Optical loading in the XMM-Newton slew source catalogue

XMM-SOC-CAL-TN-210
Version 0.1

R. D. Saxton, A.M. Read, J. Robrade & J.H.M.M. Schmitt

Feb 3 2017

1 Introduction

The XMM-*Newton* slew catalogue is constructed from data taken while the satellite moves between pointed observation targets. The data is taken from the EPIC-pn camera (Strüder et al. 2001) in FullFrame, ExtendedFullFrame or LargeWindow observing modes using the Medium filter.

In pointed observations, a dark frame, or *offset map*, is taken at the start of the observation to correct for any excess current which may be generated in each pixel due to optical photons (Smith 2008). In this way the energy-scale of real X-ray photons is not affected and false events are not produced by the addition of optical and UV flux. Slew data is processed using the offset map taken during the previous observation. As the detector slews across the sky it passes over optically-bright stars which are naturally not corrected for in the static offset map. This leads to false events being recorded. In the slew survey processing (Saxton et al. 2008) events are filtered using the expression:

```
PI>200 && FLAG==0 && PATTERN<=4
```

which removes the great majority of the false, low-energy, optically induced events. In some cases though, enough false events make it past the filtering process for a star without appreciable X-ray flux to be registered as an X-ray source. Naturally, this is a factor of the magnitude and spectral type of the star. Extremely soft X-ray sources, such as white dwarfs, have a large fraction of their events removed by the low-energy cut-off at PI=200 (roughly 200 eV). An effect that is not related to optical loading.

In the following sections we analyse the impact of this effect and suggest a way to mitigate the problem within the slew source catalogue.

2 Analysis

For this analysis we have produced a test catalogue of sources detected in slews between 2003 and the end of 2014, in detail from slew 9031400004 to slew 9275800003.

As an initial test we plot the unfiltered and filtered data from main sequence stars with magnitude increasing from 1 to 6 (Fig. 1). We can see that for the first magnitude star Deneb, the filtering process has apparently worked and no source is apparent at the position of Deneb in the filtered image. The third magnitude star, δ Aqr, does have events in the filtered image and is detected as a source. This star is of type A3Vp, has not been detected in other X-ray surveys and in principle should not be an X-ray emitter. The same is true for the $M_r = 5.3$, Carbon star TX Psc and the $M_r = 6.4$, M6III star EU Del, both of which are also detected in the filtered images.

We then plot the ratio of the filtered to unfiltered counts for each source in the test catalogue (Fig. 2). This shows that the majority of objects, with more than 40 detected unfiltered counts, have $> 60\%$ of those counts passing the filtering stage. Below 40 counts we see a very strong quantisation effect. On the other side, there is a horn of sources where $> 90\%$ of the events are removed by the filtering. Sources which are strongly affected by optical loading should be found in this horn. To test this, we cross-correlate the 133 horn objects (after removing duplicate observations of the same object) with the highest number of unfiltered counts (actually with unfiltered_cnts> 40 and the ratio of filtered_cnts/unfiltered_cnts< 0.1), with the USNO-A2 catalogue. We find 117 counterparts within 12 arcseconds (the 90% slew radius). The R magnitude of the counterparts are plotted in Fig 3.

Most of the sources (82) are bright optical stars with $m_r < 7$. Ten have $7 < m_r < 13$, 25 have $m_r > 14$ and 16 have no counterpart.

The bright stars are obviously good candidates for optical loading but there is always the chance that they are also X-ray emitters. Searching the ROSAT catalogue we find that of the 82 bright stars, 33 (27) are detected in the Bright Source Catalogue (BSC; Voges et al. 1999) within 1.5 (1.0) arcminutes and 5 are detected in the Faint Source catalogue (FSC) within 1.5 arcminutes. Therefore the majority are false X-ray sources as the ROSAT catalogues are not affected by optical flux. The ones which are X-ray emitters are likely to have their measured X-ray count rate changed, either by the addition of false events or by the conversion of good events into bad.

