SWIFT-XRT-CALDB-06

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SWIFT-XRT CALDB RELEASE NOTE

SWIFT-XRT-CALDB-06: Teldef

1 Introduction

The analysis of the Swift-XRT accuracy in determining sources position during the mission has pointed out that the telescope optical axis of the XRT has drifted constantly over the years. The boresight misalignment is regularly monitored by the XRT team and the information obtained is stored in the Swift-XRT Calibration Database (CALDB) and used by the ground software during the data calibration stage. This document describes the analysis performed on a set of observations, carried out between the second semester of 2017 and the first semester of 2019, in order to produce an updated calibration of the XRT boresight. The new boresight information determined is included in a set of teldef files, corresponding to different time periods (see Table 1). The files are included in the CALDB released by the HEASARC on October 23rd 2019 (version 20190910) to be available for the ground software processing.

FILENAME	START VALIDITY DATE
swx20170601v001.teldef	2017-06-01
swx20180101v001.teldef	2018-01-01
swx20180601v001.teldef	2018-06-01
swx20190101v001.teldef	2019-01-01

Table 1 – List of teldef files incorporating the boresight correction covered by this analysis.

2 Boresight analysis

2.1 Ground software boresight analysis

From the Swift Master Catalog we selected all the observations between June 1, 2017 and May 31, 2019 with an exposure time in PC mode larger than 5000 s. Among these, we selected those with a secure position of the optical or radio counterpart. For the observations of GRBs, we considered the optical position provided in the UVOT refined analysis circular when available, otherwise we used the optical position from other telescopes. For the observations of other–than–GRB sources, we cross–matched those sources with optical catalogues adopting the best optical or radio position available, if any.

We retrieved the cleaned event files in PC mode reprocessed locally in the UK archive with the HEASoft V6.26. We calculated for each observation the barycentric positions running the `xrtcentroid` task and we compared them with the corresponding optical ones. We discarded those observations with an intrinsic X–ray positional error larger than $6''$ and (in a very few cases) if the offset between optical and X–ray positions is larger than $10''$ (in both cases mainly due to too faint X–ray sources).

We investigated how this offset depends on the roll angle ρ to derive the proper correction for the sky coordinates for each semester from 2017 June onward (see Perri and Capalbi 2002[1] and Moretti et al. 2006[2] for details). For each semester we fitted the $\Delta\alpha$ ($\Delta\delta$) vs. the roll angle with sinusoidal laws, as described in Perri & Capalbi (2002): $\Delta\alpha = A\sin(\rho + \Phi)$; $\Delta\delta = A\cos(\rho + \Phi)$. These best fit formulae can be used to correct the sky coordinates derived from the instrument. As Figure 1 shows, a relationship between the roll angle and $\Delta\alpha$ ($\Delta\delta$) is present and the best–fitting parameters are reported in Table 2.

Grouping our observations in semesters, we find that the offset slightly increases, being the fraction of observations with offset larger than its error $\sim 13\%$ in the second semester of 2017 (slightly larger than expected being this the first semester after the last boresight correction), $\sim 15\%$ in the first semester of 2018 and up to $\sim 20 - 25\%$ during the last year, up to the end of May 2019. (see Table 2). The RA and Dec offsets between optical and X-ray positions in the four semesters are plotted in Figure 2.

Semester	N_{tot}	N	A	Φ	frac (%)
2017B	62	22	1.068 ± 0.977	-0.609 ± 0.914	13
2018A	28	13	1.209 ± 1.225	-0.402 ± 1.012	15
2018B	31	19	2.053 ± 1.007	0.099 ± 0.490	26
2019A	29	14	2.041 ± 1.164	-0.179 ± 0.570	21

Table 2 – Best–fit parameters for the relations between $\Delta\alpha$ and $\Delta\delta$ and the roll angle for each semester of the considered period. Columns are: total number of the observations matching the criteria (N_{tot}), number of observations actually used for the analysis (N), amplitude (A), phase (Φ), and the fraction of observations with offset larger than its error (frac). Errors are given at 90% confidence level.

