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DOCUMENT

Centring, drift and oscillation issues associated with OM fast mode observations

Prepared by	**Simon Rosen**
Reference	**XMM-SOC-CAL-TN-223**
Issue	**1**
Revision	**0**
Date of Issue	**10 July 2020**
Status	
Document Type	
Distribution	

European Space Agency
Agence spatiale européenne

APPROVAL

Title Centring, drift and oscillation issues associated with OM fast mode observations	
Issue 1	Revision 0
Author S. Rosen	Date 10 July 2020
Approved by	Date

CHANGE LOG

Reason for change	Issue	Revision	Date

CHANGE RECORD

Issue	Revision		
Reason for change	**Date**	**Pages**	**Paragraph(s)**

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1 INTRODUCTION

A few observations made using the fast mode of the XMM-Newton Optical Monitor (OM) are affected by issues associated with the target being significantly offset from the centre of the window. In extreme cases, these issues can make analysis difficult, unreliable and even introduce spurious effects in the data. In this technical note (TN), these issues are described and we outline, where relevant, measures taken to mitigate them.

It should be noted that some of the issues that arise are related to long observations, sometimes lasting an entire (2-day) XMM-Newton orbit. Such observations, using an OM fast mode window, which can yield many sequential fast mode exposures and therefore time-series, have become more common in recent times as long observations of extragalactic targets have become more popular.

This TN focuses on three main points: (1) Initial offsets arising from Field Acquisition (FAQ) failures, (2) spurious periodic oscillations in flux and (3) drift during the observation.

2 OM FAST MODE LIMITATIONS

It must be borne in mind that, due to telemetry limitations, the OM fast mode window is restricted in size to a maximum of two, 22x23 pixel (11"x11.5") windows. With a single fast mode window, the maximum exposure time permitted is 4400s, being half that if two fast mode windows are used. A fast mode window is only ~5 times wider than the ~2.2" FWHM of the PSF for the UV filters, which are frequently employed. In fact, the UV filters have extended, shallow wings that exceed the width of the fast mode window, with up to about 10% of the PSF being outside the window, even when perfectly centred. Thus, any source whose centroid is notably displaced from the centre of a fast mode window can suffer from loss of counts from the portion of the PSF outside the window. The OM SAS software attempts to correct for this but if/when the source centroid displacement is severe and near the edge of the window, the centroiding of the source, and hence PSF correction, become increasingly insecure. These situations can arise when the user-provided source coordinates are inaccurate or when there is an instrument operational issue, which results in the field acquisition (FAQ) exposure being lost or failing - FAQ is very important for fast mode to ensure good source centring of the source in the window.

3 INITIAL CENTRING – FIELD ACQUISITION

The location of the fast mode window in detector coordinates is derived from knowledge of the target coordinates, the spacecraft pointing direction and the star-tracker/instrument boresight misalignment information. For targets positioned at the boresight, the window has pre-defined detector coordinates, based on the misalignment matrix. However, a long-term (time-dependent) drift of the OM boresight with respect to the spacecraft start-tracker was discovered (first described in XMM-SOC-INST-TN-0041; see also XMM-CCF-REL-286). Such long-term drift, which amounts to ~5 arcsecs during the mission, to date, if not accounted for when determining the window location, leads to the window being displaced from the real source location. In addition, there is an annual variation of the OM/spacecraft boresight misalignment with a semi -amplitude of ~1 arcsec, superposed on the long-term trend. The initial boresight drift was corrected for in revolution 1559 (June 2008).

Normally, the effects of the long-term drift, the annual oscillation, imprecise user coordinates or XMM pointing uncertainty, are not a problem because, at the start of observations using fast mode, the OM performs a short FAQ exposure which identifies a number of catalogued field stars and measures the average shift of their image X,Y coordinates to those predicted based on the boresight misalignment matrix. Any such shift is then applied to the window location, thus ensuring the target source is well centred in the window.

However, when FAQ fails, the window is not repositioned and the source may be several arcseconds away from the window centre – figure 1 is a good example. This can occur due to operational/commanding problems or if insufficient field stars are identified. When coupled with random spacecraft pointing errors (of up to 4"), this can result in a source, even with precise user coordinates, being significantly displaced from the window centre.

