Mem. S.A.It. Vol. 78, 697

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The Field Camera Unit project for the WSO-UV space telescope

S. Scuderi[1], I. Pagano[1], M. Fiorini[2], L. Gambicorti[3], A. Gherardi[3], F. Gianotti[4], D. Magrin[5], M. Miccolis[6], M. Munari[1], E. Pace[3], C. Pontoni[1], M. Trifoglio[4], M. Uslenghi[2], and B. Shustov[7]

[1] Istituto Nazionale di Astrofisica – Osservatorio Astrofisico di Catania, Via S. Sofia 85, I-95123 Catania, Italy; e-mail: scuderi,ipa,cpo,mmu@oact.inaf.it
[2] Istituto Nazionale di Astrofisica – Istituto di Astrofisica spaziale e Fisica Cosmica, Via Bassini, 15 I-20133 Milano, Italy
[3] Universitá di Firenze – Dipartimento di Astronomia e Scienza dello Spazio, Largo Enrico Fermi, 2 I-50125 Firenze, Italy
[4] Istituto Nazionale di Astrofisica – Istituto di Astrofisica spaziale e Fisica Cosmica, via Gobetti 101 I-40129 Bologna, Italy
[5] Istituto Nazionale di Astrofisica – Osservatorio Astronomico di Padova, vicolo dell'Osservatorio 5 35122 Padova Italy
[6] Thales Alenia Space Italia SS. Padana Superiore 290, I-20090, Vimodrone (Milano), Italy
[7] Institute of Astronomy Russian Academy of Sciences 48 Pyatnitskaya st., 119017, Moscow, Russia

Abstract. The Field Camera Unit (FCU) is one of the focal plane instruments aboard the WSO-UV telescope, a 1.7 m UV optimized instrument that will investigate numerous astrophysical phenomena from planetary science to cosmology. The FCU will perform deep UV and diffraction limited optical imaging in both wide and narrow band filters using three channels (FUV, NUV and UVO) optimized in different wavelength ranges and will have also spectropolarimetric capabilities. The total wavelength range covered by the instrument will go from 115 nm to 700 nm. The FCU instrument will be developed and realized by the italian scientific and industrial community. This paper will describe the scientific capabilities of the camera, its architecture and the expected performances.

1. Introduction

The World Space Observatory-UV is a international collaboration led by Russia to build a space telescope dedicated mainly to UV astrophysics. Table 1 summarize WSO-UV spacecraft characterisitcs while Figure 1 shows the satellite in flight configuration. Telescope, launcher (Zenith 2SB) and platform (Navigator) will be developed in Russia. The spacecraft will be in a geosynchronous orbit at a height of 35800 km and an inclination of 51.8 degrees. The mission life time will be longer than 5 years. The telescope will be a Ritchey-Chretien with a diameter of 1.7 m with a focal ratio of F/10 and a corrected field of view of 0.5 degrees. The primary wavelength range

Send offprint requests to: S. Scuderi

Table 1. WSO-UV spacecraft characteristics

Spacecraft mass with propellant	2900 kg
Payload mass	1600 kg
Instruments compartment power consumption	750 W
Data transmission rate, (S-Band)	2 Mb/s
Service telemetry data transmission rate	up to 32kb/s
Platform star trackers pointing accuracy	30”
Stabilization and pointing accuracy	0.02”
Angular rate when stabilized	$2x10^{-5}$ °/s
Slew rate	0.1 °/s
Maximum duration of an observation session	30 hours

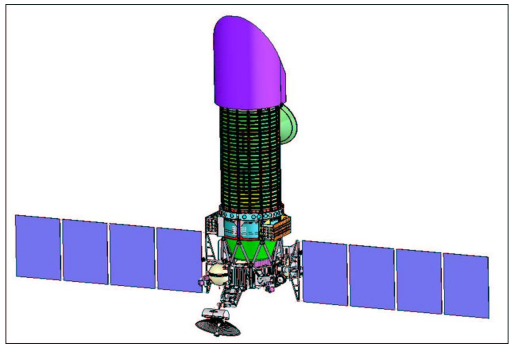

Fig. 1. WSO-UV spacecraft in flight configuration. The solar panels and the on board radio complex are deployed. The sun shade and the telescope cover are in the nominal position for observations.

