<table>
<thead>
<tr>
<th>Instrument</th>
<th>EPIC MOS</th>
<th>EPIC pn</th>
<th>RGS</th>
<th>OM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandpass</td>
<td>0.15-12 keV</td>
<td>0.15-15 keV</td>
<td>0.35-2.5 keV</td>
<td>180-600 nm</td>
</tr>
<tr>
<td>Orbital target vis.</td>
<td>5-135 ks</td>
<td>5-135 ks</td>
<td>5-135 ks</td>
<td>5-145 ks</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>$~10^{-14}$ (4)</td>
<td>$~10^{-14}$ (4)</td>
<td>$~8 \times 10^{-5}$ (5)</td>
<td>20.7 mag (6)</td>
</tr>
<tr>
<td>Field of view (FOV)</td>
<td>30' (7)</td>
<td>30' (7)</td>
<td>~5'</td>
<td>17'</td>
</tr>
<tr>
<td>PSF ($FWHM/HEW$)</td>
<td>5'/14&quot;</td>
<td>6'/15&quot;</td>
<td>N/A</td>
<td>1.4&quot;-2.0&quot;</td>
</tr>
<tr>
<td>Pixel size</td>
<td>40 μm (1.1&quot;)</td>
<td>150 μm (4.1&quot;)</td>
<td>81 μm ($9 \times 10^{-3}$ Å) (8)</td>
<td>0.476513&quot; (90)</td>
</tr>
<tr>
<td>Timing resolution</td>
<td>1.5 ms</td>
<td>0.03 ms</td>
<td>0.6 s</td>
<td>0.5 s</td>
</tr>
<tr>
<td>Spectral resolution</td>
<td>~70 eV</td>
<td>~80 eV</td>
<td>0.04/0.025 Å (13)</td>
<td>350 (14)</td>
</tr>
</tbody>
</table>

Optical & UV Monitor (OM) on-board XMM-Newton

Antonio Talavera

XMM-Newton Science Operation Centre, ESAC, ESA
OM: Instrument Description

- 30 cm Ritchey-Chretien telescope
- Focal ratio of f/12.7 and focal length of 3.8 m
- Total coverage between 170 nm and 650 nm of a 17 arcmin square field of view
- Filter wheel with 11 apertures: one blanked off, six broad band filters (U, B, V, UVW1, UVM2 and UVW2), one white, one magnifier and two grisms (UV and optical)
- Detector: micro-channel plate intensified CCD (2048 x 2048 pixels final format)
OM: Instrument Description

- Detector: micro-channel plate intensified CCD with 384 x 288 physical pixels (Active area 256x256). Amplification: $10^5$
- Photon events centroided to 1/8 physical pixel (2048 x 2048): 0.5"
- “Shift and Add” mechanism to compensate S/C drift or jitter
- Fast event timing: 500 ms in fast mode
OM: some examples

**OM UV & MOS images (M81)**

**Spectral energy distribution with grisms and filters**

**UV & X-ray light curves (X1822-371)**

**SN 2002p**

*XMM-Newton*

Antonio Talavera / XMM-SOC
OM: filters & grisms
OM: operational configuration with filters

Two basic modes:
- Imaging
- Fast mode (< 512 pix)

- Default image
- Default image + fast mode
- User defined windows (up to 5 windows, 2 in fast mode)
- Full-Frame Low-Resolution
  1024 x 1024 1” pixels
- Full-Frame High-resolution
  2048 x 2048 0.5” pixels
- Engineering modes
  (Eng 0, 1, 3, 4, 5, 6)

Total number of pixels is limited
Fast window: 22 x 23
Default configuration:
Optical Monitor: default windows
OM: operational configuration with grisms

- Single object spectroscopy: target at the boresight
- Field spectroscopy: all objects in the f.o.v.
Artifacts in OM images

- Straylight loops
- Central bright patch
- Gost images
- Streaks
Optical Monitor calibration: what is it?