The ongoing drift (and annual variation) of the OM boresight is monitored approximately annually and is corrected for in the OM SAS using a time-dependent boresight correction. However, this continuous correction is not

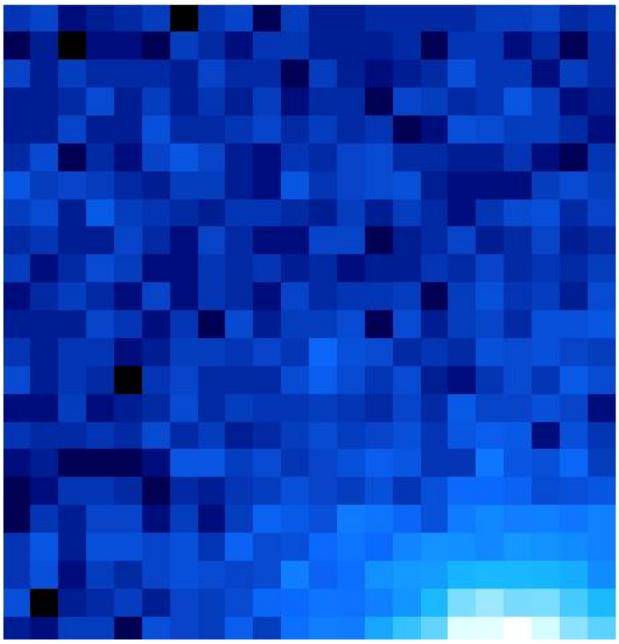

Figure 1: Fast mode image of the first exposure in an observation where FAQ was not performed due to an operational problem. The target is displaced such that its centre is just outside the window.

automatically incorporated into the observation planning and operational systems and this means the pre-defined OM fast mode window location is not automatically adjusted for the trend. Furthermore, it is not automatically applied in the operational database, meaning that the predicted positions of FAQ stars are not continuously corrected, so the effects can be seen in the FAQ data.

While a full, continuous correction within the planning system and operational database is not deemed necessary, to address the long-term drift, a new, mean correction was incorporated into the planning and operational systems, in April 2020 (around revolution 3728). This correction applies to both the location of the pre-defined fast mode window and also in the computation of the predicted positions of the field stars used in FAQ. While spacecraft pointing errors (and the annual variation) still introduce some scatter, this means that, *on average*, the predicted positions of the FAQ stars should be closer to their observed positions, and the pre-defined fast mode window is more correctly positioned so that sources will be better centred, even if FAQ fails.