The sources with optical magnitude between 7 and 12 are more difficult to understand as the optical flux should be too low to produce optical loading. Six of the ten are known X-ray sources from ROSAT or Swift. Taking as an example, XMMSL1 J084937.8-623028 (AKA HD 75908, $m_r = 7.2$) is found in the ROSAT BSC (Voges et al. 1999). This was detected in two slews; 9116200003, where it had 5 filtered and 6 unfiltered counts and 9195200005, where it had 5 filtered and 56 unfiltered counts. The reason is evident from Fig. 4, where the source circle in slew 9195200005 is traversed by an image defect probably caused by a temporary bright (bad) pixel. In this case the filtering has worked and only good X-ray events have been counted in the final source count rate. Looking now at XMMSL1 J090843.1-745054 ($m_r = 10.8$), this detection has no counterpart in X-ray catalogues but is 2.5" from the periodic variable star, ASAS J090843-7450.8. In Fig. 4 we see that the source position is also affected by an image defect which after filtering has left 4 grouped events. In the absence of other information we can only guess whether these are real X-rays or not, although the close association with a moderately optically-bright variable star makes it likely that this is a real detection of an X-ray high state of the star.

Finally we look at the fainter sources with magnitude 17-18. Taking one at random, XMMSl1 J115709.3+210035 ($m_r = 17.6$), we see that this has also been affected by an image defect (Fig. 4). This source is actually a quasar detected in the ROSAT faint source catalogue as 1RXS J115709.6+210038. From this it seems that generally for objects with $m_r >\sim 7$ the filtering is correctly removing optical photons and events created by bad pixels and other detector defects and is leaving true X-rays.

In Fig. 5 we show the filtered fraction against revolution number for all the sources in the catalogue showing that there is no obvious trend with observation date.

3 Very bright stars

In table 3 we list the 20 brightest stars in the sky and their presence in the catalogue. The flux of optical photons from the very bright stars is so high that few good events are created. The events which do pass the filtering process are usually on the edge of the point spread function, which results in a detected (false) source at a sky position which is a fraction of an arcminute away from the bright star.

There is considerable variation between observations of the same star. This is very probably due to differences in the offset map used for each slew rather than source variability.

4 Flagging

In the previous sections it has been shown that some sources in the slew catalogue are affected by events which have been created by optical loading. To aid the user extra columns giving the number of filtered counts and the number of unfiltered counts, in a radius of 1 arcminute about the source centre can be provided. For the casual user, a warning flag could be set in the catalogue to indicate detections which lie in the left hand horn of Fig. 2. A reasonable discriminator for the flag would be:

(filtered counts / unfiltered counts < 0.3) && (number of unfiltered counts > 30)

This would flag 500 of the 30,000 sources in our trial catalogue. We note that this is a very coarse flag which should only be used as an indication that optical loading *may* be present. Extremely soft sources, e.g, white dwarves, will likely have this flag set to true,

