were identified during the Diagnostics phase that would require repair work. It was therefore decided to continue testing in vacuum, and to immediately proceed to an extended Instrument characterization testing phase. This decision allowed the maintaining of vacuum and the loss of the instrument alignment within the test setup, and resulted in a significantly more effective use of the limited time available.

The planned rework phase, entailing a well determined amount of time, was performed at the end of the test period.

An overall test procedure was generated by the Science Team and reviewed prior to the test inception, addressing the above mentioned test phases. Based upon this overall procedure,

detailed procedures were generated for the execution of all the planned tests (i.e. Visible Light Channel Stray Light, Lyman- $\alpha$  Channel Efficiency, etc.).

## 8. UVCS PERFORMANCE GOALS

The performance goals for the UVCS Instrument are reported in Table I.

These values were determined based on the UVCS optical design, the preliminary component level tests, and the expected orbital conditions. Although they were not formal program requirements, these goals constituted a reference for the End-to-End test values.

<b>Table I - UVCS Performance Goals</b>					
	$\lambda$ [Å]	Efficiency	Stray Light	Spectral Resolution	Off Band Stray Light Suppression
<b>Visible Light Channel</b>	4500-6000	0.01	$3.2 \times 10^{-9}$		
<b>Lyman-<math>\alpha</math> Channel</b>	1216	0.01	$1 \times 10^{-8}$	0.141	
<b>Redundant Lyman-<math>\alpha</math> Path</b>	1216	0.0038	$1 \times 10^{-8}$	0.1	
<b>O VI Channel</b>	1048	0.0084	$1 \times 10^{-8}$	0.09	
<b>Lyman-<math>\alpha</math> &amp; O VI</b>	2537				$4 \times 10^{-10}$

## 9. PRELIMINARY TEST FACILITY EVALUATION

The ISTP Project required that comprehensive certification of the vacuum facility be performed prior to test inception. Such certification had to include:

- Cleanliness

Non-Volatile Residue (NVR) samples were taken from both the chamber internal surfaces and the shroud. The chamber was operated prior to test inception, including all the test mechanical and electrical GSE. The molecular environment was monitored by Residual Gas Analyzer (RGA) and Thermal Quartz Crystal Microbalances (TQCMs). Witness plates were also placed in the chamber and sampled for NVR after the test.

This test indicated that the environment in the chamber was very clean. Only water vapour and traces of hydrocarbons were detected at the beginning of the test. Their partial pressure decreased significantly throughout the test.

- Verification of low temperature shroud functionality

A preliminary chamber test allowed to verify operation of the shroud at the required temperature (-70 ° C). This temperature was achieved by chilling ethilic alcohol using two low temperature chillers and pumping it through the shroud.

- Instrument Support Fixture load test

A static pre-load test of the Instrument Support Fixture (ISF) was successfully performed.

- Vacuum chamber background stray light

This test is described in the following paragraph.

### 9.1. *UVCS MOCKUP TEST*

Due to the very stringent UVCS stray light requirements, preliminary testing was necessary to measure the vacuum chamber intrinsic stray light background, and to verify that this level was below the required instrument stray light level.

This test was performed in May 1995, prior to the arrival of the UVCS at SAO, utilizing the UVCS Mockup, an engineering unit available at SAO which very closely reproduces the UVCS optical design and configuration. The Mockup components are mostly flight-like, with the exception of the light trap, the PMT unit, and the internal occulter which were expected to be

functionally representative. A spare flight telescope mirror was used for this test.

The UVCS Mockup test was performed in air utilizing visible light. The measured light level was approximately  $4 \times 10^{-8}$  of the simulated disk intensity, which indicated acceptably low stray light levels in the vacuum chamber.

## **10. UVCS END-TO-END SYSTEM TEST RESULTS**

### **10.1. OPTICAL ALIGNMENT**

After successful completion of the facility certification tests discussed previously, the UVCS was installed on the support fixture and aligned to the test facility, so that the Instrument optical axis would be in the direction of the light source. For the stray light measurements, the incident beam diameter was large enough to cover the entire entrance aperture. A sketch of the test set-up is reported in Figure 5.

Optical alignment was achieved by maximizing the signal from the WLC detector, while progressively reducing the dimensions of the simulated sun by means of a diaphragm. Motion of the UVCS optical axis was achieved by small movements of the support fixture and the UVCS pointing system itself.