is 100-350 nm with an extension into the visible range. The telescope will host two spectrographs and one imager. There will be a high resolution echelle spectrograph (HIRDES) developed by Germany with a resolution of about 50000 and two channels to cover more efficiently the entire wavelength range. The second spectrograph, developed by China, will be a long slit low resolution (R ∼ 1000-2500) spectrograph (LSS). This instrument will have also two channels. The imager, Field Camera Unit, will be devoloped in Italy and will allow to obtain diffraction limited and deep UV and optical images. More detailed informationon on the WSO-UV project and its focal plane instruments can be found in Sachkov et al. (2007) and Pagano et al, (2007a).

2. The Field Camera Unit project

The Field Camera Unit (FCU) will provide the WSO-UV satellite with imaging capabilities. The FCU instrument will be developed and realized by the italian scientific and industrial community. The Italian Space Agency (ASI) has financed the phase A/B1 study of the FCU project. The main objectives of this study will be the following:

- Definition of scientific objectives
- Definition of performances requirements
- Opto-mechanical design
- Definition of the detectors architecture.
- Definition of electronics architecture
- Preliminary definition of operational modes of the cameras
- Preliminary definition of calibration procedures
- Definition of interfaces with the spacecraft
- Definition of cameras mass, power and thermal budget.

A technical team and a science team have been set up and will deliver the results of the study to ASI by the end of 2007.

The scientific interest of the italian astrophysical community toward the project is strong and several scientific projects are being developed to be carried out with the FCU instrument ranging from planetary science to extra-galactic astronomy (Pagano et al. 2007b).

Being a space telescope imaging camera the highest priorities of the FCU instrument will be to guarantee high spatial resolution and high UV sensitivity while trying to maximize the wavelength coverage and the size of the field of view. To meet this challenge we are designing an instrument that will have three different channels each of them specialized in

Table 2. FCU channels main characteristics

	Channel		
	Far-UV	Near-UV	UV-Optical
Spectral Range	115-190 nm	150-280 nm	200-700 nm
Field of View	6.6’x6.6’	1’x1’	4.7’x4.7’
Scale	0.2”/pixel	0.03”/pixel	0.07”/pixel
Pixel Size	20 μm	20 μm	15 μm
Array Size	2kx2k	2kx2k	4kx4k
Detectors	MCP (CsI)	MCP (Cs_2Te)	CCD (UV-optimized)
Filters, Polarizers, Disperser	Up to 10	Up to 23	Up to 24

a specific wavelength range. Table 2 summarizes the characteristics of the three channels. The Far-UV channel will cover the 115-190 nm range. To reduce losses in the throughput, this channel will not have any optics but the mirror to feed it. The scale of the telescope will be unchanged yielding a large field of view at expenses of spatial resolution. So for this channel we favoured sensistivity over revolution. The FUV channel filters wheels will accommodate narrow, wide band filters and a prism which will allow low resolution (R ~ 100-300) slitless spectroscopy. The NUV channel will cover the 150-280 nm range overlapping the FUV range on the shorter wavelengths side and the UVO range on the longer one. To exploit the diffraction limited optical quality of the telescope in this wavelength range, the NUV channel has the highest spatial resolution. Its filters wheels will accommodate wide and narrow band filters but also prism and polarizers. The possibility to have a spectropolarimetric mode is being investigated. Finally the UVO channel will extend to visual wavelengths to exploit the wide spectral sensitivity of its CCD detector. The pixel scale of this channel is a compromise between the need of a large field of view and of a high spatial resolution. Filters, grisms and polarizers will allow to have narrow and broad band imaging, low resolution (R ~ 100-300) slitless spectroscopy and imaging polarimetry.