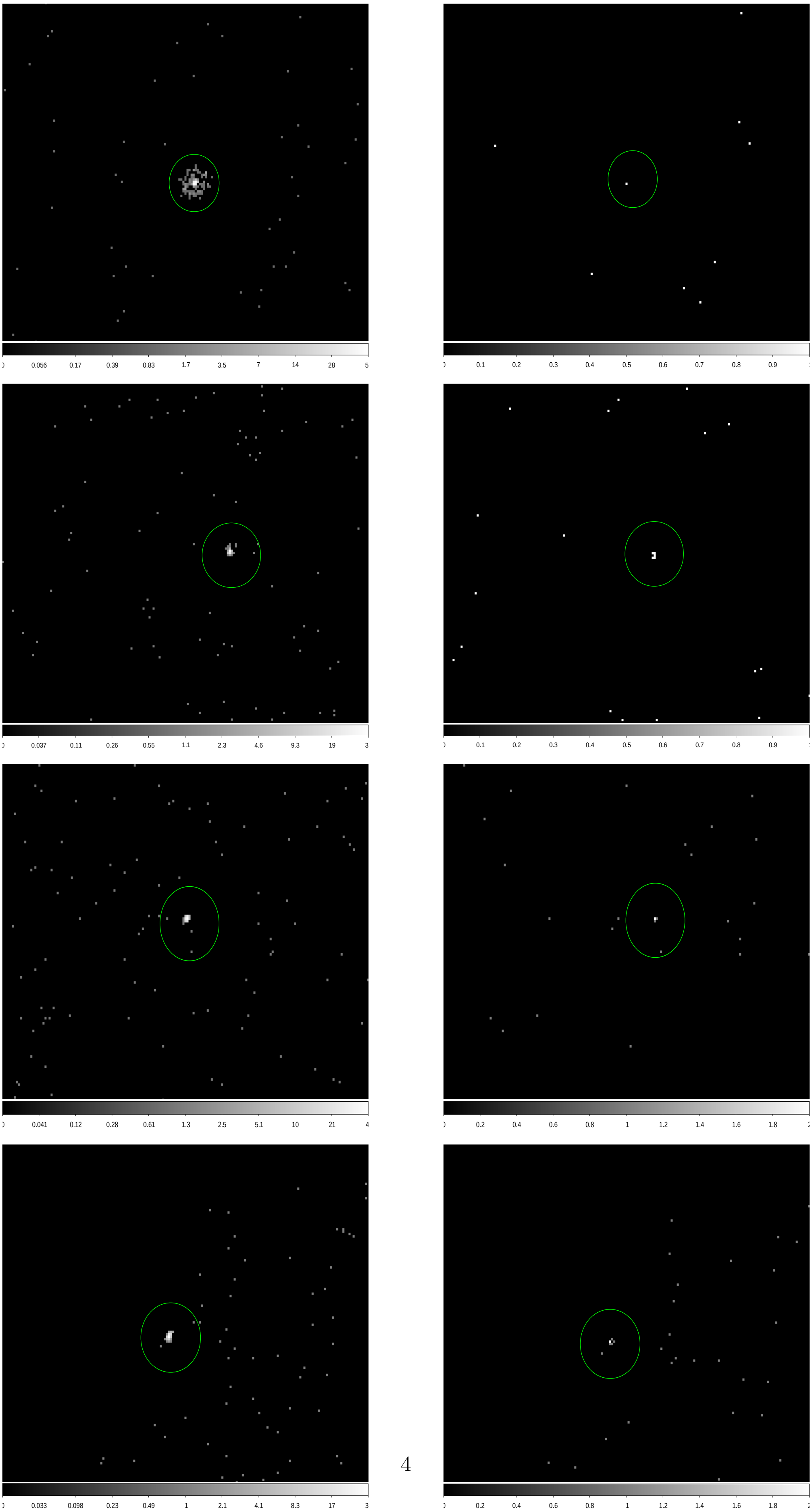

Figure 1: Unfiltered (left) and filtered (right) images of the stars, from top to bottom, Deneb ($m_r = 1.3$), δ Aqr ($m_r = 3.3$), TX Psc ($m_r = 5.3$) and EU Del ($m_r = 6.4$).