PHOTOMETRY:

Magnitudes: the origin

- \( m_1-m_2 = -2.5 \log \left( \frac{F_1}{F_2} \right) \)  
  \[ F_2 = \text{Reference} = \text{Standard star} = \text{Vega} \]
- \( m_1 = -2.5 \log F_1 + \text{Zero point} \)  
  \[ \text{Zero point} = m_2 + 2.5 \log F_2 \]
- \( m \text{ (OM)} = -2.5 \log F_{\text{OM}} + Z_{\text{OM}} \)  
  \[ Z_{\text{OM}} = \text{magnitude producing 1 count/s} \]
- Standard System: UBV (Johnson) \( \Leftrightarrow \) OM system (U, B & V filters)

**Magnitudes & colors \( \Rightarrow \) Physical parameters, models,.....**

Absolute Fluxes: modern photometry & spectrophotometry

- from magnitude to flux through Vega
- direct transformation:  
  \[ F(\lambda) = K(\lambda) \ast OM(\lambda) \]  
  \[ K(\lambda) = \text{instrumental response (= response matrix)} \Rightarrow \text{average K per filter} \]

**Absolute fluxes \( \Rightarrow \) Physical parameters, models,.....**
Optical Monitor calibration: what is it?

SPECTROSCOPY:
• dispersed light ⇒ wavelength scale
• spectral energy distribution ⇒ flux scale: Inverse Sensitivity Function (ISF)

\[
\text{ISF}(\lambda) = \frac{F_{\text{std}}(\lambda)}{\text{CR}_{\text{std}}(\lambda)}
\]

\[
F_{\text{obs}}(\lambda) = \text{CR}_{\text{obs}}(\lambda) \times \text{ISF}(\lambda)
\]

ASTROMETRY:
• from detector X, Y to R.A. & Dec: S/C attitude, OM boresight, OM geometry
• refinement through x-correlation with catalogue (USNO)
• grisms: from zero order detector position to R.A. & Dec
Optical Monitor data processing: what is it?

(I) Instrumental corrections

- Astrometry(filters & grisms):
  - Geometric distortion, Boresight
  - X,Y linearized positions

- Photometry:
  - aperture
  - PSF
  - coincidence losses and dead time
  - time sensitivity degradation

- Spectroscopy:
  - geometry: distortion, rotation
  - spectral extraction
  - spectrum count rate vs. position

(II) Calibration

- Astrometry:
  - from X,Y to R.A. & Dec
  - X,Y linearized positions

- Photometry:
  - from count rate to magnitude,
    standard UBV, color indices, AB magnitude
  - light curve
  - from count rate to absolute flux
    at effective wavelength of filter

All corrections and calibrations are included into OM data processing through corresponding SAS algorithms & CCFs

SAS RESULTS CAN BE USED DIRECTLY FOR SCIENTIFIC INTERPRETATION
OM Astrometry

- Geometric distortion
  - distortion map derived from OM image using more than 800 stars
  - it corrects positions to 0.7” rms error

- SAS provides RA & Dec for all sources detected in OM images - from X_Y, AHF (star tracker) & boresight information.

- Additional cross-correlation (in SAS) with USNO catalogue allows us to improve the coordinates:
  - Using the new boresight:
    - RMS offset from USNO < 1.5”
OM photometry: zero points

Zero points for Zero epoch

The definition of the zero point (magnitude giving one count per second) can be given as:

\[ \text{Zero}_\text{point} = m_\text{vega} + 2.5 \times \log_{10}(\text{countrate}_\text{vega}) \]

The count rate of Vega is obtained through simulations

Zero points for OM instrumental system (at zero epoch)

\[
\begin{array}{ccccccc}
V & B & U & UVW1 & UVM2 & UVW2 \\
\end{array}
\]

(Zero points, corrected to Johnson UBV are:

\[
\begin{array}{cccc}
17.9633 & 19.2661 & 18.2593 \\
\end{array}
\]
AB magnitude system for OM

An input spectrum of 1 erg/s/cm²/Hz gives a photon rate in each filter, n_phot.

