DEVELOPMENT OF THE VISIBLE AND FUV CAMERAS OF THE METIS CORONAGRAPH ABOARD SOLAR ORBITER

Luca Teriaca and the METIS Team at MPS

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MPI for Solar System Research - Göttingen
Outline

- Solar Orbiter
  - Science goals
  - Mission profile
  - Payload

- The METIS Coronagraph
  - Science
  - Conceptual design

- The METIS detection Subsystem developed by MPS
  - The team
  - Subsystem overview
  - The Visible Light Detector Assembly (VLDA) camera
  - The Current power converter
  - The UltraViolet Detector Assembly (UVDA) camera
  - The High Voltage Unit

- Summary
Solar Orbiter: science goals

• How and where do the solar wind plasma and magnetic field originate in the corona?
• How do solar transients drive heliospheric variability?
• How do solar eruptions produce energetic particle radiation that fills the heliosphere?
• How does the solar dynamo work and drive connections between the Sun and the heliosphere?
**Solar Orbiter: mission profile**

- **Flying as close to the Sun as 0.28 AU**
  - High spatial resolution
  - In situ sampling of unevolved plasma
- **Orbiting in quasi-corotation with the Sun**
  - Tracing plasma properties back to the sources
- **Climbing up to 34° over the ecliptic plane**
  - Observing the polar regions of the Sun and the equatorial corona from an unprecedented vantage point
Solar Orbiter: payload

A mission to study the Sun and its heliosphere as a coupled system

Close synergies with Earth based platforms and Solar Probe Plus
## METIS: science & top requirements

<table>
<thead>
<tr>
<th>Solar Orbiter Top-level Science Questions</th>
<th>Unique METIS contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>How and where do the <em>solar wind plasma</em> and <em>magnetic field</em> originate in the corona</td>
<td>The only Solar Orbiter instrument observing the:</td>
</tr>
<tr>
<td></td>
<td>region where the solar wind is accelerated from ≤100 km/s to near its asymptotic value</td>
</tr>
<tr>
<td>How do <em>solar transients</em> drive heliospheric variability</td>
<td>region where the first, most dramatic phase of the propagation of coronal mass ejections occurs</td>
</tr>
<tr>
<td>How do solar eruptions produce <em>energetic particle radiation</em> that fills the heliosphere</td>
<td>path of the shock front accelerating particles in the solar corona</td>
</tr>
<tr>
<td>How does the <em>solar dynamo</em> work and drive <em>connections between the Sun and the heliosphere</em></td>
<td>overall magnetic configuration (closed and open magnetic field regions of the corona)</td>
</tr>
</tbody>
</table>

*Table 1: METIS unique contribution to Solar Orbiter science*

### METIS Instrument Performance

<table>
<thead>
<tr>
<th>CORONAL IMAGING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Avg. Instrumental Stray Light</strong> ($B_{corona}/B_{disk}$)</td>
</tr>
<tr>
<td>VL: $10^{-9}$</td>
</tr>
<tr>
<td>UV: $10^{-7}$</td>
</tr>
<tr>
<td><strong>Wavelength range:</strong></td>
</tr>
<tr>
<td>VL: 580-640 nm</td>
</tr>
<tr>
<td>UV: 121.6±10 nm</td>
</tr>
<tr>
<td><strong>Spatial Resolution</strong></td>
</tr>
<tr>
<td>20 arcsec</td>
</tr>
<tr>
<td><strong>Field of view (FoV)</strong></td>
</tr>
<tr>
<td>1.5°-2.9° annular, off-limb corona</td>
</tr>
</tbody>
</table>

*Table 2: METIS instrument performances*
Figure 3-5. METIS coronagraph optical ray trace. UV path (top); VL path (bottom)

From the METIS EID-B
Figure 3-2 METIS instrument configuration.

From the METIS EID-B
METIS – MPS: Team

**Co-Is**

Joachim Woch
Luca Teriaca
Udo Schühle
Sami Solanki
Hardi Peter

**Management and AIV**

Indraneil Biswas
Local Project Manager
AIV Engineering

Luca Teriaca
Local Project Scientist
Program Responsible

Regina Aznar Cuadrado
Local Project Controller

Sandeep Ramanath
AIV Engineering

Reinhard Mueller
Quality Assurance

Tanja Macke
Project Assistant
METIS – MPS: Team

**Electrical Engineering**

- Rainer Enge
- Klaus Heerlein
- Tobias Keufner
- Sabrina Meyer (Electrical Technician)
- Michael Sperling (Electrical Technician)
- Stefan Werner (Test Engineering)

**Software Engineering**

- Martin Kolleck (GSE)
- Andreas Zerr
Two detector assemblies:

- the Visible Light Detector Assembly (VLDA)
- the Ultra Violet Detector Assembly (UVDA)

Service units:

- the High Voltage Power Supply (HPVS) serving the UVDA
- the Camera Power Converter (CPC) serving both assemblies
METIS – MPS: subsystem overview

METIS Optics Unit (MOU)

High Voltage Unit (HVU)

Ultra Violet Detector Array (UVDA)

Visible Light Detector Array (VLDA)

Connector Bracket nearby cameras

Camera Power Converter (CPC)

Interface to MPPU

+6V
+6V_RET
+35V
+35V_RET
SET_SCREEN (Analog differential)
SET_MCP (Analog differential)
Hｂ_SCREEN (Analog differential)
Hｂ_MCP (Analog differential)
Hｂ_I_MCP (Analog differential)
HV_SAVE (TLI)
TEMP (PT1000)

Channel Link (315 Mbps): CLK x 3 + DATA
SPI (2MHz, TDI):
MISO, MOSI, CLK, SSN

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SPI (2MHz, TDI):
MISO, MOSI, CLK, SSN