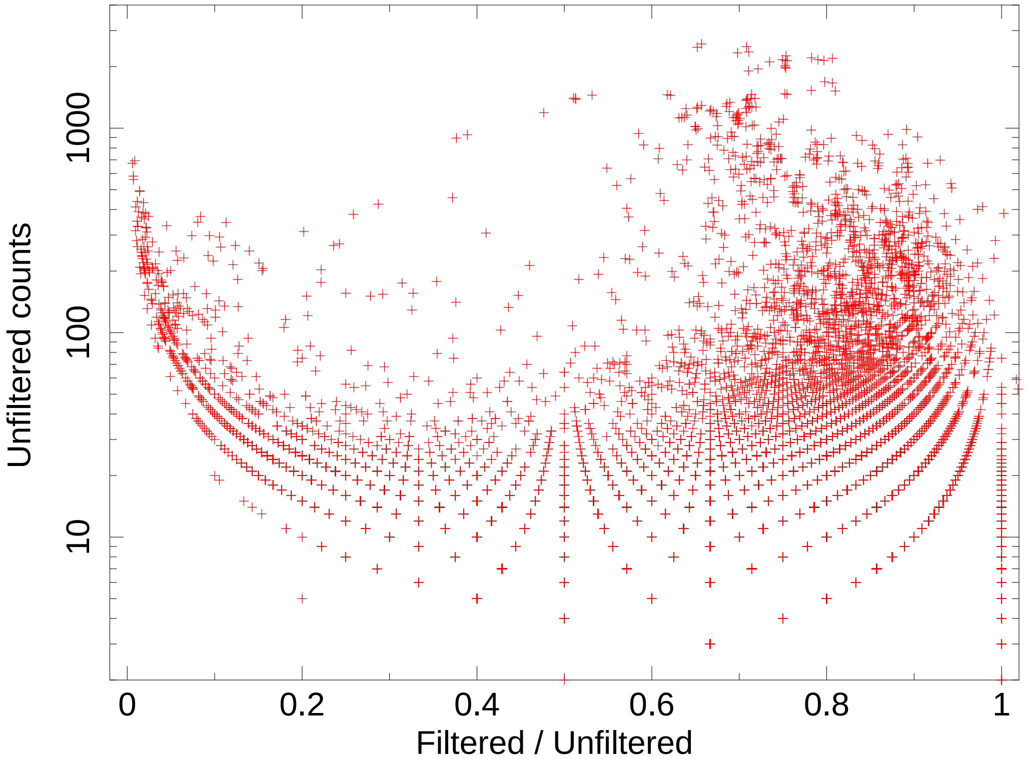

Figure 2: The ratio of the number of events which have passed a filtering process designed to remove non-X-ray events to the number of unfiltered events. For detections with small numbers of counts the plot is heavily quantised with multiple detections represented by a single point.

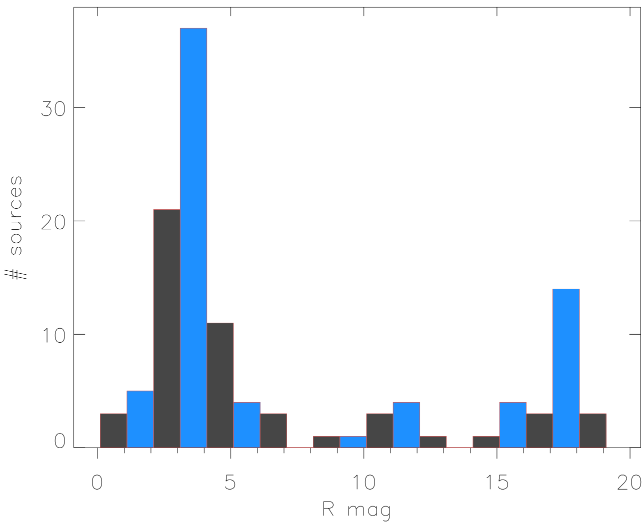

Figure 3: The optical magnitude (m_r) of detections with a filtered/unfiltered event rate < 0.1 and number of unfiltered counts > 40.