3. Opto-Mechanical design

Figure 2 shows the layout of the focal surface of the telescope with superimposed the fields of view of the three channels of the FCU. This area has a diameter of 150 mm and as it can be deduced from the figure is rather crowded. Figure 3 shows the space where the FCU will be located in the instrumental compartment, that is between the primary mirror unit and the optical bench that supports the spectrographs. This space is a cylinder of about 1 meter in diameter and about 20 cm in height. Due to this kind of geometry it is necessary to use a mirror to fold the optical beam coming from the telescope in a direction parallel to the optical bench where the three channels of the FCU will be deployed.

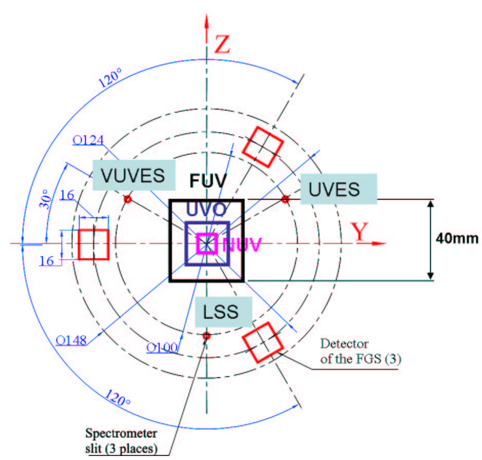

Fig. 2. Sketch of the WSO-UV telescope focal surface with the positions of the slits of the spectrographs and of the FGS. The FOV of the FCU channel as projected onto the sky are also shown.

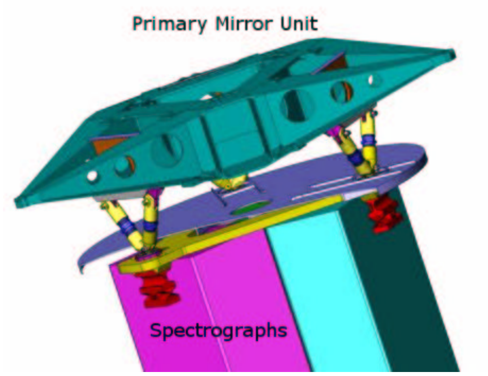

Fig. 3. A 3D model of the scientific instrumentation compartment showing the area where the FCU instrument will be located, that is on the optical bench between the primary mirror unit and the spectrographs.

After a preliminary analysis we decided to develop an all reflective design to maximize throughput and to stay as much as possible close to, if not on, the optical axis to simplify the design. We are considering three optical designs which differ for the central pick up mirror layout.

1. Rotating pick up mirror: in this case the folding mirror will be flat and using a mechanism will rotate feeding one of the three channels at a time.
2. Pyramid pick mirror: this layout foresee to use three fixed mirrors (possibly having optical power and a specialized coating) which will be oriented to feed all three channels at the same time.
3. Fixed pick up mirror coupled with dichroic(s): the mirror will fold the optical beam, a first dichroics will extract from it the FUV beam and a second one will separate the NUV beam from the UVO beam.

The last layout has interesting advantages because will not use any mechanism and would allow to image the same field simultaneously with the three channels. Unfortunately it has been discarded because, in the focal surface of the telescope, there is not enough room to accommodate the resulting opto-mechanical layout. Furthermore it requires R&D activities, related to the design and the manufacture of the dichroics, which are not compatible with the schedule of the project. The surviving designs have both advantages and disadvantages. The most evident drawback of the first layout is the possibility of a mechanism failure which will reduce the FCU capabilities. For the second design the main problem is the mechanical accommodation of the mirror in the center of the focal surface. A trade-off process, taking into account the problems related to the opto-mechanical design or to the FCU or telescope operations, is well under way.