The zero points in AB system are defined as:

\[ \text{Zero\_point} = -48.60 - 2.5 \times \log(1./n\_phot) \]

Zero points in AB system for OM (at zero epoch)

<table>
<thead>
<tr>
<th>V</th>
<th>B</th>
<th>U</th>
<th>UVW1</th>
<th>UVM2</th>
<th>UVW2</th>
</tr>
</thead>
<tbody>
<tr>
<td>17.9230</td>
<td>19.0809</td>
<td>19.1890</td>
<td>18.5662</td>
<td>17.4120</td>
<td>16.5719</td>
</tr>
</tbody>
</table>
OM counts to flux conversion based in white dwarfs

Count rate to flux conversion (from WD's)

<table>
<thead>
<tr>
<th>uvw2</th>
<th>uvm2</th>
<th>uvwl</th>
<th>u</th>
<th>b</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>2120</td>
<td>2310</td>
<td>2910</td>
<td>3440</td>
<td>4500</td>
<td>5430</td>
</tr>
</tbody>
</table>

5.71e-15, 2.20e-15, 4.76e-16, 1.94e-16, 1.29e-16, 2.49e-16

This gives erg/cm²/s/Å

the relative errors (stdev/mean) are:

<p>| | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0.054</td>
<td>0.0401</td>
<td>0.068</td>
<td>0.042</td>
<td>0.068</td>
<td>0.013</td>
</tr>
</tbody>
</table>
OM counts to flux conversion from White Dwarfs versus Pickles and BPGS spectral libraries

<table>
<thead>
<tr>
<th>Filter</th>
<th>A0V</th>
<th>B0V</th>
<th>F0V</th>
<th>G0V</th>
<th>K0V</th>
<th>M0V</th>
<th>Vega</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>2.50E-16</td>
<td>2.48E-16</td>
<td>2.52E-16</td>
<td>2.54E-16</td>
<td>2.56E-16</td>
<td>2.65E-16</td>
<td>2.50E-16</td>
</tr>
<tr>
<td>B</td>
<td>1.36E-16</td>
<td>1.16E-16</td>
<td>1.41E-16</td>
<td>1.53E-16</td>
<td>1.60E-16</td>
<td>1.81E-16</td>
<td>1.34E-16</td>
</tr>
<tr>
<td>U</td>
<td>1.71E-16</td>
<td>1.94E-16</td>
<td>1.80E-16</td>
<td>1.83E-16</td>
<td>1.88E-16</td>
<td>2.01E-16</td>
<td>1.70E-16</td>
</tr>
<tr>
<td>UVW1</td>
<td>4.96E-16</td>
<td>4.72E-16</td>
<td>4.96E-16</td>
<td>4.51E-16</td>
<td>3.88E-16</td>
<td>1.09E-16</td>
<td>4.86E-16</td>
</tr>
<tr>
<td>UVM2</td>
<td>2.20E-15</td>
<td>2.14E-15</td>
<td>2.10E-15</td>
<td>1.84E-15</td>
<td>1.66E-15</td>
<td>n.a.</td>
<td>2.19E-15</td>
</tr>
<tr>
<td>UVW2</td>
<td>6.06E-15</td>
<td>5.56E-15</td>
<td>7.15E-15</td>
<td>6.05E-15</td>
<td>5.76E-15</td>
<td>n.a.</td>
<td>5.88E-15</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Filter</th>
<th>A0V</th>
<th>B0V</th>
<th>F0IV</th>
<th>G0V</th>
<th>K0V</th>
<th>M0V</th>
<th>WD’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>V</td>
<td>2.48E-16</td>
<td>2.50E-16</td>
<td>2.50E-16</td>
<td>2.55E-16</td>
<td>2.56E-16</td>
<td>2.61E-16</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>1.29E-16</td>
<td>1.17E-16</td>
<td>1.38E-16</td>
<td>1.44E-16</td>
<td>1.55E-16</td>
<td>1.80E-16</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>1.66E-16</td>
<td>1.97E-16</td>
<td>1.77E-16</td>
<td>1.88E-16</td>
<td>1.85E-16</td>
<td>1.94E-16</td>
<td></td>
</tr>
<tr>
<td>UVW1</td>
<td>4.79E-16</td>
<td>4.76E-16</td>
<td>4.84E-16</td>
<td>5.02E-16</td>
<td>5.15E-16</td>
<td>3.14E-16</td>
<td>2.49E-16</td>
</tr>
<tr>
<td>UVM2</td>
<td>2.15E-15</td>
<td>2.17E-15</td>
<td>2.18E-15</td>
<td>2.27E-15</td>
<td>2.02E-15</td>
<td>1.42E-15</td>
<td>1.29E-16</td>
</tr>
</tbody>
</table>