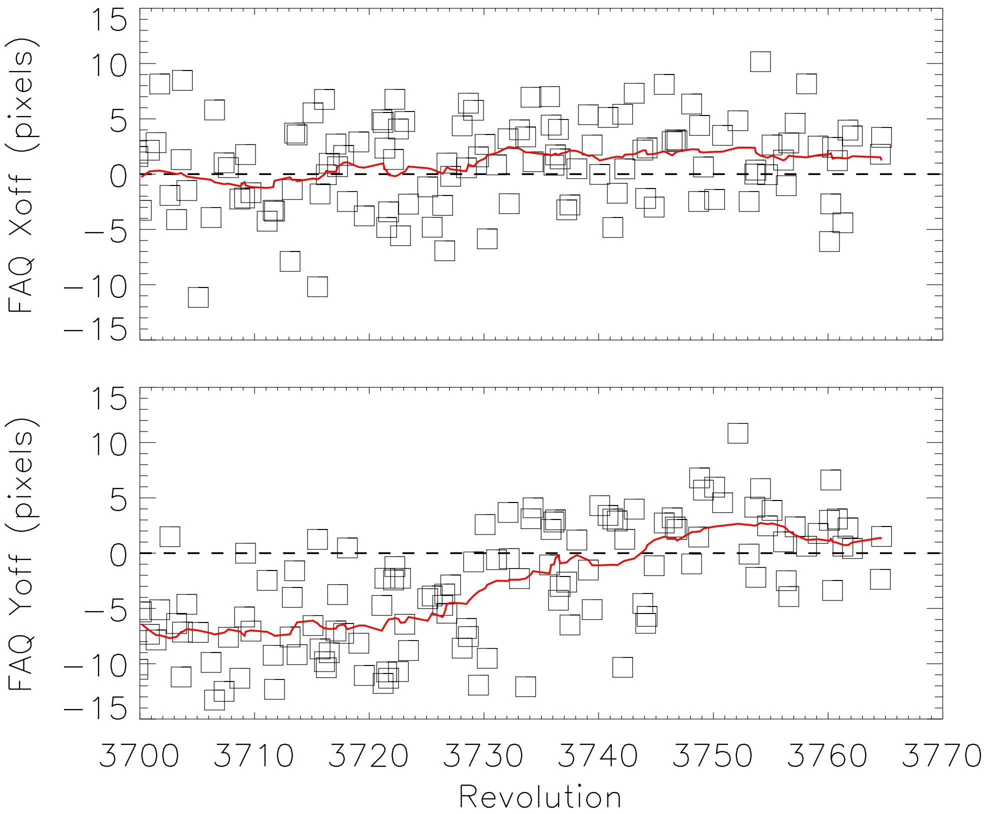

Figure 2: X axis (upper panel) and Y axis (lower panel) OM FAQ offsets (squares), i.e. the offset between predicted and observed image positions of the FAQ stars, obtained from recent observations taken before and after the update of the log-term drift of the OM boresight relative to the spacecraft. The horizontal black dashed lines mark the zero offsets, while the red curve in each panel is a running mean of the data (21 data points averaged per running mean point). The X axis is largely unchanged but in the Y axis, there is a clear move back towards zero offsets, on average.

This is illustrated in figure 2 where we show the FAQ offsets in X and Y, obtained from revolutions before and after the April 2020 update of the boresight in the operational system. The reduced offset in the Y axis (which, during recent epochs, was much more affected than the X axis) after revolution ~3735 is evidence that, on average, the update results in a marked improvement. The correction was not used in all observations until revolution ~3745, hence the gradual trend towards zero rather than a step transition. It is not possible, currently, to gauge the improvement in fast mode centring when FAQ fails because there have been no such FAQ failure cases since implementation of the new correction and it will take time for sufficient statistics to accumulate to confirm such an improvement but we expect the observed reduction in the required FAQ correction to be reflected in the fast mode target centring.

4 FLUX OSCILLATIONS

In at least one extreme case, where the source is close to the edge of the fast mode window, another effect, i.e. spurious oscillations in flux, with a timescale of ~3300s and/or ~1650s, has been witnessed. In many OM observations, a set of some 10 stars are identified in the image at the start of an exposure and their centroids are subsequently tracked by onboard software every 20s, providing a measure of the tracking history of the OM that is used to correct the arrival positions of photons for drift during an exposure. This tracking history data from each observation, where available, has been Fourier analysed, and the results stacked over the mission. The results shown for the two image axes, are shown in figure 3. Clear 'periodic' signals are present, with timescale of ~1650/3300s (0.0006/0.0003 Hz). This is seen in the entire stack but also in temporally distinct sub-intervals, indicating a regular spatial variation that is persistent. The spatial variation of the tracking data corresponds closely to the timescale of flux oscillations mentioned above.

From figure 4, which shows part of an observation affected by the flux oscillations, it is clear the tracking history spatial oscillations, which have a semi-amplitude of only ~0.5-1 pixels (0.25-0.5 arcsecs), closely correlate with the flux oscillations. Furthermore, analysis of the housekeeping data shows clear periodic cycles, with similar timescales, in the temperature data of several OM temperature sensors – two examples are included in figure 4. The temperature variations result from heater cycling processes associated with the OM. While it remains to be established which (and indeed, even whether) these heating cycles are directly responsible for the spatial variations, it is highly likely that they are driving an expansion/contraction process that is moving the OM telescope relative to the spacecraft body.

As such, for sources near the edge of a fast mode window, such oscillations move part of the source in and out of the window. While the SAS software attempts to correct for missing PSF, the accuracy is reduced when a substantial fraction of the source is outside the window. Furthermore, photons arriving outside the window are not time-tagged and cannot, therefore, be corrected for tracking shifts by the OM SAS. Consequently, the oscillation of flux is unsurprising since count rates cannot be adequately corrected. In such extreme cases, the flux oscillations cannot be removed reliably.