[1] Perri & Capalbi 2002, A&A 396, 753

[2] Moretti et al. 2006, A&A 448, L9

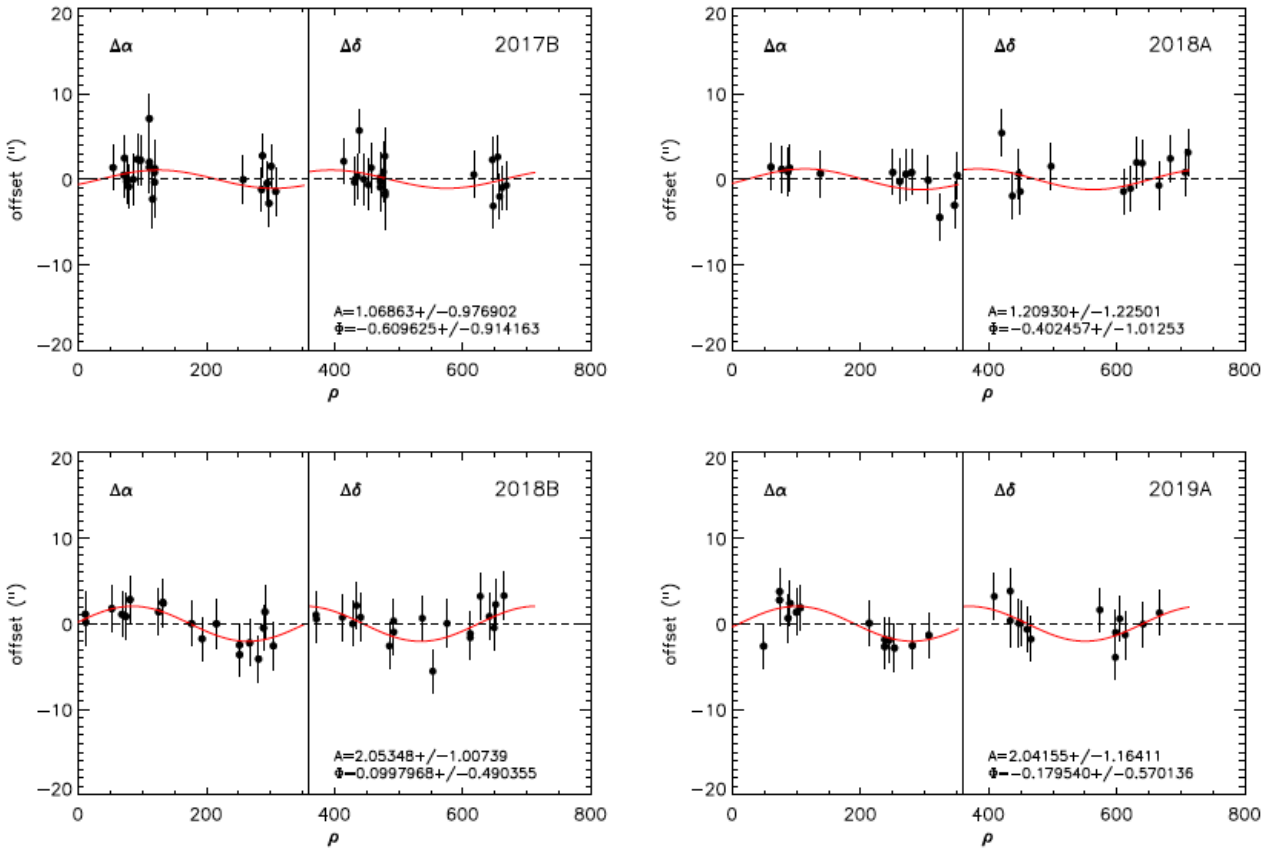

Figure 1 – $\Delta\alpha$ and $\Delta\delta$ vs. the roll angle ρ for each semester. The red line is the sinusoidal function for the best–fitting parameters reported in the inset.

2.2 New teldef correction

Our analysis suggests that the drift of about $1''$ per year observed in previous years is still in place. The fraction of observations with offset larger than its error of last 12 months observations is $> 20\%$, clearly indicating that a new boresight correction is needed.

The new boresigth correction was first included in a set of teldef files and then applied to the original data in order to verify that it reduces the number of observations with offset larger than its error. The results are visible in Fig. 3, where it is clear that the applied correction significantly reduced the offset. We can also confirm that the systematic error included in the XRT pipeline ($3.5''$) is still enough and does not need to be changed/increased.

