The ASCE UV linear polarization analyzer

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May, 2002
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1. Introduction

The Advanced Spectroscopic and Coronagraphic Explorer (ASCE) (http://cfa-www.harvard.edu/asce/) mission has been designed to make major breakthroughs in the following solar physics topics: solar wind, energy transport through the lower atmosphere, coronal mass ejection’s heating and acceleration. The use of spectroscopic and polarimetric diagnostic techniques provides the detailed empirical description of the coronal plasma. The ASCE payload includes three coaligned optical channels: the Advanced Ultraviolet coronagraph spectrometer (AUVCS); the Advanced Large Aperture Solar Coronagraph (ALASCO); and the Advanced Solar Disk Spectrometer (ASDS). Their design is based on the designs of some of the SOHO instruments, such as UVCS/SOHO (Kohl et al. 1995) and LASCO/SOHO (Brückner et al. 1995), with improved performances and new capabilities enhanced by a 13 m extendible boom. In fact, ASCE will measure, for the first time in the extended corona: the Helium abundance, flow speed, and temperature; the magnetic field strength; and the electron velocity distribution.

The four AUVCS paths, which have a common mirror mechanism and internal occulter, are the:

- **HeII Path (HeP)** for line profile and intensity measurements from 26 to 37 nm (2nd grating order) and from 48 to 74 nm (1st order), including the He I 58.4 nm and the He II 30.4 nm lines;

- **EUV Spectroscopy Path (EUVSP)** for line profile and intensity measurements from 38 to 70 nm (2nd grating order) and from 75 to 140 nm (1st order);

- **EUV Polarimetric Path (EUVPP)** for polarimetric measurements that will explore the measuring of anisotropic ion velocities and coronal magnetic fields over the wavelength range 94 to 125 nm;

- **Electron Velocity Distribution Path (EVP)** for measurement of the profiles of electron scattered, coronal HI Lya radiation for determination of the velocity distributions of coronal electrons.

ASCE was proposed for the first time to the NASA/MIDEX (Medium Class Explorers and Missions) in 1998 and was selected for Phase A study (Gardner et al. 1999), and it has been proposed again to the NASA/MIDEX, with some major updates and modifications, in October 2001. It has been selected again for a Phase A study in April 2002 (NASA Press Release 2002).

In both proposals, the Department of Astronomy and Space Science of University of Florence (DASS) responsibility is the design, the procurement and the characterization of the EUV
polarimeter assembly that belongs to the EUVPP path. The polarimeter is designed to measure the linear polarized brightness of the hydrogen Lyman series lines, and, in general, of all the most intense EUV lines in the wavelength range 95–125 nm. The measurement of the change in strength and in direction of the polarization vector of the hydrogen Ly-α, Ly-β, and Ly-γ lines, is a signature of the Hanle effect, which is related to the magnetic field strength (Fineschi et al. 1999).

The research activity carried on by the XUVLab, a laboratory facility for VUV measurements at DASS (Chiuderi et al. 1998; Corti et al. 1999; XUVLab Team 2001), was the characterization of the polarizing properties of a selected number of materials which best perform as reflecting polarization analyzers (Corti 2001). The XUVLab is also involved in the definition and testing of the EUV polarimeter MCP detector in collaboration with the Istituto di Astrofisica Spaziale e Fisica Cosmica, CNR, Milano (Pace et al. 2000) and in the definition and development of the flight model of the UV polarimeter in collaboration with Officine Galileo.

2. Experimental characterization of an UV polarimeter prototype

The ASCE UV polarization analyzer wavelength range (90–125 nm) cover all the most intense EUV resonantly scattered lines (HI Lyman series lines and OVI 103.2 nm line) in the solar extended corona. The ASCE goal is to exploit the linear polarization modifications, induced by the Hanle effect in the EUV coronal resonance scattering process, to retrieve the magnetic field vector. In this wavelength range, there is a lack of efficient polarizers and below the cutoff of the Lithium Fluoride (LiF), at 105 nm, there are no transparent materials, therefore transmission polarizers/retarders cannot be used. The alternative is to exploit the polarization by reflection off a mirror surface. In addition, a complex index of refraction makes all materials optically behave like metals, that is they do not perform as ideal polarizer at the Brewster angle of incidence.