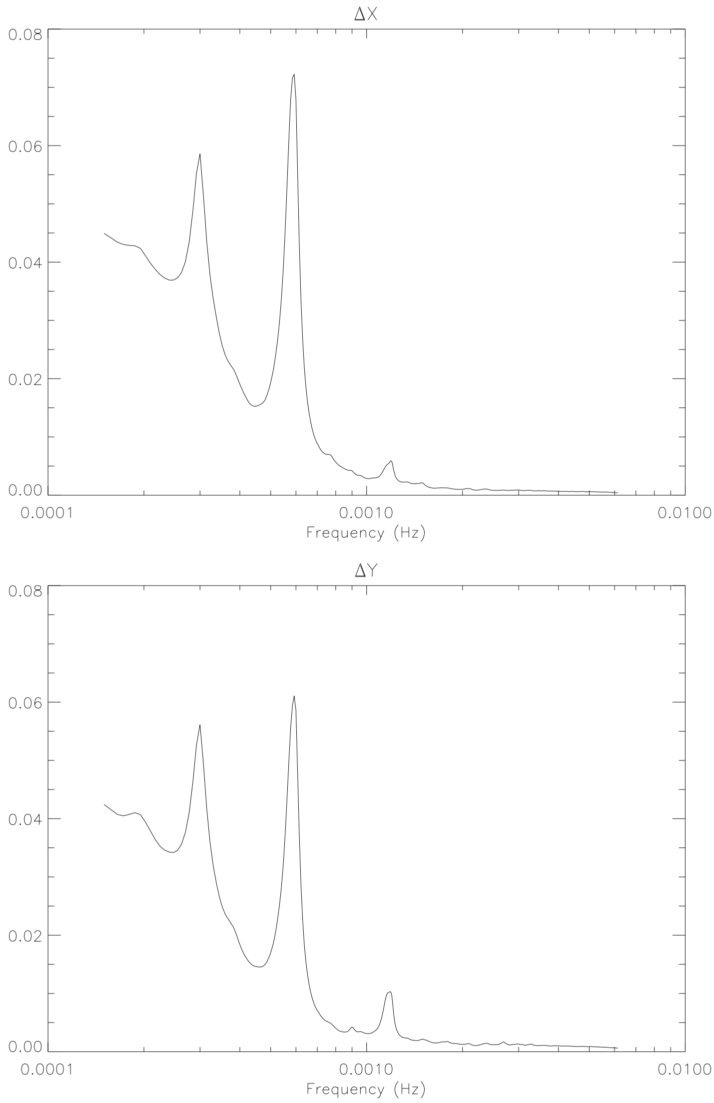

Figure 3: A stack of the Fourier analyses of the available OM tracking history data over observations from the whole mission, for the X (upper panel) and Y (lower panel) axes (from P. Rodriguez).

