X-ray Loading, Gainshift &
(Modified) Timing Mode
of XMM-Newton’s EPIC-pn

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Abstract
Knowing the instrument’s behaviour is highly important when analysing the collected observational data. Here we investigate the issue of the energy gainshift associated with the EPIC-pn instrument on-board XMM-Newton, when it is operated in Timing mode. The gainshift arises as a result of CTE effects or X-ray loading. This depends on the source brightness and the effectiveness of the noise correction. X-ray loading has clearly been detected in imaging mode, while the importance of its impact on the Timing mode observations is still under investigation. The consequences of X-ray loading in general are pattern migration from higher to lower pattern types and a shift to lower energies for all events associated with the affected CCD column. Current results show a clear correlation between X-ray loading and X-ray flux of the source, but other correlations may also reveal ways to understand and correct for the energy gainshift in the data. A peculiar case of Timing mode is the Modified Timing mode, and here we also explain its properties and its potential impact on the scientific results dealing with bright X-ray sources.

X-ray loading

Definition and the cause
Measurements with the EPIC-pn camera of the XMM-Newton satellite may be contaminated by IR, visible and UV photons. In order to prevent the contamination thin, medium or thick blocking filters are used. In addition an offset map is calculated which is used for subtracting the constant, measured level of produced charge from the detected source events. Very bright X-ray source may contaminate the pn offset map, giving rise to X-ray loading. This leads to the loss of the source signal resulting in:
- pattern migration from higher to lower pattern types
- shift to lower energy for all subsequent events associated with the affected pixel

Gainshift

Traps caused by contamination of the silicon with titanium are causing loss of charge upon read-out (Charge Transfer Inefficiency). For bright sources these traps are filled fast, and any correction of CTS causes an over-correction. This means that we end up with a shift of events towards higher energies. In addition, X-ray loading shifts the events in the opposite direction. To correct for such energy shifts one can apply a gainshift correction to the EPIC-pn data when fitting it together with simultaneous data from other X-ray missions (Duro et al. 2011).

Affected observations

Here we analyse archival Timing mode observations where we look for the amount of X-ray loading in individual columns of offset maps. X-ray loading occurs mostly in the innermost columns as most of the flux comes from the source position, as is evident from the Fig. 2. Thus, excluding them would often remove most severe effects of X-ray loading. These columns are usually removed because of the pile-up. It should be noted, however, that the loading may occur even for cases where the source count rate is pile-up limited (see XMM-0002C-EPIC/T-089 for a study on imaging mode data).

In Fig. 3 a correlation between the X-ray count rate and the maximal X-ray loading seen for different sources observed in Timing mode is evident.

Reserved Timing Mode

To get high S/N data of bright sources, one may observe with EPIC-pn instrument set in Timing mode. Nevertheless, telemetry limit of ∼ 100 mCrab makes it difficult to observe sources such as Cygnus X-1 with fluxes ∼ 100 mCrab without going into counting mode. To bypass the telemetry limit, two steps are performed onboard the XMM-Newton and one on the ground (see below), which results in more telemetry allocated to the EPIC-pn and less data sent (Kendziorra et al. 2004). Modification implies a re-calibration of the instrument, mainly due to the lost information on the single-to-double ratio of events caused by increased lower energy threshold. A new response matrix is calculated based on the archival Timing mode observations by measuring energy dependent probability distribution of split events. With this combination we can observe objects of few hundreds mCrab.

Figure 1: Amount of X-ray loading in comparison with objects apparent magnitudes taken from Simbad show no clear correlation.

Figure 2: Offset maps are calculated before each observation while pointing at the source. As this one shows, they can be used in estimating X-ray loading.

Figure 3: Thick filter Timing mode observations show that X-ray loading is increasing with increasing rate. Note four Modified Timing mode observations at the bottom.

Figure 4: The effect of the gainshift correction, when applied in EPIC-pn data, has fitted simultaneously with PCA data. Panel b represents the fit without the correction and with clear disagreement of the data, while panel c shows the improvement when corrected for gainshift of ∼ 2% (see post 2005 for more details on the spectral analysis of these data of Cygnus X-1).

Figure 5: The best fit model (shown in red) to the same EPIC-pn data now compared to Chandra data (blue) shows four disagreement in the position of 4 keV x-ray emission line and resonant iron absorption line (Chandra values by Hanke et al. 2009). Only when applying a gainshift of ∼ 2% to EPIC-pn data (as in the Fig. 3), agreement is reached.

Figure 6: Top: Measured EPIC-pn Timing mode spectra (blue) and Modified Timing mode spectrum generated from these data (red), fitted with an absorbed power-law. Middle: The redistribution of events in the Modified Timing mode leads to an apparent soft excess. Bottom: New response matrix for the Modified Timing mode fully describes the behaviour of this mode (Fritz 2005).

References