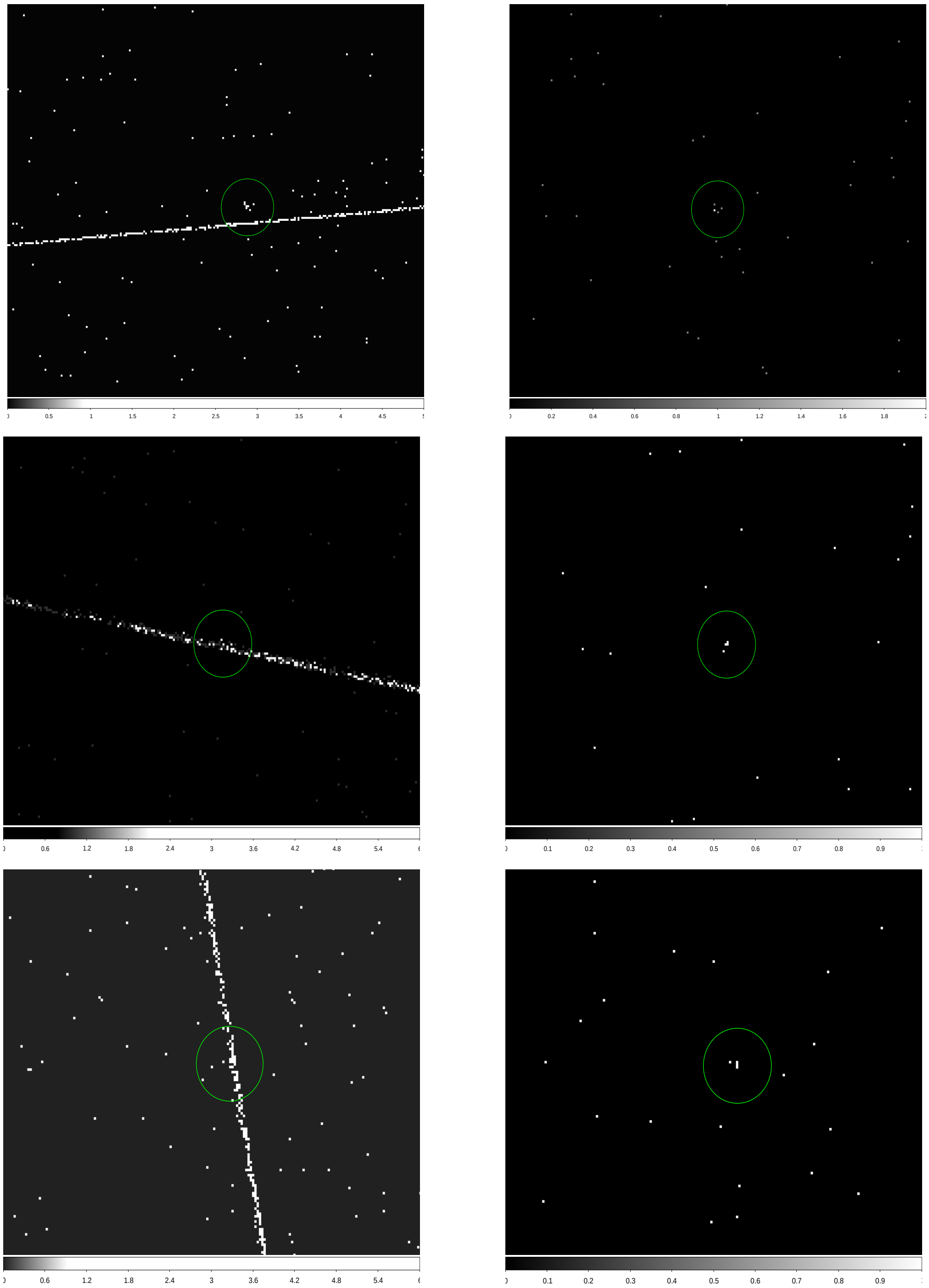

Figure 4: Top: an unfiltered image about the position of XMMSL1 J084937.8-623028 ($m_r = 7.2$) from slew 9195200005 (left) and the same image after applying standard filterering (right). Middle: an unfiltered image of the detection XMMSL1 J090843.1-745054 ($m_r = 10.8$) from slew 9258400002 (left) and after standard filterering (right). Bottom: an unfiltered image from slew 9184000004 about the position of the $m_r = 17.6$ object XMMSL1 J115709.3+210035 (left) and after filtering (right).

