



<b>Publication Year</b>	2018
<b>Acceptance in OA</b>	2020-11-05T11:03:30Z
<b>Title</b>	The solar orbiter Metis and EUI intensified CMOS-APS detectors: concept, main characteristics, and performance
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<b>Publisher's version (DOI)</b>	10.1117/12.2313800
<b>Handle</b>	<a href="http://hdl.handle.net/20.500.12386/28157">http://hdl.handle.net/20.500.12386/28157</a>
<b>Serie</b>	PROCEEDINGS OF SPIE
<b>Volume</b>	10699

# PROCEEDINGS OF SPIE

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Udo Schühle, Luca Teriaca, Regina Aznar Cuadrado, Klaus Heerlein, Michela Uslenghi, Stephan Werner, "The solar orbiter Metis and EUI intensified CMOS-APS detectors: concept, main characteristics, and performance," Proc. SPIE 10699, Space Telescopes and Instrumentation 2018: Ultraviolet to Gamma Ray, 1069934 (6 July 2018); doi: 10.1117/12.2313800

**SPIE.**

Event: SPIE Astronomical Telescopes + Instrumentation, 2018, Austin, Texas, United States

# The Solar Orbiter Metis and EUV Intensified CMOS-APS detectors: concept, main characteristics and performance

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## ABSTRACT

Two instruments aboard the Solar Orbiter mission, the Extreme Ultraviolet Imager and the Metis coronagraph, are using cameras of similar design to obtain images in the Lyman alpha line of hydrogen at 121.6 nm. Each of these cameras is based on an APS sensor used as readout of a single microchannel plate intensifier unit whose output current is converted into visible light photons through a phosphor screen. Before integration on the respective instruments, both detector's flight models have been characterized and calibrated. In this paper, we describe the two camera systems, the results of qualification tests, and report their performance characteristics.

**Keywords:** Lyman-Alpha camera, Far Ultraviolet detector, Solar Orbiter mission

## 1. INTRODUCTION

The Far Ultraviolet (FUV) spectral range (120-200 nm) is of particular importance for solar physics studies as it contains spectral lines that are powerful diagnostics of the solar atmosphere. The Lyman alpha line of hydrogen at 121.6 nm, the brightest solar emission line, is of particular relevance. When observed against the solar disk, it provides information on the region at the base of the solar corona. On the other hand, coronagraphic (solar disk occulted) observations reveal the emission from the radiatively excited hydrogen in the extended corona. Two telescopes, the Extreme Ultraviolet Imager<sup>[1]</sup>, designed to take close-up high-resolution images of regions of the solar disk, and the Metis coronagraph<sup>[2]</sup>, designed with an external occulter to observe the corona in visible light and at the Lyman alpha wavelength, are using cameras of similar design.

Both instruments are embarked on the ESA/NASA mission Solar Orbiter<sup>[3],[4]</sup> that will fly closer to the Sun to study it from close up and from progressively inclined orbits that will provide an unprecedented viewpoint.

Each of them has a channel for observations of the Lyman alpha line based on a CMOS APS sensor used as readout of a single microchannel plate (MCP) intensifier whose output current is converted into visible light photons (detected by the APS) through a phosphor screen. The intensifier and screen assembly is actually the same for both cameras but with a 1k × 1k Star-1000 APS sensor in the Metis coronagraph UltraViolet Detector Assembly (UVDA)<sup>[8]</sup> and with a 3k × 3k CMOS APS sensor<sup>[5]</sup> for the High Resolution Lyman Alpha Imager of EUV<sup>[6]</sup>.

Before integration in the respective instruments, both detectors have been qualified and characterized at facilities at Max Planck Institute for Solar System Research (MPS) and calibrated in the UV range using the detector calibration beamline of the Metrology Light Source<sup>[9]</sup> of the Physikalisch-Technische Bundesanstalt (PTB). In this paper we give a description of the two camera systems, the results of space qualification tests, and report their performance characteristics.

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## 2. DETECTOR DESIGN SPECIFICATIONS

To achieve the high spectral purity required by the EUI and Metis telescopes, a “visible-blind” microchannel plate intensifier is necessary for a highly sensitive detector at the Lyman Alpha wavelength of 121.6 nm. The intensifiers are incorporated in the focal plane assembly (FPA), a camera housing (providing the necessary thermo-mechanical, mounting, power, and commanding interfaces) with an APS sensor and its front end electronics. The two Lyman-Alpha cameras of EUI and Metis use different image sensors: The EUI camera is using an APS sensor with  $3k \times 3k$  format and a dual readout electronic system providing a “high gain” and “low gain” channel, specially developed for the Solar Orbiter mission<sup>[7]</sup> and fabricated by CMOSIS<sup>[5]</sup>.