WD’s:

- 2.49E-16
- 1.29E-16
- 1.94E-16
- 4.76E-16
- 2.20E-15
- 5.71E-15
OM fluxes in AB system

If \( n_{\text{phot}} \) is the number of photons produced by 1 erg input spectrum, then \( 1/n_{\text{phot}} \) is the rate to flux conversion factor (in frequency space).

Count rate to flux conversion in AB system (frequency)

<table>
<thead>
<tr>
<th>uvw2</th>
<th>uvm2</th>
<th>uvw1</th>
<th>u</th>
<th>b</th>
<th>v</th>
</tr>
</thead>
<tbody>
<tr>
<td>2120.</td>
<td>2310.</td>
<td>2910.</td>
<td>3440.</td>
<td>4500.</td>
<td>5430.</td>
</tr>
</tbody>
</table>

This gives erg/cm\(^2\)/s/Hz

Note that the effective frequency of a filter can be any within the filter range since the flux is constant. Even if we are in frequency space, we can characterise the filter by its effective wavelength.
OM fluxes in AB system

We can then convert these factors to lambda space by multiplying by \((c / \lambda^2)\) and we get:

<table>
<thead>
<tr>
<th></th>
<th>(uvw2)</th>
<th>(uvm2)</th>
<th>(uvw1)</th>
<th>(u)</th>
<th>(b)</th>
<th>(v)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2120.</td>
<td>2310.</td>
<td>2910.</td>
<td>3440.</td>
<td>4500.</td>
<td>5430.</td>
</tr>
<tr>
<td></td>
<td>5.70e-15</td>
<td>2.21e-15</td>
<td>4.82e-16</td>
<td>1.94e-16</td>
<td>1.25e-16</td>
<td>2.50e-16</td>
</tr>
</tbody>
</table>

This gives \(\text{erg/cm}^2/\text{s}/\text{A}\)

Not surprisingly, if we compare these last factors with the ones derived directly from WD's fluxes, we have:

\[
\begin{array}{cccccc}
1.002 & 0.994 & 0.988 & 0.999 & 1.029 & 0.995 \\
\end{array}
\]
OM grisms calibration

Wavelength calibration:
- F-type stars: HD 221996, HD 224317 (V & UV grisms, low & high resolution)
  HD 13499, HD 13434 (V & UV grisms, low resolution, across FOV)
  (Field stars at different positions in FOV (V & UV grisms))
- White dwarfs with Hydrogen lines (BPM 16274, GD50,...) (for V-grism)

Flux calibration:
- Spectrophotometric standard stars (WD):
  GD 153, HZ 2

Grisms distortion:
- 3C273
- other science observations
OM grisms calibration: wavelength

- The wavelength scale: anchor point → zero order

  Measuring zero-order position: it can be predicted for User Def. observing windows, (with less accuracy for full frame images), and then refined by centroiding algorithm

- Wavelength range:
  - Vis-grism: 3000 - 6000 A
  - UV-grism: 1800 - 3600 A (second order contamination)

  *(the range could be extended, but not the flux calibration)*

- Wavelength scales
  - UV: \( \lambda (\text{A}) = 991.778 + 1.8656 \times X + 0.0007713 \times X^2 \)  
    (\(X \) : pixels from zero order)
  - Vis: \( \lambda (\text{A}) = 200.898 + 5.626 \times X \)

    - internal error: < 7 A (UV)
    - global shift due to zero order position: about +/- 10 A
OM grisms data calibration: wavelength