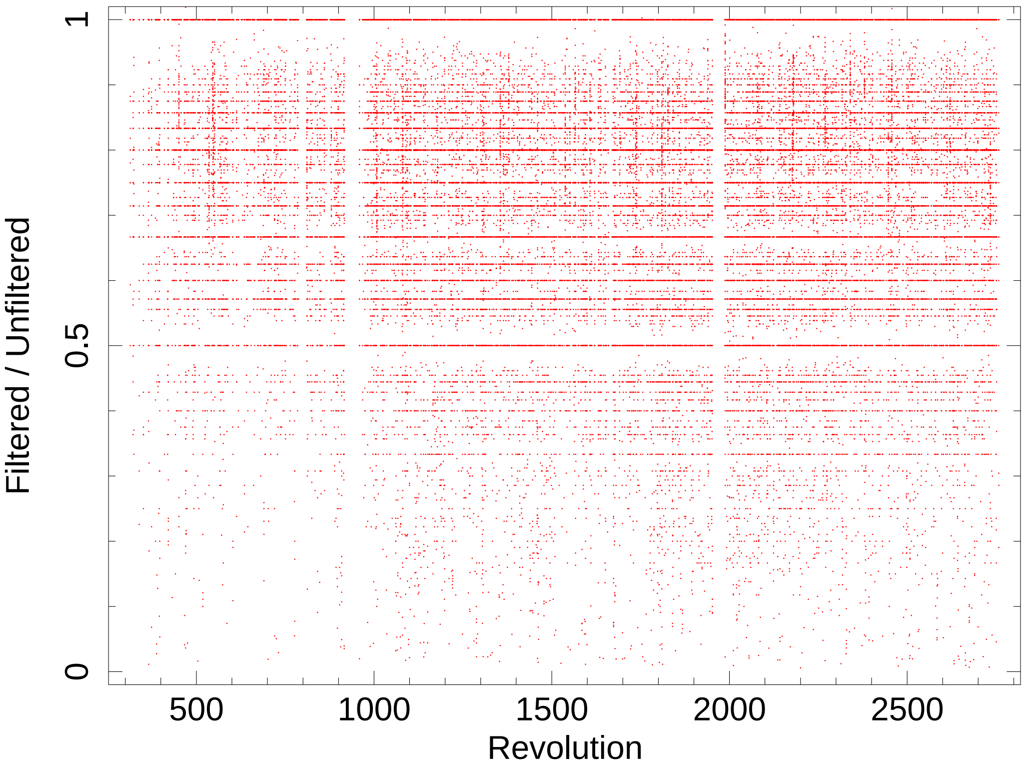

Figure 5: Ratio of filtered to unfiltered counts for all of the sources in the catalogue plotted against revolution number.

Table 1: **The brightest stars in the sky and their presence in the slew catalogue**

Star	Spec Type	OBSID	Counts[a]	exp[b]	Comment
Sirius	A1V+DA	9106500003	8	4.9	detected
Canopus	A9II	9080300003	4	3.5	detected at 48" off-source.
		9127600002	0	7.0	
		9132800002	5	4.9	counts separated into 3 and 2, no detection.
		9150400003	0	13.7	
		9236200002	2	3.8	no detection
		9242600003	1	5.7	no detection
Alpha Centauri	G2V+K1V	9158500002	0	9.8	
		9242300002	1	6.2	no detection
Arcturus	K0III	9193000004	0	7.6	
Vega	A0Va	9263200005	4	6.1	no detection
		9270000004	2	3.6	no detection
		9273100004	4	5.2	detected at 0.5' off-source.
Capella	G1III+K0III			not slewed over	
Rigel	B8Iae	9159400002	0	1.8	
		9159500004	4	3.5	detected in soft band.
		9205500003	17	5.5	2 src at 24" (10cts), 36" (7cts) off-source.
		9243400002	3	5.6	no detection
Procyon	F5IV-V+DQZ			not slewed over	
Achernar	B6Vpe	9156300003	7	3.8	widely spread, no detection
		9199900002	0	1.6	
		9272700003	2	9.2	no detection
Betelgeuse	M1-M2Ia-ab			not slewed over	
Beta Centauri	B1III	9159400002	4	9.2	detected at 50" off-source
		9168100002	6	5.6	detected at 22" off-source
Altair	A7Vn	9144600002	1	8.9	no detection
Alpha Crucis	B1	9130700005	4	2.1	detected in soft band
		9150000002	3	6.4	no detection
		9258400002	4	4.2	detected at 32" off-source
Aldebaran	K5III	9232400003	0	5.1	not detected
Spica	B1III-IV	9047800002	5	4.5	no detection, counts from background
Antares	M0.5Iab+B3V	9159300002	5	3.8	widely spread, no detection
Pollux	K0III	9180300002	9	5.3	detected, events widely spread
Fomalhaut	A4V	9100400002	3	3.5	no detection
Mimosa	B1IV			not slewed over	
Deneb	A2Ia	9192900002	3	7.1	no detection
		9219700023	1	8.1	no detection