METIS – MPS: subsystem overview
METIS – MPS: subsystem overview

Figure 3-2 METIS instrument configuration.
METIS – MPS: VLDA camera

• 2k x 2k ISPHI sensor by CMOSIS
• Digital I/F (FPGA Board) + Sensor Board
• LVDS SPI control I/F:
  – DAC programming, digital pixel control, HK
• Channel-Link Data I/F
  – 2x parallel 14-bit ADC data (15 / 7.5 MHz) from sensor
• Sensor internal temperature sensor
• Annealing interface
METIS – MPS: VLDA camera

Annealing connector

Data connector

Power connector

Cold finger IF
- Custom sensor by CMOSIS
- QE > 50% @617nm
- 2kx2k / 100ke-
- 4 transistor PPD pixel architecture, rolling shutter
- Elimination of Reset and kTC noise by correlated double sampling (CDS)
- Differential analog outputs, signal level optimized for external ADC part
- Radiation tolerant design/process >70 krad (Si)
  - radiation qualification testing: Gamma, Proton DD and Heavy Ion
**METIS – MPS: VLDA sensor**

APS 2k x 2k, two analog outputs, CMOSIS 15/7.5 MHz  5 / 2.5 fps readout, rolling shutter no windowing capability in rows!

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame rate</td>
<td>fps</td>
</tr>
<tr>
<td>Full Well</td>
<td>ke⁻</td>
</tr>
<tr>
<td>Dark noise @ RT</td>
<td>e⁻</td>
</tr>
<tr>
<td>Dark current (293 K)</td>
<td>e⁻/s</td>
</tr>
<tr>
<td>Sensitivity (617nm)</td>
<td>%</td>
</tr>
<tr>
<td>Non-linearity</td>
<td>%</td>
</tr>
<tr>
<td>PRNU (local)</td>
<td>%</td>
</tr>
<tr>
<td>Power consumption</td>
<td>mW</td>
</tr>
</tbody>
</table>

**Parameter**

- **Frame rate**: fps
- **Full Well**: ke⁻
- **Dark noise @ RT**: e⁻
- **Dark current (293 K)**: e⁻/s
- **Sensitivity (617nm)**: %
- **Non-linearity**: %
- **PRNU (local)**: %
- **Power consumption**: mW
• Common Power Supply for UVDA and VLDA
• Clean supply voltages for both cameras
• Optimized efficiency due to operation of POL converters
• LVDS Camera switch-on signals
• Annealing Heater Switch-on
• Low Inrush Current
Sealed MCP with phosphor screen output
Fiber optic coupler (2:1 de-magnification)
APS Star 1000
FEE electronics (sensor and FPGA boards)
Thermal interface
Temperature sensor
High Voltage Power Supply

Figure 1: Sensitivity dependence with wavelength. These measurements were obtained on 23rd April 2012 summing up three different colours.
Top: Low gain frames; middle: High gain frames; bottom: ratio of the low to the high gain values.
METIS – MPS: UVDA camera

- FPGA Control + Sensor Board
- Supply by +5.2 V, 3.3 V, and 2.5 V provided by CPC
- Programmable pixel voltages (DAC)
- LVDS SPI Control I/F
- 14-bit ADC
- Channel-Link data I/F 48 MHz / 21 bit
  => effective data rate: 12 MHz x 16 bit = 192 Mbit/s
METIS – MPS: UVDA intensifier – sensor coupling

...carried out by ProxiVision GmbH
METIS – MPS: UVDA sensor

- Camera design with STAR1000 sensor

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame rate</td>
<td>11 fps</td>
</tr>
<tr>
<td>Full Well</td>
<td>95 ke-</td>
</tr>
<tr>
<td>Readout noise</td>
<td>47 e-</td>
</tr>
<tr>
<td>Dark current</td>
<td>3135 e-/s (+25 °C)</td>
</tr>
<tr>
<td>Shutter</td>
<td>Rolling</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>20 % (frontside)</td>
</tr>
<tr>
<td>Power cons</td>
<td>100 mW</td>
</tr>
<tr>
<td>Radiation hard</td>
<td>230 krad (TID)</td>
</tr>
</tbody>
</table>
METIS – MPS: UVDA camera

Intensifier

Data connector

Power connector

Cold finger IF
**METIS – MPS: HVU**

- Voltage supply for intensifier:
  - Phosphor Screen Supply: 0 V to +6000 V @ 1 µA
  - MCP Supply: +400 V to 1000 V @ 1 to 100 µA (HV Optocoupler)
- Supply input power:
  - 25 V+/-1% /45 mA and 6 V+/-0.3 V /30 mA
  => <1 W nominal (1.3 W at worst case max.)
- 2 analog control lines (differential) 0 to 4 V for MCP / Screen from MPPU
- Analog HK (differential) for Screen, MCP, and MCP current
- Direct regulation of SCREEN output voltage
  - Operation frequency (150kHz) => free running Royer converter => very low power, low EMI
- “HV-Safe” functionality by setting output voltage to ~1/20th of nominal output
- Shunt resistors on HV outputs (protection)
- Temperature sensor PT1000
- Primary current limiter
- Removable Ground-Stud
Summary

- The METIS instrument aboard Solar Orbiter is an inverted occultation coronagraph capable of performing broadband imaging and polarization in the visible range (580-640 nm), and narrow band imaging in FUV (H I Lyman α).
- It will provide images and electron density maps of the solar corona from unprecedented view points.
- It will provide info on the coronal regions and transients producing the plasma particles later observed in situ.
- MPS is providing both cameras and the support units forming the METIS detection subsystem, the heart of the instrument.