### **10.2. WHITE LIGHT CHANNEL STRAY LIGHT EVALUATION**

The WLC Stray light test was performed first, due to its inherently more lenient experimental conditions. The initial test is in fact performed in air, thus allowing for time efficient optimization of the set-up and of the Instrument alignment. Should the chamber stray light have proven to be unacceptably high, it would have still been relatively simple to modify the chamber set-up (i.e. baffling system, light source, etc.), avoiding the time losses due to recovery from vacuum and subsequent pump-down cycles.

A high pressure mercury arc lamp (1kW) was utilized in the WLC Stray light test. A filter was utilized to eliminate the infrared portion of the light emitted by the source. Several neutral density filters were used as needed, to reduce the incident beam intensity, as well as a green filter to isolate the 546 nm Hg line.

The values for the stray light levels were obtained as the ratio of the apparent “coronal” intensity to the simulated “solar disc” intensity, obtained respectively by pointing the UVCS into the  $2.7 R_0$  direction and into the simulated sun center direction. Note that in the experimental set-

up, the simulated sun is corona-less. Values of approximately  $2 \times 10^{-8}$  were measured for the WLC stray light.

### **10.3. VISIBLE LIGHT CHANNEL EFFICIENCY**

A value of  $4.0 \times 10^{-3}$  was measured at 5460A (Hg) for the efficiency of the UVCS visible light channel.

As in all the efficiency measurements performed during this test campaign, the end-to-end radiometric efficiency was obtained as the ratio of the intensity measured at the UVCS detector to the intensity of the incident beam, as measured by an NIST calibrated diode.

### **10.4. DETECTOR OPERATIONS**

Cross Delay Line (XDL) Detectors<sup>6</sup> are utilized in both the Lyman- $\alpha$  and the O VI Channels of the UVCS. The test procedures included provisions for safe operation of the detectors, in terms of:

- vacuum chamber pressure, and
- incident beam intensity.

The XDL's are operated safely at a pressure equal or less than  $3 \times 10^{-5}$  Torr. A vacuum gauge was installed in the vacuum chamber to monitor the pressure in the volume immediately surrounding the detectors.

On the initial chamber pump-down, although the ambient vacuum chamber pressure was well below the XDL operational limit, it was noted that the pressure internal to the Spectrometer Assembly (SPA) was not sufficient to allow XDL operation. To achieve the required vacuum level in a practical amount of time, it was decided to partly remove one of the SPA side panels, to allow for enhanced vacuum conductance into the SPA. This issue resulted in the modification of one of the SPA flight panels, which was required to assure proper and safe operation in flight.

The intensity of the incident light beam was closely monitored throughout all test phases to avoid damage to the detectors. Neutral density filters of various transmission factors were used as necessary to maintain the light at safe levels at all times when high voltage was applied to the detectors. High voltage was always applied in small increments, up to the operating voltage.

### 10.5. *LYMAN- $\alpha$ CHANNEL EFFICIENCY AND STRAY LIGHT EVALUATION*

The efficiency of the Lyman- $\alpha$  channel was measured at 1165 Å (Kr I), 1216 Å (H<sub>2</sub> Lyman- $\alpha$ ), and 1236 Å (Kr I).

Various light sources were utilized for the UVCS calibration in the UV, to allow for the measurement of the desired parameters.

For the efficiency measurements, a Samson glow discharge lamp was used, in conjunction with the appropriate gas (Ar, Kr, etc.).

The efficiency values measured<sup>1</sup> for the Lyman- $\alpha$  Channel are reported in Table II.

<b>Table II - Lyman-<math>\alpha</math> Channel Efficiencies</b>	
1165 Å (Kr I)	$2.5 \times 10^{-3}$
1216 Å (H I Lyman- $\alpha$ )	$2.0 \times 10^{-3}$
1236 Å (Kr I)	$1.9 \times 10^{-3}$

The stray light level<sup>1</sup>, defined as the ratio of the stray light count rate to the simulated solar disc count rate is  $<1 \times 10^{-8}$ . This value is an upper limit, since it may be dominated by stray light in the vacuum facility.