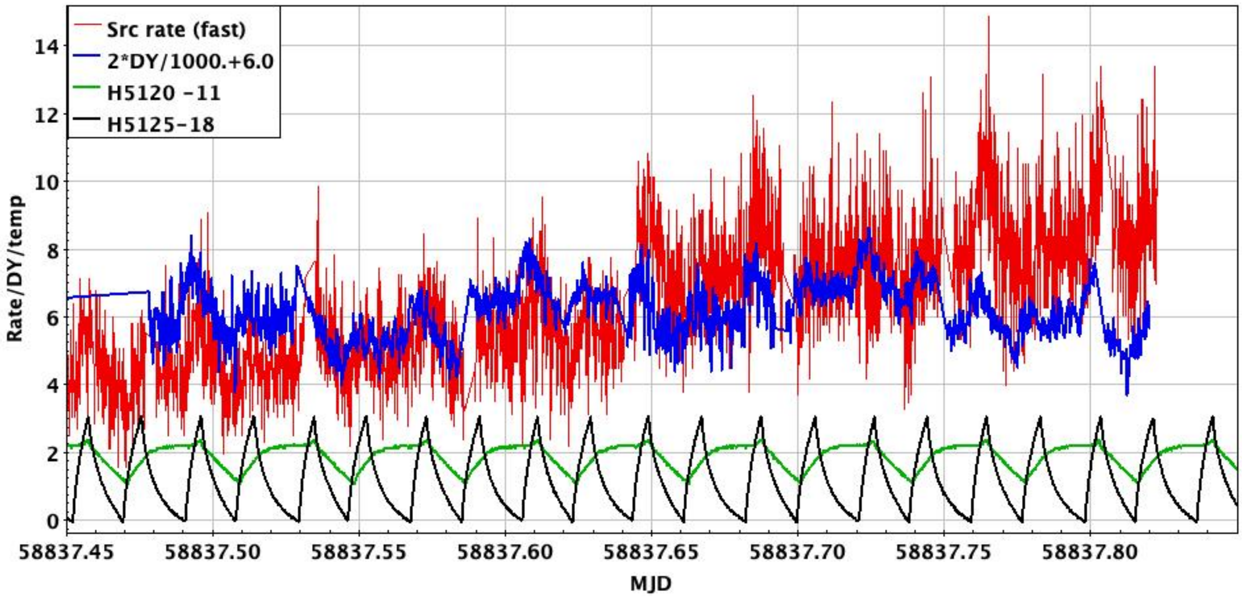

Figure 4: Part of the timeseries of a source located near the edge of a fast mode window is shown is red. The corresponding tracking history data (in the Y direction) is overlaid in blue, scaled and vertically offset for greater clarity. The temperature data from two sensors (H5120 (green) and H5125 (black)) on the OM instrument, are shown, with vertical offsets, for clarity.

5 DRIFT DURING LONG OBSERVATIONS

For long observations, spacecraft drift can cause the source to move substantially (up to 4"), sometimes moving it close to the edge or partially out of the window if already offset. A good example is shown in figure 5. Unfortunately, this drift is difficult to predict. If a target was previously observed, the drift is often similar, hence potentially predictable. However, recent counter-examples show that possible changes in the spacecraft orbit make the drift behaviour unpredictable. This is an effect that was addressed earlier in the mission. At that time, the ESOC Flight Dynamics team made a change that significantly improved the attitude stability within observations. Since some drift remains on some occasions, in 2018, flight dynamics were asked to investigate again. The conclusion was that the drifts under discussion appear to be caused by some limitation of the flight dynamics sun steering law (SSL) modeling and could probably only be improved by a SSL update every few hours using the timeline. Such a move had been considered earlier in the mission but never approved due to the attitude jumps that can occur at the moment of the update.

