# XMM-Newton CCF Release Note

XMM-CCF-REL-387

## Astrometry: time variable boresight - 2022 update

S. Rosen
P. Rodríguez

February 1, 2022

## 1 CCF components

| Name of CCF | VALDATE | List of Blocks changed | CAL VERSION | XSCS flag |
|---|---|---|---|---|
| XMM_BORESIGHT_0032 | 2000-01-01T00:00:00 | OM_ANGVAR<br>EMOS1_ANGVAR<br>EMOS2_ANGVAR<br>EPN_ANGVAR<br>RGS1_ANGVAR<br>RGS2_ANGVAR | | No |

## 2 Changes

The XMM-Newton Time Variable Boresight was implemented in 2012. It is described in the release notes XMM-CCF-REL-286 and XMM-CCF-REL-290.

The extrapolations made to derive corrections to the Euler angles based on past data imply that new updates of these corrections may be necessary from time to time. Updates were made in 2014, 2015, 2017, 2018 and 2020, each update taking into account new data obtained after the previous one. They were implemented in XMM_BORESIGHT_00XX.CCF (XX=24-31), the most recent described in XMM-CCF-REL-380).

The existing CCF elements allow an extrapolation of the offset trend to be made but as new observations arrive, after some time we witness systematic deviations from the predicted offsets. Therefore it is necessary to produce a new update using the most recent data.

As previously, we have analyzed the astrometry offsets derived from the pipeline PPS source lists for the EPIC and OM instruments, adding to the previous data set the observations obtained until November 2021 (Rev. 4020 for OM and to Rev. 4010 for EPIC). We have modeled the offset variations with time by means of long term variations plus a periodic (nearly one year) oscillation (Talavera & Rodríguez-Pascual [1]).

For the OM, an error in the two most recent analyses (see section 8) is rectified in this update. As the correct data show an upturn in the Y axis at late epochs (> 2018), we fitted the long term trends with polynomials of order 2, 3 and 4 (in fact applied to the Z axis as well). As can be seen in figure 1, in the Z axis, the differences between second, third and fourth order representations of the long term trends are minimal ($\leq 0.2$ arcsecs). In the Y axis, the differences are more evident, mainly over the interval of extrapolation (2022-2024). At 2023.0, the third (orange) and fourth order (green) curves are, respectively, $\sim$1.2 arcsecs and $\sim$0.6 arcsecs above the second order function (red), the latter being an inadequate description of late-epoch measurements. The scatter and the limited duration of the upturn make it difficult to asertain whether the third or fourth order trends is likely to provide the more accurate extrapolation over the coming year (statistical analyses do not provide a basis for a clear distinction). As a result, we favour the fourth order function because it implies less extreme changes in the next 12 months - extrapolation of the 3rd order function looks likely to overestimate the data trend. In any case, new data during the next year will be closely monitored and the trend adjusted accordingly.

The long-term trend in the EPIC data is, as for the last release, represented by a third order polynomial plus a periodic variation with a timescale of order 10 years. The general functional form is

$$\Delta = (P_1+P_2\times T+P_3\times T^2+P_4T^3+P_5T^4)+P_6\times\cos[2\pi\times(T-P_7)/P_8)]+P_9\times\cos[2\pi\times(T-P_{10})/P_{11})]$$

where $\Delta$ is the measured offset and $T$ is the time in Julian days elapsed since January 1, 2000 (MJD 51544.0). The new best-fit parameters are given in Tab.1.

The long-term cyclic component in the EPIC data is of low amplitude (0.07 and 0.24 arcseconds in the Z and Y axes, respectively).

To avoid large deviations in the extrapolation, for EPIC we have used the IDL function TS_FCAST(X,P,N), where X are the fitted values up to November 01 2021, and P=838 and N=419.

As explained in XMM-CCF-REL-290, the same offsets obtained for EPIC can be used to process RGS data.

## 3 Scientific Impact of this Update

The release notes XMM-CCF-REL-286 and XMM-CCF-REL-290 explain, in detail, the improvements in the astrometry achieved with the Time Variable Boresight.