The Metis camera is using a space-qualified STAR1000  $1k \times 1k$  format imaging chip<sup>[8]</sup>.

Both cameras are using an intensifier with microchannel plates and a phosphor screen converting the UV radiation to visible light. The requirements for a high dynamic range, high resolution, and large active area are leading to a design with a single microchannel plate (MCP) with a potassium bromide (KBr) photocathode that provides sufficient sensitivity and amplification for the APS-based detection system. To protect the photocathode, the intensifier tube is closed by a magnesium fluoride entrance window. A high voltage supply unit (HVU) provides the adjustable voltages of up to +1 kV for the MCP and +6 kV with respect to the MCP output for the phosphor screen. Figure 1 shows the principle design of the cameras. The detailed requirements are given in Table 1.

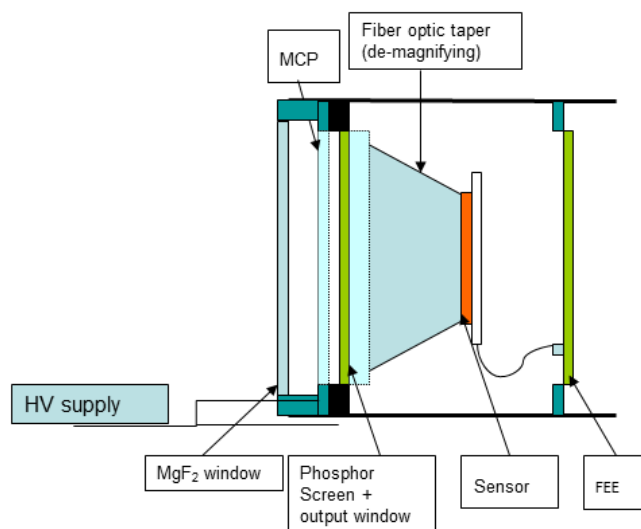


Figure 1. Schematic representation of the intensifier with a CMOS APS sensor

Table 1. Detailed requirements of the intensifier for the EUI and Metis cameras

Component	Material and characteristics	
Entrance window	VUV grade MgF <sub>2</sub> plate	4 mm thickness “c-cut” orientation of the crystal
Intensifier body	Microchannel plate	49 mm diameter 10 micron pores/ 12 micron pitch 40 mm diameter of active area Up to 1 kV

	Photocathode	KBr of > 0.35 micron thickness
Output coupler	Fiber optic plate	6 micron fibers 40 mm diameter of active area
	“P46” phosphor anode	Up to 6 kV
Fiber optic taper	de-magnifying taper	6 micron fibers EUI: 1.41:1 de-magnification Metis: 2:1 de-magnification
HV supply	Stabilized, regulated	1 kV (MCP) + 6 kV (anode)

### 3. INTENSIFIER DESIGN SOLUTIONS

All intensifier tubes and connecting parts have been made to specifications and procured from ProxiVision GmbH. The intensifier tube is sealed with a  $MgF_2$  window of 4 mm thickness with a “c-cut” orientation of the crystal, to minimize polarization effects. The mechanical interface is provided by a ceramic mounting ring glued to the body with non-conductive structural epoxy adhesive. The “P46” anode is deposited on the output fiber optic flat on the back side of which a fiber optic taper is mated. Figure 2 shows the exploded view of these items. In the case of EUI a  $2k \times 2k$  subfield of the  $3k \times 3k$  pixel of this sensor with 10 microns pixel size is used and a fiber optic taper is required for re-scaling the image by a factor 1.41/1, to match the useful size of 20 mm x 20 mm of the sensor. In the case of the Metis camera, a de-magnification of 2/1 is necessary to map the active area over the  $1k \times 1k$  sensor with 15 micron pixel size.