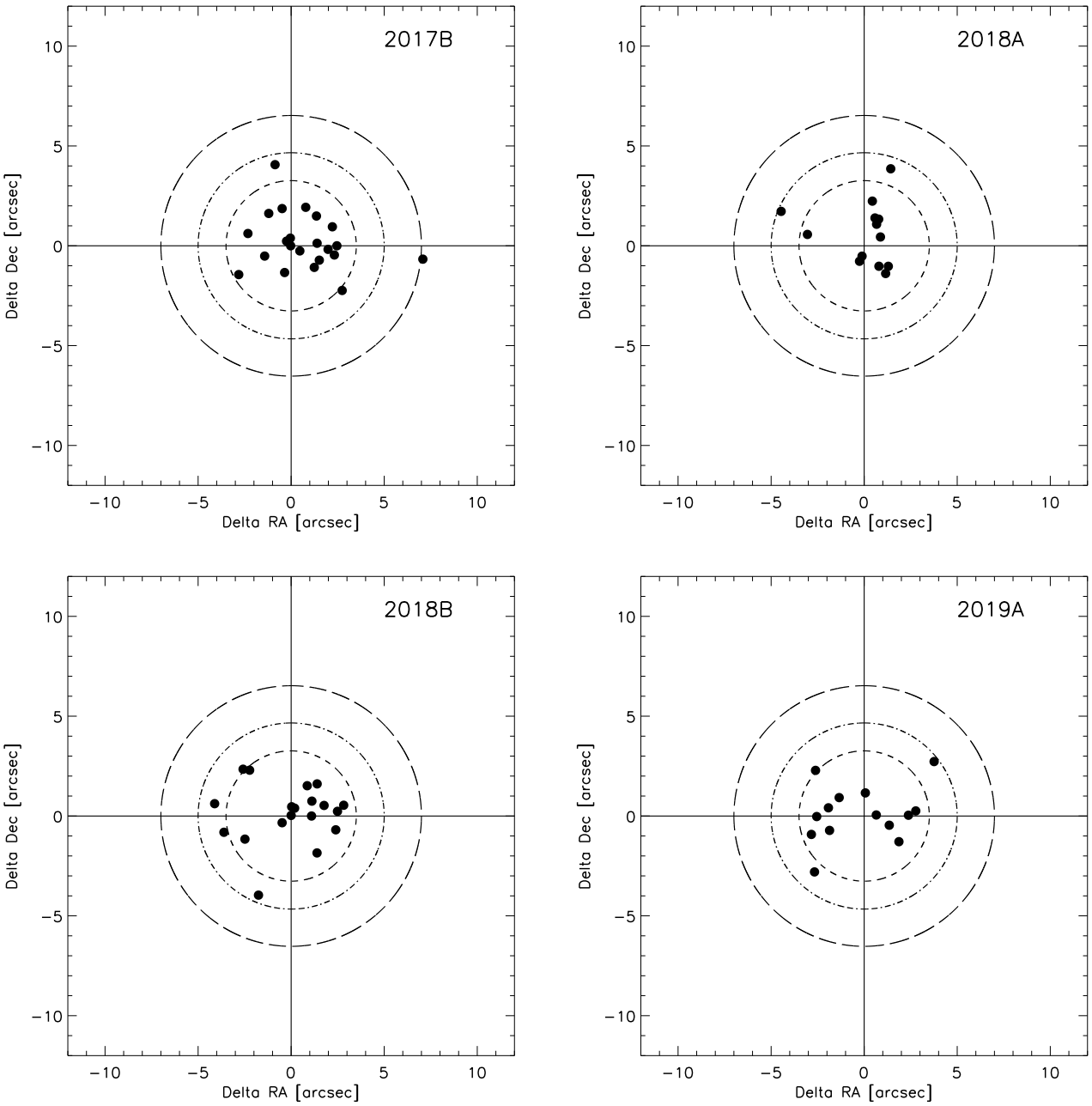

Figure 2 – $\Delta\alpha$ vs. $\Delta\delta$ for each semester. The circles correspond, from the inside towards the outside, to a distance (offset) of 3.5″, 5″, and 7″, respectively.