### 10.6. *REDUNDANT LYMAN- $\alpha$ PATH EFFICIENCY AND STRAY LIGHT EVALUATION*

The efficiency of the Redundant Lyman- $\alpha$  channel was measured at 1236 Å (Kr I).

The efficiency value measured for the Lyman- $\alpha$  Channel is reported in Table III<sup>1</sup>. The reported value includes the reflectance of the telescope mirror, the efficiency of the grating, the reflectance of the redundant mirror, and the counting efficiency of the XDL detector. The instrument stray light level, defined as the ratio of the equivalent stray light count rate to the simulated solar disk count rate was  $<5 \times 10^{-8}$ . Based on the more extensive stray light



measurement of the Lyman- $\alpha$  channel, this value is probably limited by the test arrangement.

<b>Table III - Redundant Lyman-<math>\alpha</math> Channel Efficiencies</b>	
$\lambda$	Efficiency
1236 Å (Kr I)	$1.0 \times 10^{-3}$

### 10.7. O VI CHANNEL EFFICIENCY

The efficiency of the O VI Channel was measured at 1025 Å (H<sub>2</sub> Lyman- $\beta$ ), 1048 Å (Ar I), and 1066 Å (Ar I)

For the efficiency measurements, a Samson glow discharge lamp was used, in conjunction with the appropriate gas.

The efficiency values measured for the O VI Channel are reported in Table IV<sup>1</sup>.

<b>Table IV - O VI Channel Efficiencies</b>	
$\lambda$	Efficiency
1025 Å (H <sub>2</sub> Lyman- $\beta$ )	$3.0 \times 10^{-3}$
1048 Å (Ar I)	$4 \times 10^{-3}$
1066 Å (Ar I)	$3.4 \times 10^{-3}$

The stray light level for the O VI channel was measured as part of the redundant Lyman- $\alpha$  path test. (See Section 10.6).

### **10.8. SPECTRAL RESOLUTION**

A platinum / neon light source was utilized for the spectral resolution and wavelength scale measurements of the Lyman- $\alpha$  Channel, due to its high number of very narrow peaks.

The Berlin PTB hollow cathode lamp (with Xe and Ar gas) was used for the spectral resolution test of the O VI Channel.

The spectral resolution is expressed as the Full Width at Half Maximum of the measured profile (in pixels), as obtained by a gaussian fit of the experimental data. The measured results are summarized in Table V<sup>1</sup>.

<b>Table V - UVCS Spectral Resolution</b>	
	<b>FWHM [pixels]</b>
Lyman- $\alpha$ Channel	1.7
Redundant Lyman- $\alpha$ Channel	~3.5
O VI Channel	< 2.5

The value for the O VI channel is considered to be an upper limit, since the intrinsic line width of the light source (as operated) was not known.

### **10.9. OFF-BAND STRAY LIGHT SUPPRESSION**

The off-band stray light suppression was measured with a pen ray Hg lamp at 2537 and 1800 Å.

The measured off-band sensitivity was  $3 \times 10^{-11}$ , which is significantly better than the performance goal value of  $4 \times 10^{-10}$ .

### **10.10. FLAT FIELD CALIBRATION**

A microwave (Kr) source was used for the flat field calibration of the Lyman- $\alpha$  channel.

The Samson lamp (Ar) with monochromator was used for the O VI Channel flat field calibration.

### **10.11. MECHANISM CALIBRATION**

In addition to the optical characterization discussed so far, various UVCS mechanisms were calibrated, leading to the update (or initial definition) of many of the UVCS flight software tables. This effort included:

- Entrance slits
- Occulter plate
- Telescope mirrors
- Gratings
- Telescope roll mechanism

### **10.12. SOFTWARE TESTING**

Extensive flight software testing was also accomplished during the UVCS End-to-End System Test campaign. A new flight software version was installed and tested, as well as a new version of the UVCS Telemetry and Command software.

## **11. SUMMARY OF RESULTS**

In the period from June 1 until July 24, 1995, a comprehensive set of system level functional and optical tests were performed on the SOHO UVCS Instrument.

Although performed under severe schedule constraints, this End-to-End System Test was very successful and served to validate fully the UVCS optical design. All test results showed that the primary scientific objectives of the UVCS Mission are achievable.

## 12. REFERENCES

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