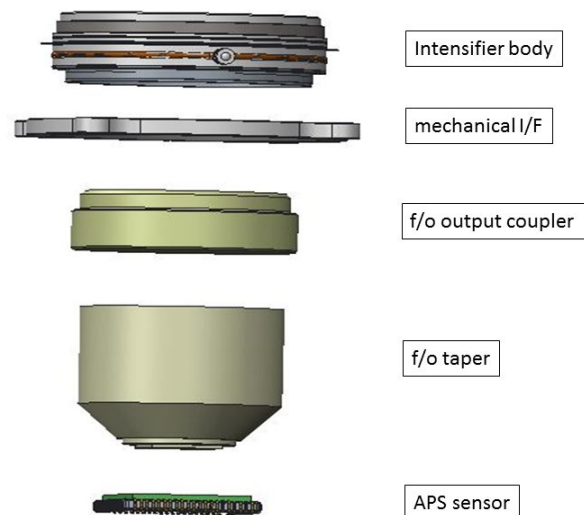


Figure 2. Design of the intensifier with CMOS APS sensor readout, connected by a fiber optic taper.

The mating of the intensifier with the sensor by optical fiber coupling involves several gluing processes. All connections have passed the thermal and mechanical qualification tests required for the space flight on Solar Orbiter and were verified for optical performance in the UV. The assembled intensifier and sensors have been integrated into the EUI and Metis camera systems as shown in Figure 3.

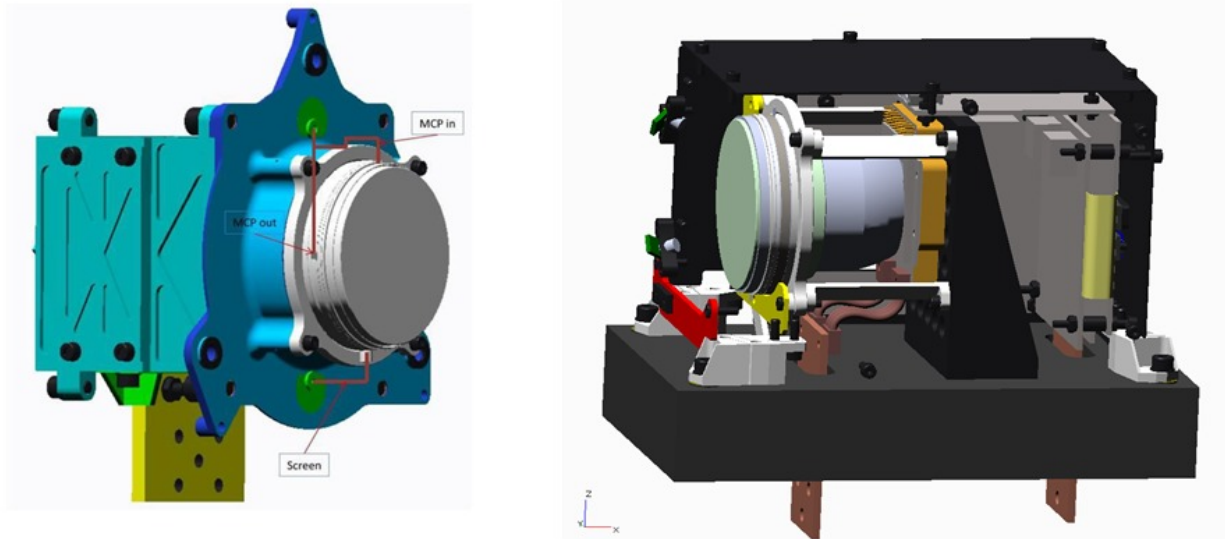


Figure 3. CAD derived views of the Metis (left panel) and the EUV (right panel) Lyman-alpha cameras showing the mounting of the intensifiers.

#### 4. PERFORMANCE CHARACTERIZATION

All units of the cameras have been characterized and calibrated before being integrated in the EUV and Metis instruments, using facilities at the Max Planck Institute for Solar System Research (MPS). A special vacuum chamber was built specifically for this purpose.

For characterization at 121.6 nm the chamber was mounted to the MPS reflectometer facility that is equipped with a Lyman alpha source (Type: Resonance HHe-LM-L) and a narrow-band interference filter to suppress all longer wavelengths. Several optical setups have been used, with different distances between the light source and the detector, to produce high intensity, quasi-flat irradiation of the full detector area. Using this quasi-flat illumination, a burn-in of the intensifier was carried out to stabilize the gain of the MCPs.