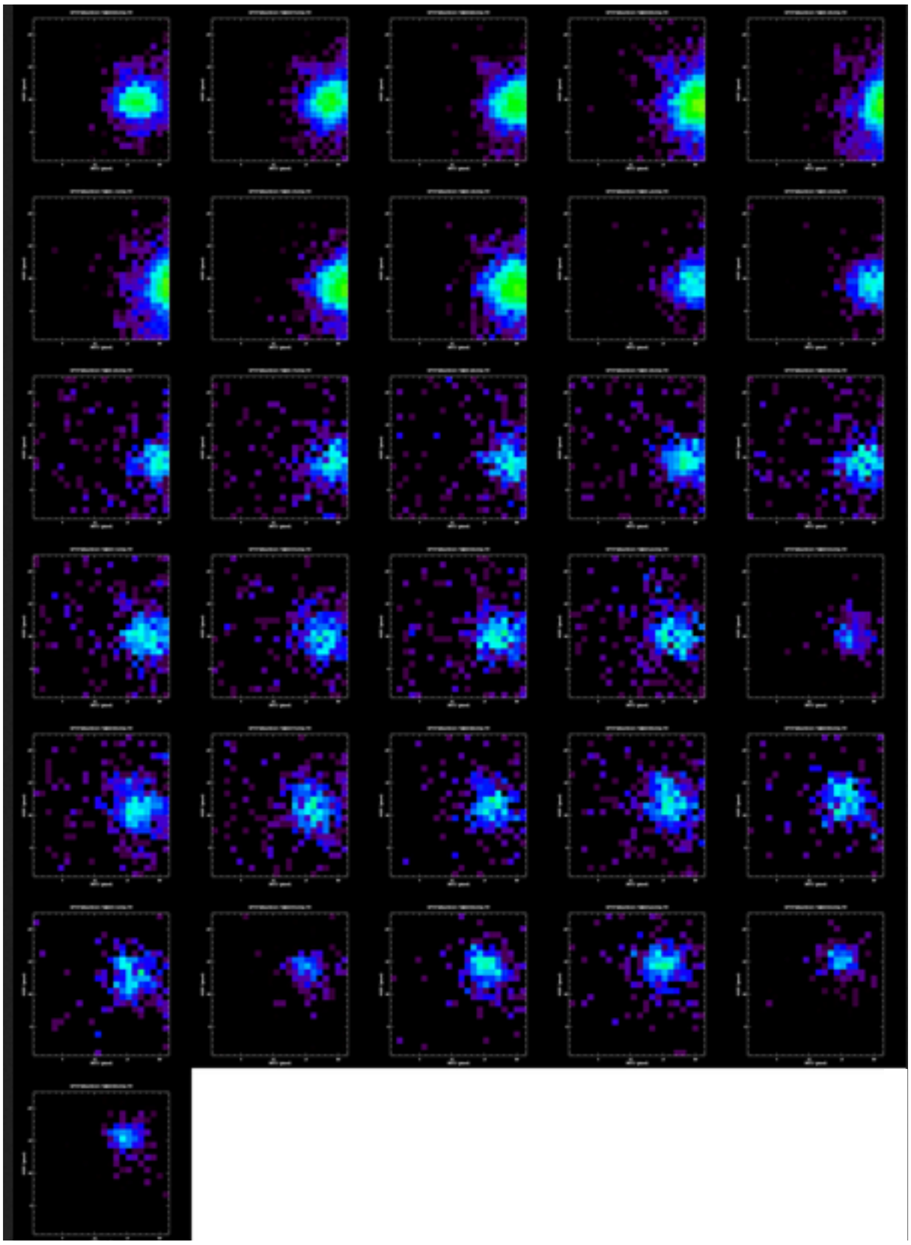

Figure 5: Images from a set of 31 sequential OM fast mode images from an observation lasting a full XMM orbit, where significant drift was present. Brightness changes are mainly associated with the use of different filters. Clear drift of the source to the right, of 2-3 arcsecs is seen in the first 6 exposures before the source moves back into the window in later exposures.

One possible option under consideration to address this problem is the development and use of a ‘new’ OM mode which would facilitate repeated FAQ exposures during long observations, thus enabling the fast mode window location to be adjusted regularly, after the initial set-up FAQ is performed.

6 CONCLUSIONS

Efforts to address the issue of (sometimes) poorly centred sources in the fast mode window, when FAQ fails, have been (partially) addressed by implementing, in April 2020, an update of the long-term, time-dependent shift of the mean OM/spacecraft boresight offset, both in the XMM planning system and operational database. While other factors, such as the annual ~1 arcsec OM boresight oscillation and random (~4 arcsec) spacecraft pointing errors, will continue to cause offsets, on average, sources are expected to be better centred when FAQ fails, as a result of the update. Analyses of post-update FAQ data indicates a significant improvement can be expected, though the low frequency of FAQ failures with fast mode usage will require significant further time to elapse before sufficient statistics become available to confirm that sources are generally better centred in the fast mode window when FAQ fails.

Spurious oscillation of source flux on a timescale of ~1650/3300 seconds, seen in an extreme case where the source is close to the edge of the fast mode window, are associated with ~0.5-1 pixel spatial oscillations of the instrument relative to the spacecraft, which cause part of the source to ‘wobble’ in and out of the window - this cannot be corrected for, reliably. These spatial movements appear to be correlated with thermal cycling of some part of the instrument, though the exact origin remains uncertain.

In the case of drift during an observation, which can amount to several arcseconds, changes implemented by flight dynamics early in the mission, and in 2018, were made, with consequent improvements but it is understood that further improvements are unlikely. Alternative approaches to tackle this issue are being considered.