[a] The number of counts found, after applying the filter (PI> 200 && FLAG==0 && PATTERN<= 4), in a radius of 1 arcminute about the source.
[b] Exposure time (seconds).

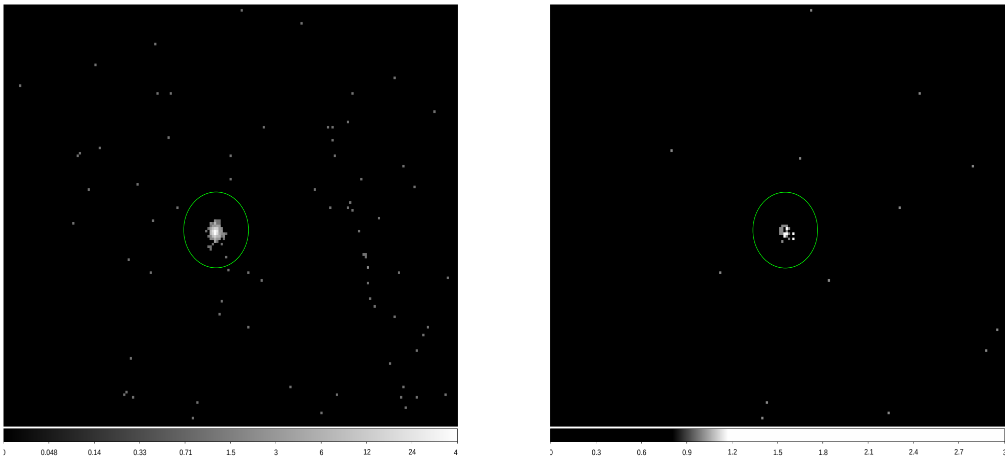

Figure 6: An unfiltered image about the position of the ultra-soft White Dwarf, HZ 43, from slew 9202200005 (347 counts; left) and the same image after applying standard filterering (28 counts; right).

e.g. HZ43, a white dwarf used to calibrate the XMM-Newton camera soft response, has 28 filtered counts and 347 unfiltered counts in slew 9202200005, a ratio filtered / unfiltered = 0.08 (Fig. 6). Another white dwarf, WD 2211-495, has 6 filtered and 28 unfiltered counts (ratio=0.21) in slew 9218200002. Other soft sources, such as the isolated neutron star RX J1856.5-3754 are less affected (ratio$\sim$ 0.6) and would not be flagged.

5 Summary

- Optical photons from very bright stars ($m < 3$) produce many bad events but few good events in filtered slew images. They may or may not produce a detection in the final catalogue. When a source *is* produced it is usually on the outskirts of the point spread function and hence at a position several tens of arcseconds away from the actual stellar position.
- Less bright stars ($3 < m_r < 7$) tend to produce a false source, due to optical loading, at the position of the star.
- Fainter optical objects ($m_r > 7$) do not cause optical loading but may be detected if they have genuine X-ray emission.
- Criteria, based on the ratio of unfiltered to filtered counts, can be applied to the slew catalogue to flag sources which may be affected by optical loading.
- Genuine X-ray emitting objects, which have been flagged, are likely to have their X-ray count rates altered by the destruction of good events by optical photons or by the addition of false events.

References

Saxton, R., Read, A., Esquej, P. et al. 2008, A&A 480, 611
Smith, M. 2008, XMM-SOC-CAL-TN-0051, Issue 1.2
Strüder et al. 2001, A&A 365, L18
Voges, W., Aschenbach, B., Boller, T. et al. 1999, A&A, 349, 389