Although the corrections derived are small, we annually update the model parameters to min-

Table 1: Best-fit parameters implemented in this CCF.

| Instrument/ coordinate | $P_1$ | $P_2$ | $P_3$ | $P_4$ | $P_5$ | $P_6$ | $P_7$ | $P_8$ | $P_9$ | $P_{10}$ | $P_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| EPIC/Y | +0.55 | $-3.4 \times 10^{-4}$ | $+7.9 \times 10^{-8}$ | $-4.6 \times 10^{-12}$ | | +0.18 | −8.72 | 362.9 | −0.07 | +176.25 | 3138.0 |
| EPIC/Z | +0.41 | $-9.6 \times 10^{-4}$ | $+2.1 \times 10^{-7}$ | $-1.2 \times 10^{-11}$ | | +1.37 | −12.31 | 365.4 | +0.24 | −118.70 | 3493.3 |
| OM/X | −1.5 | $+9.2 \times 10^{-4}$ | $-3.9 \times 10^{-8}$ | $-1.5 \times 10^{-11}$ | $+1.0 \times 10^{-15}$ | −1.01 | −20.03 | 365.8 | | | |
| OM/Y | −2.6 | $+2.8 \times 10^{-3}$ | $-6.6 \times 10^{-7}$ | $+7.9 \times 10^{-11}$ | $-3.4 \times 10^{-15}$ | +0.77 | −18.47 | 365.1 | | | |

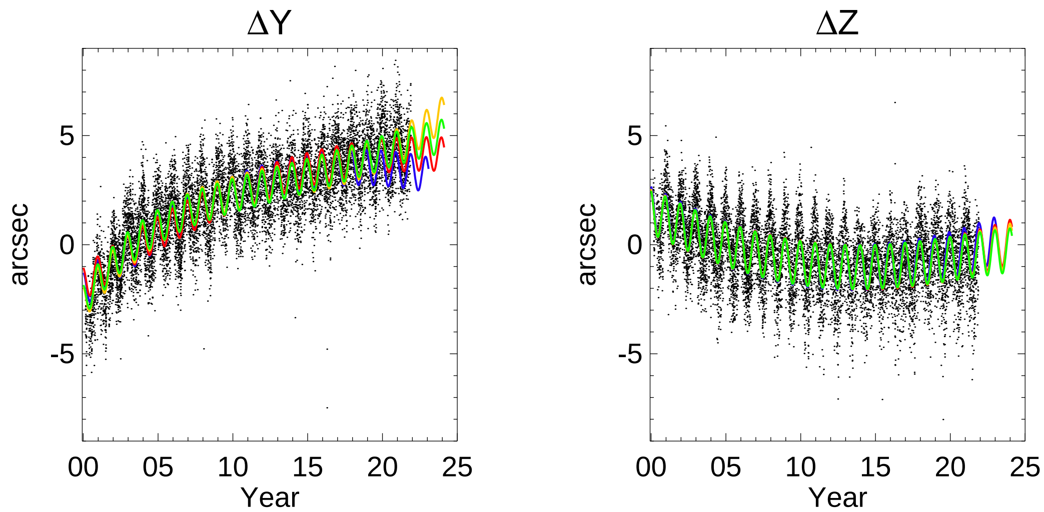


Figure 1: OM measured offsets and fits: for CCF_0031 (blue) and CCF_0032, in red (2nd order polynomial), orange (third order polynomial) and green (fourth order polynomial)

imise the growth of significant deviations in the near (∼ 1 year) future (but note section 8).

Figures 1 and 2 show, for the OM and EPIC, respectively, the offsets and the fitted corrections. The differences between CCF version 31 (blue curves) and this new CCF can be seen there. For the OM, it should be noted that the second order curve (blue) implemented in XMM_BORESIGHT_0031.CCF, is incorrect (see section 8). As noted in section 2, for the long-term trend in OM, the different polynomial representations tested, differ by up to 1.2 arcsecs in the projected boresight deviation at 2023.0.

# 4 Estimated Scientific Quality

The quality of the corrections can be assessed by comparing the catalogue offsets obtained with the constant and the new variable boresight. This comparison was presented in the previous release notes, XMM-CCF-REL-286 and XMM-CCF-REL-290.