- Wavelength scale variations across f.o.v.:
  - HD 13499 offset observations and field stars in fflr science observations:
    - *Wavelength shift on right hand part of the image: up to 50 Å*

- Resolution: limited by mod_8
  - UV grism: better than 15 Å @ 2600 Å (from NGC 40 observations)
  - V grism: worst than UV
  - Mod_8 is stronger in V grism (because of higher response)
OM grisms data calibration: flux

The Flux scale:
Inverse Sensitivity Function (ISF)
ISF(\(\lambda\)) = \(\frac{F_{\text{std}}(\lambda)}{CR_{\text{std}}(\lambda)}\)
\(F_{\text{obs}}(\lambda) = CR_{\text{obs}}(\lambda) \times ISF(\lambda)\)

OM_GRISMCAL_0004.CCF

- Flux accuracy: around 10% (slightly worst at long wavelength end of V_grism)
- UV and V common range: excellent agreement!!!
- V, B, U, UVW1, UVM2, UVW2 versus Grisms: excellent agreement!!!
- Time sensitivity variation: < 1% p.a.
Optical Monitor calibration: what's new?

Response matrices for OM:
- UVW2, UVM2, UVW1, U, B, V filters
- UV and V grisms
OM data reduction with SAS: accuracy

- Astrometric precision (image photometry):
  - RA\_off = -0.22 ± 1.8 arcsec  Dec\_off = -0.40 ± 2.1
  (limit is 0.7” due to residual distortion and catalogue uncertainties)

- Photometric precision:
  - 0.02mag (2%) for MS stars
  - 0.04mag (4%) for MS stars in U filter (due to Balmer discontinuity effects)
  - 10% for non Main Sequence stars

- Grisms spectra:
  - absolute flux: errors < 10% (up to 2% depending on spectral type)
  - wavelength: internal accuracy: 7Å (UVgrism), 15Å(Vgrism) / possible 10 Å shift
  - wavelength across f.o.v.: up to 50Å shift
  - spectral resolution: 15Å for UVgrism (worst in Vgrism)
  - absolute flux: errors < 10% (up to 20% at edges of spectral range)

- Cross-calibration: overlap of grisms and grisms versus filters: EXCELLENT (<10%)
OM grisms data reduction with SAS

HZ 2

black: standard spectrum
colors: OM grisms observations
red stars: OM filters (average)
OM data reduction with SAS

BPM16274

BPM16274

STIS (UV) + Model
OM UVgrism
OM Vgrism
OM filters

Flux (erg/cm²/s/Å)

wavelength (Å)
OM data reduction with SAS

HZ 15

OM UV$_{\text{grism}}$ (contam. 0$_{\text{orders}}$)
OM V$_{\text{grism}}$
IUE LWR3367
Stone 1977

artifacts
OM data reduction with SAS

Spectral Energy Distribution of objects in the OM f.o.v.
OM Catalogue: available soon

No of observations: 1251
<100 sources (175)
100 - 499 sources (616)
500 - 999 sources (346)
1000 - 1999 sources (79)
2000 - 2999 sources (24)
3000 - 3999 sources (6)
>3999 sources (5)
The Crab: OM(231, 291, 344 nm) versus VLT(429, 657, 673 nm)
The Crab: OM(231, 291, 344 nm) versus composite X_opt_radio

<table>
<thead>
<tr>
<th>OM filter</th>
<th>Count rate</th>
<th>AB mag</th>
<th>AB Flux (erg/cm²/s/A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UVW2</td>
<td>0.12</td>
<td>18.84</td>
<td>7.05e-16</td>
</tr>
<tr>
<td>UVM2</td>
<td>0.29</td>
<td>18.74</td>
<td>6.49e-16</td>
</tr>
<tr>
<td>UVW1</td>
<td>1.89</td>
<td>17.88</td>
<td>9.11e-16</td>
</tr>
<tr>
<td>U</td>
<td>5.18</td>
<td>17.40</td>
<td>1.00e-15</td>
</tr>
</tbody>
</table>
XMM–NEWTON OM B filter: Comet Tempel 1

XMM-Newton images of Tempel 1 during the impact