Calibration of XMM-Newton Optical Monitor

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Introduction

- Throughput – Response curves, Photometry, Colour transformations and Coincidence loss
- PSF including effects of coinc. loss and mod8 noise
- Astrometry – removing distortion
- Flats and Darks
- Straylight – cause, and what to do
- Timing
- Grisms

Throughput

- Filters:

V	510-580 nm	
B	390-490	
U	300-390	
UVW1	245-320	
UVM2	205-245	
UVW2	180-225	
Vis. grism (2)	290-500	0.5 nm/pix
UV grism (1)	200-350	0.25 nm/pix

- No change in response at least to rev 261.

- Response curves:
  - Three spectrophotometric standards (white dwarfs: BPM16274, LBB227 and GD153) were observed.
  - Counts were compared with pre-flight simulations to calculate “fudge factors” ➔ correction curve.
  - The model response curves multiplied by correction curve give in-flight OM response. These curves have just been updated. (*in CCF and update in CCF soon*)

- Photometry:
  - Using new response curves, an observation of Vega was simulated.
  - Zero points in U-, B- and V-filters were set to match literature values (0.03, 0.03, 0.025). (*in CCF and update in CCF soon*)
  - UV zero points set to give 0.025 mag in Vega

$$mag = -2.5\log(counts) + zeropoint$$

  - Limiting magnitude after 1000s (to 6 sigma) is 21.0 in V, 22.0 in B and 21.5 in U, 23.5 in White.
  - For aperture photometry, need PSF (see later).

- UV flux calculations:
  - A set of zero points for the UV filters is also given.
  - counts ➔ magnitude ➔ flux.
  - Magnitudes defined relative to **Vega**, which has a known flux.

$$-0.025 - mag(UV) = -2.5\log[Flux(Vega)/Flux(source)]$$

  - BUT if you want the flux *per unit wavelength*, it depends on the shape of your spectrum.
  - Simulator: takes spectra of known flux and different types and calculates counts in each filter.
  - Can then compare with your counts.
  - *Not in SAS yet. (See SAS watchout page)*

- UBV colour transformation.
- OM system to Johnson UBV system.
  - Dedicated ground-based photometric observations of 5 calibration fields ~100 stars per field used.
  - Only stars with <5% coincidence losses used.
  - Linear transformations. Coefficients of colour transforms (for different star types) obtained for intervals $-0.4 < u-b < 1.0$; $0.25 < b-v < 1.35$.
  - Extending colour range using G153 field.
  - Results (*in CCF*) close to simulations (using Bruzual-Persson-Gunn-Stryker atlas). Simulations used to extend colour range to blue and red and metal-poor stars.

- Coincidence loss
  - Coincidence loss when more than one photon arrives in same place within same frame.
  - Significant above ~ 10 c/s for a point source (but depends on frame time, and width of source).
  - you *lose counts*
  - AND it affects the *shape* of the PSF

- Can use equation for point source:

$$ph_{\text{in}} = \frac{\ln(1 - cts_{\text{detected}} T)}{T_{\text{ft}} - T}$$

- An empirical coincidence loss curve (obtained by measuring actual count rates for stars of different magnitudes) gives a set of offsets from the theoretical curve. (*in CCF*)
- 400 stars measured.

Point Spread Function

- Approximately radial in shape, and increasing with photon energy from 2.26 pix (~1.14") FWHM in V.
- Direct measurement of curve of growth for CCF limited by small numbers of appropriate, isolated stars and large scatter.
- For UBV filters, curves normalised with respect to count rate within radius of 12 pixels (6") .
- Strong dependence on count rate to frame rate ratio, because of coincidence loss and mod8 noise.

- Daophot:
  - Can use a function for many (~500) stars in FOV ➔ good average PSF for a range of count rate intervals.
  - Assumed PSF goes to zero at 12pix, and used background annulus between 14 and 18pix.
  - Moffat function best fit, with β=2.0
  - Systematic differences from fit in daophot tabulated in lookup table.

- Coincidence loss dominates systematic errors → need to divide into 5 groups with different count to frame rate ratios.
- PSF becomes ⇔ as the count rate ⇐
- Formal errors are overestimated due to mod8 noise.