A measurement of the resolution of the intensifier system was tried with this setup. The best resolution result was obtained by placing the light source at a distance of about 140 cm away from the detector and by using a pinhole limiting the source size to 1 mm. A USAF 1951 target was placed directly on the entrance window of the intensifier which was exactly 7.5 mm in front of the focal plane (i. e., the photocathode on the MCP). In Figure 4 we show, as sample of the results, an image of the target obtained with the EUV camera. The inserts on the left hand side show cuts through the smallest feature of the target (in horizontal and vertical direction), while the insert on the right shows a cut across the edge of the largest square. This shows a fall-off to 50% of the intensity within two pixels of 14.1 microns and this verifies a minimum of the possible MTF of 25% with 18 line pairs per millimeter. This simple analysis is neglecting effects like diffraction from the target, possible pixel-to-pixel cross talk, and the geometry with the finite source size of 1 mm, contributing with more than 5 microns to the blur size of the image.

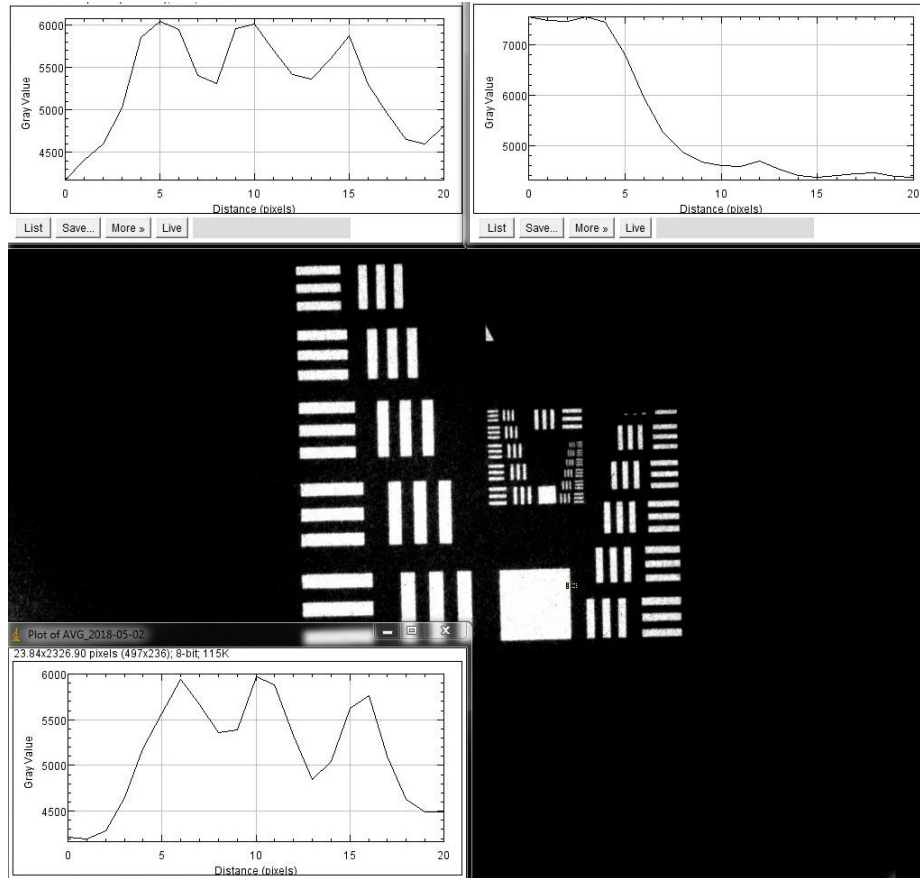


Figure 4. Results of a resolution test using imaging of a USAF 1951 resolution target. The inserts on the left show cuts through the smallest horizontal and vertical features of the target while the insert on the top right show a cut through the edge of the largest square.

## 5. RADIOMETRIC CALIBRATION

The calibration of the spectral radiometric response was carried out at the Metrology Light Source (MLS) of the electron storage ring of the Physikalisch-Technische Bundesanstalt (PTB) in Berlin. The MLS<sup>[9]</sup> provides monochromatized synchrotron radiation for a beam line dedicated specially for the radiometric calibration of detectors with traceability of the radiometric quantities to a primary detector standard. The cameras were transported to Berlin in the vacuum chamber and mounted at the beamline for detector characterizations of the MLS. In this setup the vacuum chamber can be moved horizontally and vertically under vacuum relative to the MLS beam. In this way the MLS beam can be positioned at any place of the detector. The spectral response of the cameras was measured between 110 nm and 310 nm, in order to characterize the suppression at wavelengths longer than 122 nm, which is important for the overall spectral purity of the telescopes. Figure 5 shows the response of the Metis UVDA<sup>[10]</sup> and the EUI Lyman-alpha<sup>[11]</sup> camera flight units. In Figure 6 we show the response of the cameras vs MCP voltage. Between 300 V and 800 V the dynamic range can be adjusted within four orders of magnitude with saturation setting in above 750 V.