Therefore no VUV ideal reflection polarizer can be used and the performances of a reflecting plate for VUV polarization analysis are characterized by two features: the throughput and the polarization efficiency. The trade-off between these two parameters, considering different reflecting materials, determines the best plate material for VUV polarization analysis. The use of a single reflection polarization analyzer is to be preferred with respect to multiple reflections which presents a lower throughput and an higher complexity of alignment and development.

The work done at XUVLab consists of the design and fabrication of a single-reflection linear polarization analyzer (see Figure 1), and of the selection, via laboratory tests, of the best reflection plate material and incidence angle for the ASCE UV polarimeter spectral region 90–125 nm (Corti and Romoli 2001; Corti and Romoli 2002). The polarimeter prototype consists of an entrance pinhole, a polarizing/reflecting plate, and a detector. A vacuum stepper motor rotates the assembly around the optical axis to detect the polarization modulation.
curve. The polarizing plate holder and the detector holder can be manually adjusted to allow different incidence angles (45° ± 70°) on the polarizing plate. The detector is a photomultiplier (PMT) (Hamamatsu Mod. R5600U-06), operating in the photon counting regime to detect very weak signals, coupled to a Tetraphenyl Butadiene (TPB) phosphor plate to extend the PMT sensitivity at short wavelengths (Naletto et al. 1995). The experimental setup used for the VUV polarization measurements is sketched in Figure 2. The radiation source is a hollow cathode lamp (HCL), i.e. a continuous gas discharge lamp that emits radiation at the spectral lines of several ions of the buffer gas (usually a inert gas). The dispersing element is a 0.5 m Johnson-Onaka monochromator optimized for the spectral region from 30 nm to 200 nm. The radiation emerging from the exit slit of the monochromator is then reflected by a gold toroidal mirror that polarizes and focuses the beam on the entrance pinhole of the polarization analyzer, that is placed in a vacuum chamber. Owing to the off-axis reflection by the gold mirror, the reflected radiation is partially plane polarized. The whole system is vacuum sealed by Viton O-rings and it can be evacuated down to 10^{-6} mbar.

The material and the incidence angle selection has been performed for several different materials, selected after an analysis of their optical constants reported in literature (Palik 1985; Palik 1991).

The experimental measurements performed at the XUVLab on five materials (gold, quartz, MgF_2, LiF, and CaF_2) (Corti 2001; Corti and Romoli 2002) had shown that the Calcium Fluoride is the best material for the HI Lyman series lines and the best incidence angle was 70°.

Unfortunately, only a relative comparison of the performance of different materials can be done, due to the lack of knowledge on the linear polarization degree of the incident radiation and
Figure 2. The experimental setup at the XUVLab for the vacuum UV polarization measurements.
The ASCE UV linear polarization analyzer on the material reflectivity (Corti 2001). To overcome this problem we plan some measurements at the Bessy synchrotron (Berlin), using wavelength-tunable synchrotron radiation, and at the LENS laboratory (European Laboratory for Non-linear Spectroscopy), with a high-order ($7^{th}$ and $9^{th}$) harmonic laser beam (the fundamental harmonic is in the spectral window 780–820 nm).

The synchrotron and the laser radiation are both fully linearly polarized allowing us to measure the absolute reflectivities, and therefore, to calibrate the XUVLab polarization analyzer. Once the polarization analyzer is calibrated, it will be possible to test the performance of the polarimeter in terms of sensitivity and efficiency because the accuracy on the reflectivity knowledge is directly related to the accuracy on the linear polarization measurements. The calibrated analyzer allows also measuring the polarimetric characteristics of several devices such as gratings, mirrors, and other ASCE optical components that can influence the polarimetric measurements of the extended solar corona.