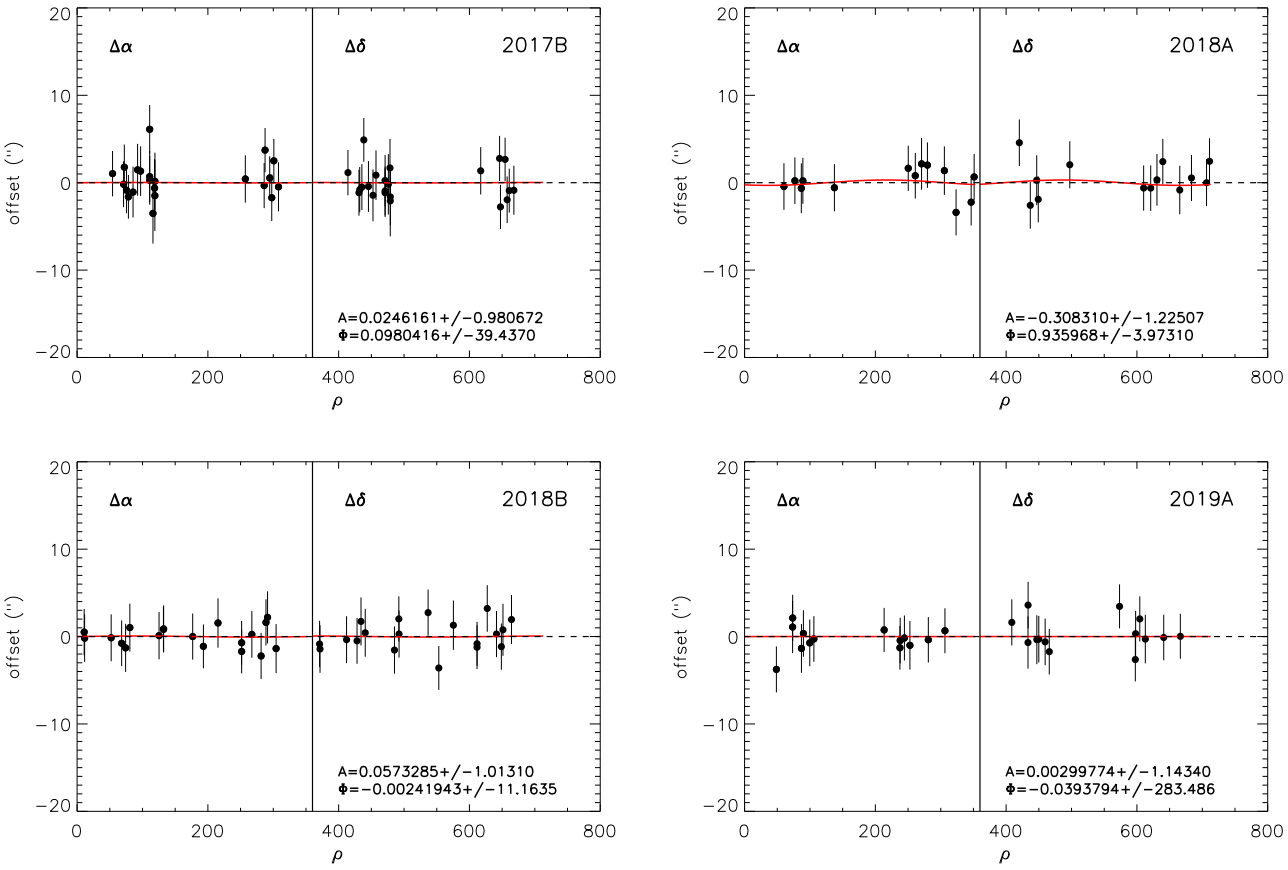

Figure 3 – $\Delta\alpha$ vs. $\Delta\delta$ vs. the roll angle ρ for each semester **after the new boresight correction**. The red line is the sinusoidal function for the best–fitting parameters reported in the inset.

Table 3 – Sources and observations selected to derive the best-fit boresight for the time period between the second semester of 2017 and the first semester of 2019. The table includes source name, RA and Dec of the optical source position, and sequence number for each observation.