## 6. CONCLUSIONS

Two cameras have been developed and qualified for the Lyman-Alpha channel of the EUI and Metis telescopes on the Solar Orbiter mission. They are based on two different CMOS-APS sensors with identical image intensifiers based on single multichannel plates. The flight units have been characterized and calibrated at subsystem level (before integration in the telescopes).

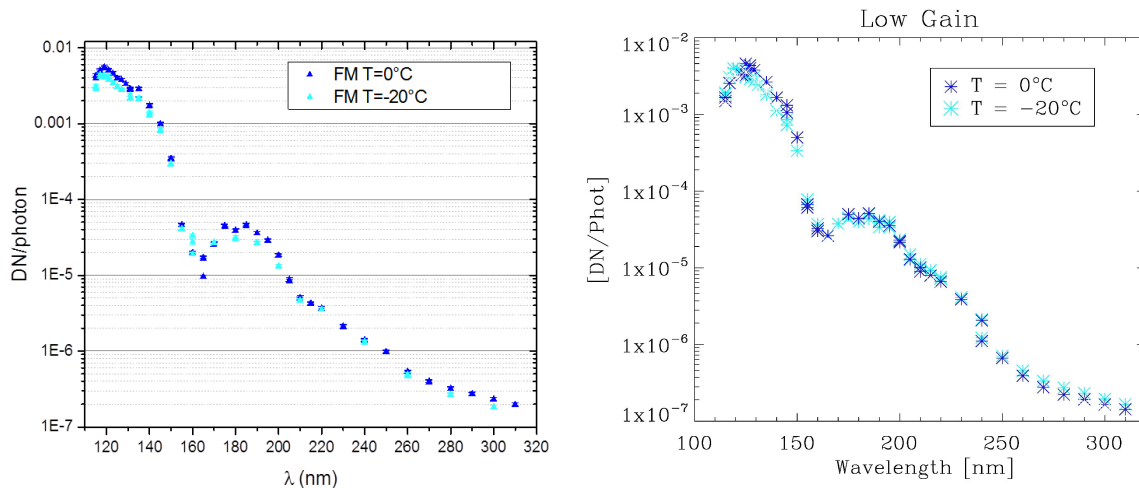


Figure 5. Spectral response of the Metis UVDA camera (left panel) and the EUV intensifier (right panel) between 110 nm and 310 nm.

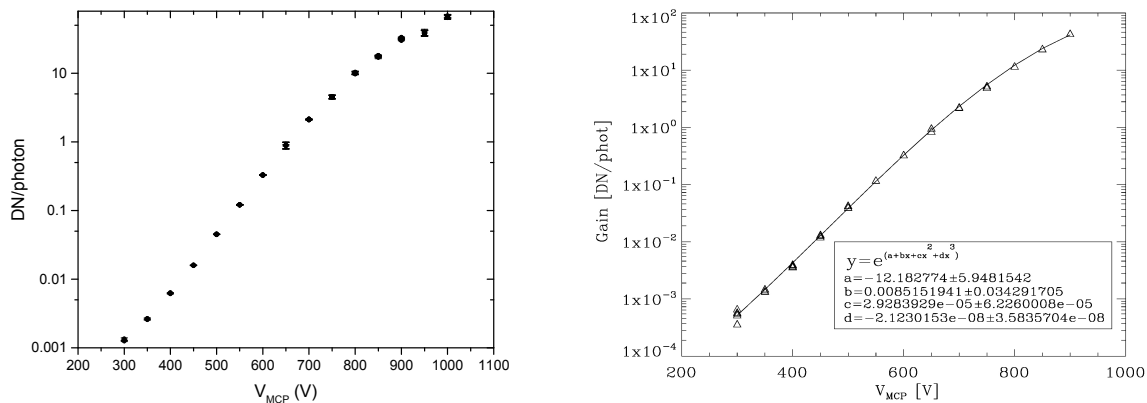


Figure 6. The conversion efficiencies as a function of the voltage applied to the MCP for the Metis UVDA (left panel) and the EUV (right panel) intensifiers.

## 7. ACKNOWLEDGEMENTS

The development of the EUV intensifier system and the Metis UVDA electronic camera system has been financed by the German Space Agency (Deutsches Zentrum für Luft- und Raumfahrt - DLR). A contribution to the Metis Detection System from the Italian Space Agency (Agenzia Spaziale Italiana - ASI) is gratefully acknowledged.

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