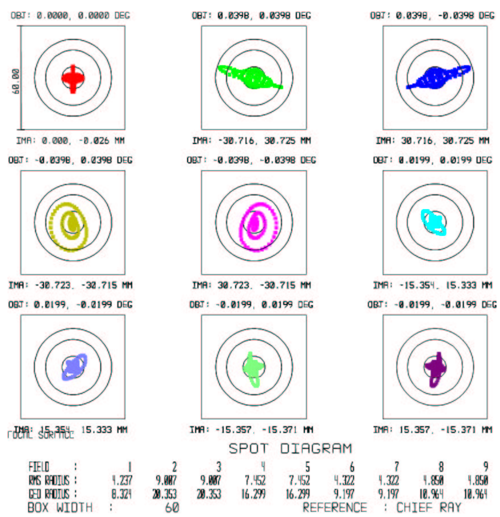

Fig. 4. Spot diagrams for the UVO channel and the rotating mirror optical layout. The three circles are the Airy's disks at 200, 500, and 700 nm (from the smaller to the larger). The spot diagrams are shown for different positions on the field of view.

Figure 4 shows the spot diagrams for one of the optical design using a rotating mirror. The spot diagrams refers to the UVO channel and have been calculated for different positions on the field of view. The Airy's disk at three different wavelengths (200, 500, 700 nm) are also plotted showing that at 500 nm and 700 nm the design is always diffraction limited while at shorter wavelengths this is not true on border of the field.

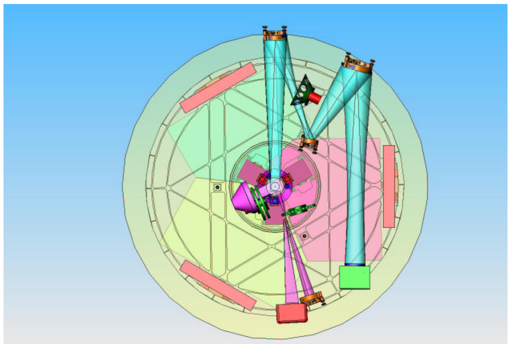

Fig. 5. Opto-mechanical for the three channels of FCU in case of a rotating mirror layout. NUV channel is the one on the bottom part of the drawing, the UVO channel is the one that expands on the whole bench and the FUV channel is the one closest to the center of the optical bench.

Figure 5 shows a top view of one of the opto-mechanical designs of the FCU for a rotating mirror layout. The three channels can be easily distinguished (see the caption of Figure 5 for explanation. Apart the positions of the mirrors, filter wheels and detectors are also shown. The optical bench, in this case, has a diameter of 1.3 meters.

4. Detectors

The FCU will use two different kind of detectors. For the FUV and NUV channels, MCP based detectors in sealed configuration will be used. The sealed configuration will eliminate the need for pumping and reduce contamination problems. Each of the MCP detectors will be specialized for the wavelength range where it will be used. So the FUV detector will have a CsI photocathode directly deposited on the MCP while in the case of the NUV detector Cs_2Te will be used as photocathode deposited on the detector's window. In both cases the MCP will be coupled to a fluorescent screen and then to a fiber optic tapered bundle that, in turn, will be coupled to a CCD (see Fig. 6). The MCPs will have a diameter of 40 mm and will be resampled in a 2kx2k format. The UVO channel will instead use a CCD detector with 15 μm pixel size and 4kx4k format. The CCD will be back side illuminated. Its cooling system will either be an active one, using a Thermo Electric Cooler or a passive one, in which case the CCD will be connected to an external radiator.

5. Operating modes

We are planning to implement the following operating modes for the FCU instrument:

- **optical mode** - All the three channels will allow to have narrow, medium and wide band imaging and also low resolution slitless spectroscopy. Polarimetric modes are foreseen for the NUV and UVO channels and a spectropolarimetric mode in under study for the NUV channel.
- **parallel mode** - In case the pyramid pick up mirror will be selected solution for the opto-mechanical layout, two channels of the FCU could be used at the same time looking at different parts of the sky. The implementation of this mode will be subject to thermal and power bugdet analysis. Furthermore one channel of the camera can be used when one of the spectrographs is working as primary instrument. In this case the only restriction could come from limitation of data transfer rate.
- **high temporal resolution mode** - The FUV, NUV and UVO channels can all be operated in a mode where subarrays of the detector can be read-out, thereby reducing the readout time and permitting a more