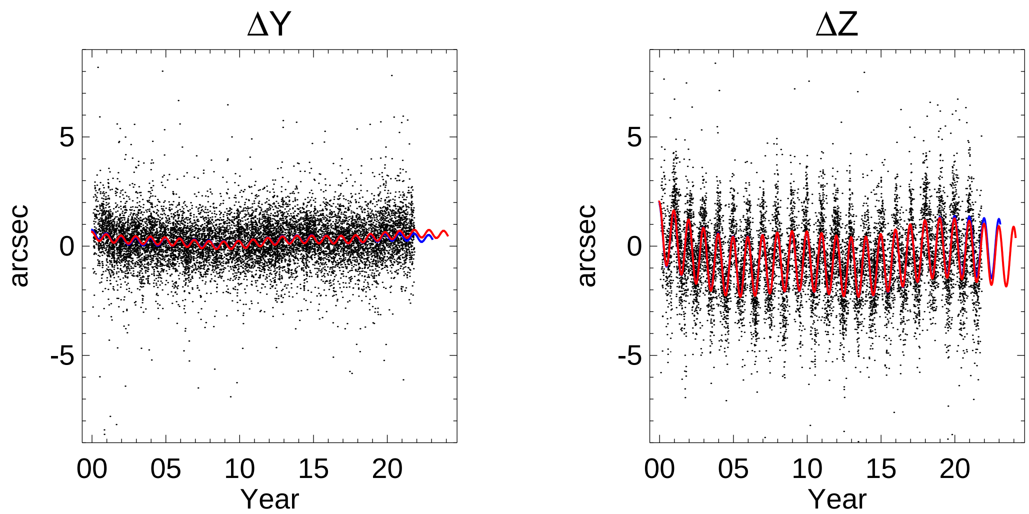


Figure 2: EPIC measured offsets and fit: in blue CCF_0031, in red CCF_0032

## 5 Test procedures

The concept of time variable boresight and its implementation were intensively tested in their first issue. At that time more than 4000 observations obtained since the beginning of the XMM-Newton operational life were processed with SAS using the new concept CCF.

Since this new release implements just a small increment in the variation of the Euler angles offsets, we have processed a recent ODFs to confirm the normal functioning of the related SAS tasks.

## 6 Summary of the test results

As noted before, the results of extensive tests on the time-variable boresight approach can be seen in XMM-CCF-REL-286 and XMM-CCF-REL-290. For the latest update, for EPIC, the tests are limited to confirming that the new boresight is correctly implemented.

For the OM, we further confirm, from a test observation processed with both the new and previous boresight CCFs, that the offsets of sources in the field relative to their GAIA DR2 counterparts (prior to rectification against an astrometric reference catalogue), are consistent with the change of the time-dependent boresight between the new and the previous (erroneous) boresight CCFs, at the observation epoch.

## 7 Expected updates

The fit to the long term trend observed in the measured offsets assumes an extrapolation beyond the available data. This update provides offsets until February 2024. However, following our experience these offsets will deviate from the true trend in about one year. Therefore we shall continue monitoring the offsets in the future to confirm the predicted trend or to modify the fit as we have been doing with the last updates.

## 8 An error in recent updates of the time-dependent OM boresight

Analysis of the time-dependent boresight for the OM has been incorrect in the previous two updates (XMM-CCF-REL-375 and XMM-CCF-REL-380). This was due to (a) the erroneous inclusion of data from around 400 (of some 11000) observations for which the astrometric catalogue cross-correlation, which is routinely performed in pipeline processing, failed - the mean Y and Z axis deviations (for each observation), measured between the OM source positions and counterparts in the astrometric reference catalogues, are used in deriving the time-dependent boresight corrections, and (b) position angles used in the analysis were incorrect. The impact of the former issue has been found to be negligible but the latter error leads to a deviation of the offsets from the correct ones, mainly in the Y axis. From figure 1, comparing the second order fit to the correct data (red) against the incorrect curve from XMM_BORESIGHT_0031.CCF (blue) shows differencess of about 0.40 arcsecs and 0.06 arcsecs in the Y and Z axes, respectively, at 2018.0, while at 2022.0, the differences increase to 0.9 arcsecs in Y and 0.19 arcsecs in Z. As noted in section 2, however, the data at later epochs (>2018) suggest that the second order fit to the correct data is now inadequate in the Y axis and the current update is based on fourth order polynomial representations of the long term trends for OM.

Generally, this error in the previous two updates does not cause an issue with OM source astrometry because positions are, in anycase, usually rectified via a comparison of field objects against an astrometric reference catalogue during pipeline processing. However, for cases where that astrometric rectification for the field failed, source positions based on CCF version 0031, will be offset according to the aforementioned boresight error ∼1 arcsec. Note that boresight version 0030, where a similar issue pertains, was never used in pipeline processing.

## References

[1] Talavera A., Rodríguez-Pascual P., 2011, XMM-SOC-TN-0041, available at:

`http://xmm2.esac.esa.int/~xmmdoc/CoCo/CCB/DOC/Attachments/INST-TN-0041-1-0.pdf`.