3. The microchannel plate detector

The research and development activities concerning the design and the experimental assessment of Micro-Channel Plate (MCP) based detector are performed by a collaboration between the Istituto di Fisica Cosmica of the CNR Milano (IASF/CNR) and the Department of Astronomy and Space Science of University of Florence (Pace et al. 2000).

The MCP detector coupled to an anode array read-out is the detector of choice when the photon fluxes are very low and photon counting capabilities are required, as for the EUV extended corona measurements. In addition, some constraints, such as the small volume available to place the detector, the requirement of measuring photon fluxes without imaging, and the need of having a low mass, has pointed out MCP coupled to a discrete anode pattern as the best solar blind detector for the UV polarization analyzer.

The MCP detector assembly for the flight model (see Figure 3) will have a frontal repeller grid (> 90% transmission), a photocathode deposited on the MCP front surface, and a Z-stack MCP configuration for high gain and low ion feedback. The MCP stack will be coupled to the anode array, with a 1 mm gap between them. The detector will measure variations of the photon flux without imaging capabilities, so that no spatial resolution is required. A uniform response (< 5%) will be the main constraint, since the spotlight in the polarimeter will rotate over the detector surface. A non-uniform MCP response should provide unwanted spurious signals.

A bull’s eye structure of the anode is required for alignment purposes. The central anode will contain the deliberately out-of-focus image of the entrance slit of the polarimeter, while the other anodes will monitor and ensure the optical alignment. The outer anodes will be used to align the polarimeter the first time and to maintain this alignment. The size of each anode has been calculated to get the same area for all the outer anodes, in order to facilitate the alignment procedure, and the annuli in the bull’s eye are split into four segments, thereby providing bi-dimensional information on the alignment direction.
4. Technical design and development of the flight model

An experimental assessment study is planned to develop a laboratory prototype of the MCP detector head, specifically designed for the ASCE UV polarization analyzer. The research activities will produce the know-how and will define the ultimate technical specification and requirements for developing the flight model detector. At that time, a selected company will be in charge of producing the engineering model and the flight models for the ASCE mission.
and control electronics. The door closure mechanism is driven by a stepper motor provided of limit sensors.

The Officine Galileo main activities, in the frame of this program, are the following:

- study and analysis of scientific requirements for the assembly definition in collaboration with the XUVLab;
- keeping of contacts with the scientific community in order to correctly monitor program evolution;
- definition of mechanical and electrical interfaces between the Officine Galileo assembly and the integrated system;
- assembly configuration and I/F drawings and following development drawings;
- performing of structural and thermo-mechanical analysis;
- procurement and design documentation preparation and issuing;
- design and development of an E.G.S.E. for the execution of functional tests;
- manufacturing of a qualification model;
- management of the detector procurement and its integration into the assembly;
- development of the flight model of the assembly;
- integration and test campaign for the flight models;
- assistance to the Program during the integration phase of the assembly into the System.

Due to the fact that the UV polarimeter is designed to work in the UV wavelength range, the instruments shall be considered critical from the contamination point of view, both from the particulate and for the molecular aspects. These two forms of contamination can have important impacts on the instrument performances in terms of signal attenuation, obscuration, scattering phenomena, and background noise; moreover, contaminants increase the risk of damage and failure of sensitive devices, such as the MCP detector. For these reasons, Officine Galileo has predisposed a contamination control and cleanliness plan for assembly, integration and test that concern of cleanroom, workbenches class 100 and suitable garments to reduce contamination till acceptable levels. Concerning the cleanliness requirements, on the lateral side of the assembly housing a port to an ion vacuum pump will allow to evacuate the polarimeter in order the windowless Z-stack MCP detector to operate in vacuum on ground.