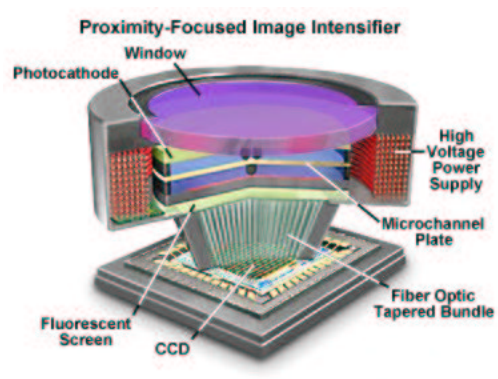

Fig. 6. Skematic view of an intensified CCD.

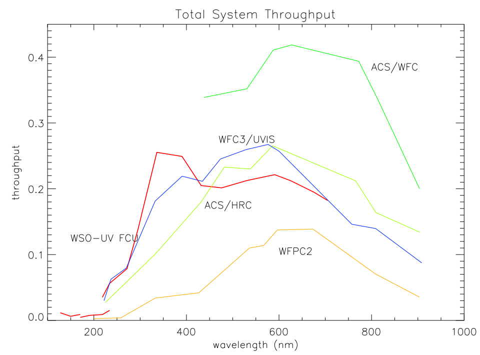

Fig. 7. System throughputs of FCU instrument channels as functions of wavelength compared to that of HST imaging instruments.

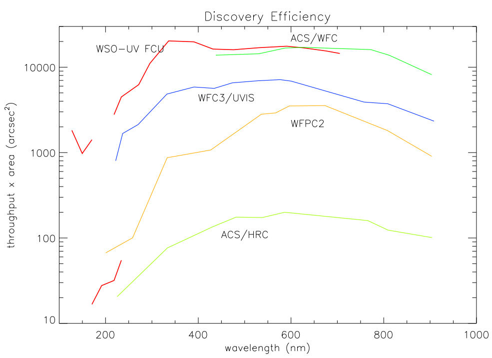

Fig. 8. Discovery efficiencies of of FCU vs. wavelength compared to that of the HST imaging instruments. Discovery efficiency is defined as the system throughput multiplied by the area of the field of view. Note that the y-axis is logarithmic.

rapid observing sequence. The FUV and NUV detectors can also operate in a time tag mode whereby the image location and the time of arrival of the detected photons are recorded permitting a few ms temporal resolution at the expense of increased data volume.

– **calibration mode** - The FCU optical design will include a calibration unit with a set of continuum source lamps covering the full wavelength ranges of the three detectors. These lamps will be used periodically to perform flat field calibrations.

6. Performances

Figure 7 plots the expected system throughputs of the three FCU channels compared to the ones of cameras that have flown or will flew on board the Hubble Space Telescope i.e. WFPC2, ACS/WFC, ACS/HRC and WFC3/UVIS (Bond et al 2006). The plotted quantities are the total throughputs, including the telescope, all of the optical elements of the instruments themselves, the sensitivities of the detectors and filter transmissions. Throughputs for FCU are estimated based on the best information currently available and are subject to change. The throughput of the UVO channel is much better than that of WFPC2 which, by the way, is the oldest of the HST cameras, and is comparable to that of ACS/HRC and WFC3/UVIS being better in the UV range. ACS/WFC, being optimized in the visual range, has a much better throughput than the UVO channel.

Another quantity that is useful when comparing different instruments, especially in the context of wide-angle surveys, is the discovery efficiency, defined as system throughput times the area of the FOV as projected onto the sky. In Figure 8 we plot the discovery efficiencies of FCU vs. wavelength again compared to that of the HST imaging instruments (Bond et al 2006). Due to its large field of view, the UVO channel of the FCU has a discovery efficiency equal or greater than that of ACS/WFC. The performances of the FUV channel are even better when compared to HST because, in this case (by the way ACS/SBC is not present in the plot), no camera working in this wavelength range has a large field of view.

Acknowledgements. The present work, a Phase A/B1 study of the Italian participation to WSO-UV, is funded by Italian Space Agency (ASI), under contract ASI/INAF No. I/085/06/0.

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