- Best fit PSFs + lookup table for the 5 groups, integrated to make curves of growth for CCF. (*in CCF very soon*)

cfrr groups for psf

(cfrr = raw_counts*frame time)

interval	cfrr_min	cfrr_max	cfrr_mean
1	0.302218	0.438046	0.363866
2	0.207666	0.319276	0.244647
3	0.113273	0.195941	0.152977
4	0.057578	0.113619	0.076828
5	0.032703	0.058966	0.042198

- Mod8 noise (fixed patterning)
  - 256×256 CCD ➔ 2048 ×2048 centroided pixels (each 0.4765" on sky) .
  - Photon splash ~ 1.1 CCD pixels FWHM.
  - Centroided in real time by *Look Up Table.*
  - BUT LUT does not account for variations in photon splash shape over face of detector or with count rate ➔ "pixels of unequal sizes".
  - Can compute the 8 × 8 noise from background sky
  - SAS mod8 routine re-samples the counts based on true pixel sizes.

Astrometry

- Optics, filters and detector ➔ image distortion ➔ shifts of up to 20".
  - Measured detector position of >200 stars
  - Obtained sky coords of same stars and used to predict detector position, assuming no distortion
  - Compared the two lists of detector coordinates and fitted a 3rd order polynomial to the differences.
- Using map, r.m.s. deviation is 1.5". Same map for all filters. (*in CCF*)
- Also used on board for window coordinates.

Flats and Darks

- Dark count is very low: 2.5×10^{-4} c/s/pix $\pm$ 9%
  - Some variation with brightness of sources in field despite blocked filter.
  - Investigations on-going to find out whether there is a light leak affecting UV filters.
  - Small (7%) variations and no trend with time.
- Pixel to pixel variations:
  - An LED is used to illuminate the detector by backscatter of photons from the blocked filter.

- BUT it is not a uniform illumination.
- Used to make *bad pixel* map (*new CCF soon*)
- Used to investigate (CCD) pixel to pixel non-uniformities.
- Photometry shows us that that variations are small (< 5 %) so need lots and lots of counts to improve matters. Up to now unity flat field has been better than real one.
- Rev 130 – 343 included 40 hours flat field time
  ➔ to make a "superflat", with illumination pattern removed. 2048x2048 image with better than 5% statistics per pixel.
  (*unity flat field in CCF – new one soon*)

- Large scale sensitivity variations:
  - Investigated using a *mosaic* observation.
  - One field offset by 2' in each direction.
  - Variation not above 2-3% level.

Straylight

- Internal reflection of light within the detector window: gives “smoke ring” near bright stars.
- Reflection of off-axis starlight (12 to 13') and background from part of detector housing.
  - Position of loop varies according to the field.
  - In the example, cts/pix = 5.8 outside region and 23.6 inside loop. (But star has 12000)
  - Wavelet methods assume artifacts are not like stars.
  - Difficult to remove contamination without distorting star images.

- A successful approach is found in proprietary software by JL Starck (CEA, Saclay), who has kindly allowed us to show some products.
- BUT even if the results are nice, the corrected images do not have the correct flux/count rates.
- And wavelet methods cannot work for extended sources.

Timing

- Full FOV is 17×17'
- Fast mode resolution
  - Time tagged photons with minimum 100ms
- For fast mode, each photon is recorded in the area of one or two tiny windows (22×23 pixels)
- Field Acquisition by the OM enables more accurate pointing (~ 0.1")
  - small offsets added to window coordinates to make sure source is in window.

(*SAS timing chain now working*)

Grisms

- UV and Optical grisms.
- Dispersed first order image and zeroth order image displaced in dispersion direction.
- Default windows containing zeroth and first order spectra for target source.
- IDL tool for extracting spectra.
- Predictions of counts in zeroth and first order for different stellar types and magnitudes.

- Initial wavelength calibration for optical grism established, better ones being worked on.
- UV calibration awaiting observations.
- New UV grism offset position to reduce zero order contamination.
- *Grism analysis is to be included in SAS in the future.*

For further information

Please see:

- the XMM User Handbook.
- SAS User Handbook.
- Goddard's ABC guide.
- CCF release notes …