The collaboration with the XUVLab had, at present, led to the definition of an alignment procedure program and to a preliminary concept study for detector uniformity degradation test on flight. Moreover, an optimized pinhole size has been proposed by XUVLab on the basis of the new ASCE instruments characteristics.
4.1. EUV Polarimeter Alignment Procedures

The alignment procedure for the EUV polarimeter consists of two steps: the polarimeter internal alignment and the alignment of the EUV polarimeter to the EUV spectrometer. In the alignment procedure the polarimeter is divided into 4 subassemblies: the rotating assembly, on which the polarizer and the detector are mounted; the fixed assembly, including the interface with the rotating assembly (front and back ball bearings), the interface with the spectrometer and the port for the vacuum ion pump; the front cover, with the pinhole, that interfaces with the fixed assembly; the back cover, with the electrical ports, that interfaces with the fixed assembly.

Table 1. UV Polarimeter alignment specifications

<table>
<thead>
<tr>
<th>Coalignment optical axis – rotation axis:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Angular Offset with respect to polarizer center</td>
<td>±0.5° ±0.2 mm</td>
</tr>
<tr>
<td>Coal. spectrometer – polarimeter optical axes</td>
<td>±0.2°</td>
</tr>
<tr>
<td>Rotation range</td>
<td>±150°</td>
</tr>
<tr>
<td>Rotation accuracy</td>
<td>±0.1°</td>
</tr>
</tbody>
</table>
4.1.1. EUV polarimeter internal alignment

The alignment requirements specified in Table 1 can be achieved mechanically, i.e. within the machining precision of the mechanical parts. This alignment procedure aims to verify the optical alignment of the assembled parts of the polarimeter. The alignment and the assembling of the polarimeter components is performed with the following procedure.

1. Alignment of the optics (polarizer and detector simulator) inside the rotating assembly.
   (a) The rotating assembly is mounted on an alignment tool which replicates the interface with the fixed assembly, but gives access to the optical parts. On the rotating assembly, the polarizer, the detector simulator, and the alignment mirror, perpendicular to the optical axis, are mounted.
   (b) Identification of the direction of the rotation axis by means of autocollimation on the alignment mirror (the mirror is then removed).
   (c) Alignment of the polarizer.

2. Optical and mechanical alignment of the pinhole with respect to the front cover interface plane. The axis of the pinhole is identified with coordinates (relative to a reference pin) and with angles (relative to an optical reference cube).

3. Replacement of the detector simulator with the detector.

4. Integration of the rotating assembly on the fixed assembly, with verification of ball bearings clearance.

5. Front cover integration.


7. Verification of the polarimeter alignment
   (a) The polarimeter is mounted on an alignment tool having the same mechanical interface of the spectrometer.
   (b) Alignment of the source (251 nm line of Hg lamp) with the rotation axis.
   (c) Verification of the alignment.

8. Repeat step 7 after thermal and vibration tests.

The alignment and the assembling activities require the following tools:

- Detector simulator, a glass plate with a crosshair that identifies the center of the detector.
• Alignment mirror, to be placed in front of the rotating assembly, perpendicularly to the optical axis.

• Alignment tool that holds the rotating assembly for the internal alignment.

• Optical bench with Hg lamp, pinhole and focusing optics.

4.1.2. EUV polarimeter to spectrometer alignment

The EUV polarimeter is assembled in the EUV spectrometer unit. The alignment is performed using the alignment reference cube of the polarimeter, and is verified using the 251 nm Hg line with the alignment rulings of the grating.

4.2. On flight detector performances monitoring

To monitor the detector performances change on flight two procedures are proposed. The first one concerns the detector central anode uniformity check to assure that no stray polarimetric signals are introduced by different spatial response of the anode. This test can be performed using the OVI 103.7 nm unpolarized coronal line, which can be selected via an appropriated grating rotation, and allowing the polarimeter assembly to rotate over the entire roll angle range.

The second procedure concerns the reflecting plate-detector response degradation respect to the pre-flight calibrations carried out in the laboratories to earth. This kind of monitoring can be achieved using the general in flight radiometric calibration for the entire instrument, which will be performed probably with astronomical reference sources (e.g. stars) or with a dedicated calibration service lamp.

Concerning the anode response degradation, it is mandatory to include a procedure to prevent the use of the same anode area for long time. This is feasible planning a periodical roll angle phase shift of the polarimeter assembly, which allows to exploit different anode surface zones during the standard, three positions, polarization measurement procedure.

Finally, it is also planned a pulse height calibration procedure, to determine the best discriminator threshold. This calibration is a loop-procedure which consists of the possibility to vary the discriminator threshold, record and then reset the counts number. The resultant behavior represents the integral distribution of the pulse height over a selectable time.

4.3. EUV Polarimeter pinhole size

In ASCE 1999 proposal document the UV polarimeter pinhole size was $1\,mm \times 1\,mm$, which corresponds to a spectral range of $0.417\,nm$ and a spatial resolution of $100\,arcsec$ along the tangential direction. The spatial resolution along the radial direction is defined by the slit width.
With the same pinhole size, the ASCE 2001 UV polarimeter has a spectral range of \(0.556\, nm\) and a spatial resolution of \(275\, arcsec\). The spatial resolution is not acceptable and then we must resize the pinhole height to match the ASCE 1999 spatial resolution by multiplying it by a 0.375 factor. Table 2 shows a comparison between the characteristics of the two instruments relevant for the UV polarimeter.

**Table 2. Instruments basic characteristics.**

<table>
<thead>
<tr>
<th></th>
<th>ASCE 1999</th>
<th>ASCE 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope mirror dimensions ((h \times w))</td>
<td>(250, mm \times w(r))</td>
<td>(70, mm \times w(r))</td>
</tr>
<tr>
<td>Focal length ((f))</td>
<td>(2000, mm)</td>
<td>(750, mm)</td>
</tr>
<tr>
<td>Entrance slit ((h_s \times w_s))</td>
<td>(19, mm \times 10, \mu m) to (350, \mu m)</td>
<td>(9, mm \times 14, \mu m) to (350, \mu m)</td>
</tr>
<tr>
<td>Reciprocal dispersion</td>
<td>(0.417, nm/mm)</td>
<td>(0.556, nm/mm)</td>
</tr>
</tbody>
</table>

The telescope mirror width, as a function of the observational height, for the two ASCE versions is given by the same expression because the boom distance is the same.

### 4.3.1. ASCE 2001 vs. ASCE 1999 throughput comparison

The throughput general expression is given by:

\[
U = S_{tel} \cdot \Omega_{slit} \tag{1}
\]

where \(S_{tel}\) is the telescope area \((h \cdot w(r))\) and \(\Omega_{slit}\) is the solid angle subtended by the slit on the sky \((S_{slit}/f^2)\), where the slit aperture \((S_{slit})\) defines the spatial resolution. In the case of the UV polarimeter, though, the spatial resolution along the tangential direction is defined by the pinhole height \((h_p)\), therefore the solid angle is given by the product of the slit width \((w_s)\) for the pinhole height. The throughput can be expressed as:

\[
U = h \cdot w(r) \frac{w_s \cdot h_p}{f^2} \tag{2}
\]

and assuming the same slit width, we obtain:

\[
U_{2001} = 0.75 \cdot U_{1999} \tag{3}
\]

that is a 25% reduction of the throughput with the same spatial resolution.
4.3.2. ASCE 2001 pinhole size

Note that the pinhole width does not affect the throughput value, its value can be set slightly wider than the slit width (maximum 350 µm) in order to measure the total line intensity. Setting a pinhole width of 350 µm gives a spectral range of 0.195 nm that is wider than the line widths of the H I Lyman lines series and O VI lines observed into equatorial streamers by SOHO/UVCS. Then, at last, the suggested dimensions for the ASCE 2001 UV polarimeter pinhole are:

\[ h_p = 350\mu m, \; w_p = 350\mu m. \]  

with the slit width \( w_s \leq 300 \mu m \). The slit width can be reduced, compatibly with the minimum countrate required, to permit the observation of finer structures on the solar corona. Note that the suggested pinhole size fits the expected transversal size (about 0.1 R_☉) of the coronal loops.

References


NASA Press Release 02-069, April 17, 2002