Source name	Right Ascension	Declination	Observation ID
	Semester 2017B		
Mrk590	02 14 33.56	-00 46 00.2	00037590020
Mrk590	02 14 33.56	-00 46 00.2	00037590021
Mrk590	02 14 33.56	-00 46 00.2	00037590022
GRB170705a	12 46 48.97	+18 18 26.4	00760064001
GRB170705a	12 46 48.97	+18 18 26.4	00760064002
GRB170705a	12 46 48.97	+18 18 26.4	00760064011
GRB170705a	12 46 48.97	+18 18 26.4	00760064012
GRB170705a	12 46 48.97	+18 18 26.4	00760064015
SwiftJ0215.7+3522	02 15 44.35	+35 20 41.2	00087065011
GRB170710a	15 27 16.87	-38 29 06.0	00761119001
GRB170714a	02 17 23.96	+01 59 32.9	00762535001
GRB170714a	02 17 23.96	+01 59 32.9	00762535002
GRB170714a	02 17 23.96	+01 59 32.9	00762535003
GRB170714a	02 17 23.96	+01 59 32.9	00762535004
GRB170714a	02 17 23.96	+01 59 32.9	00762535007
GRB170728b	15 51 55.45	+70 07 21.2	00765130000
XB1916-053	19 18 47.87	-05 14 17.1	00087248021
GRB170803a	11 39 44.11	-16 18 38.0	00766081001
GRB170803a	11 39 44.11	-16 18 38.0	00766081003
GRB170803a	11 39 44.11	-16 18 38.0	00766081004
GRB170804a	00 25 34.29	-64 47 03.1	00766194001
GRB170804a	00 25 34.29	-64 47 03.1	00766194002
GRB170804a	00 25 34.29	-64 47 03.1	00766194003
WASP 121	07 10 24.06	-39 05 50.5	00010206003
GRB170810A	12 31 45.33	+03 39 38.9	00767284001
GRB170810A	12 31 45.33	+03 39 38.9	00767284003
KIG637	14 34 49.75	+54 32 03.8	00087242010
KIG637	14 34 49.75	+54 32 03.8	00087242015
KIG637	14 34 49.75	+54 32 03.8	00087242016
GRB171010a	04 26 19.46	-10 27 45.9	00020779005
GRB171010a	04 26 19.46	-10 27 45.9	00020779006
GRB171010a	04 26 19.46	-10 27 45.9	00020779002
GRB171010a	04 26 19.46	-10 27 45.9	00020779003
GRB171010a	04 26 19.46	-10 27 45.9	00020779004
GRB171010a	04 26 19.46	-10 27 45.9	00020782006
GRB171010a	04 26 19.46	-10 27 45.9	00020782012
GRB171020a	02 36 59.62	+15 12 16.0	00780845001
V405 Aur	05 57 59.29	+53 53 44.9	00088607001
GRB171205a	11 09 39.57	-12 35 17.4	00794972001
GRB171205a	11 09 39.57	-12 35 17.4	00794972002
GRB171205a	11 09 39.57	-12 35 17.4	00794972003
GRB171205a	11 09 39.57	-12 35 17.4	00794972004
GRB171205a	11 09 39.57	-12 35 17.4	00794972006
GRB171205a	11 09 39.57	-12 35 17.4	00794972008

Table 3 – *continued* - Sources and observations selected to derive the best-fit boresight for the time period between the second semester of 2017 and the first semester of 2019. The table includes source name, RA and Dec of the optical source position, and sequence number for each observation.

Source name	Right Ascension	Declination	Observation ID
GRB171205a	11 09 39.57	-12 35 17.4	00794972012
GRB171205a	11 09 39.57	-12 35 17.4	00794972017
GRB171205a	11 09 39.57	-12 35 17.4	00794972018
GRB171205a	11 09 39.57	-12 35 17.4	00794972019
GRB171205a	11 09 39.57	-12 35 17.4	00794972020
GRB171205a	11 09 39.57	-12 35 17.4	00794972021
GRB171205a	11 09 39.57	-12 35 17.4	00794972022
GRB171205a	11 09 39.57	-12 35 17.4	00794972023
GRB171205a	11 09 39.57	-12 35 17.4	00794972024
GRB171205a	11 09 39.57	-12 35 17.4	00794972025
GRB171205a	11 09 39.57	-12 35 17.4	00794972026
GRB171205a	11 09 39.57	-12 35 17.4	00794972027
GRB171205a	11 09 39.57	-12 35 17.4	00794972028
GRB171205a	11 09 39.57	-12 35 17.4	00794972029
GRB171205a	11 09 39.57	-12 35 17.4	00794972030
GRB171205a	11 09 39.57	-12 35 17.4	00794972031
GRB171205a	11 09 39.57	-12 35 17.4	00794972032
GRB171222a	09 53 06.73	+35 37 35.5	00799669001
	Semester 2018A		
Mrk1148	00 51 54.76	+17 25 58.5	00080868001
GRB180115a	00 48 09.27	-15 36 49.9	00805318000
CXOUJ164710.2-455216	16 47 10.18	-45 52 55.8	00030806062
CXOUJ164710.2-455216	16 47 10.18	-45 52 55.8	00030806065
1RXSJ075813d2p835637	07 58 13.20	+83 56 37.0	00088459001
GRB180205a	08 27 16.74	+11 32 30.9	00808625010
3C410	20 20 06.56	+29 42 14.2	00088393001
AXJ1949.8+2534	19 49 52.00	+25 34 24.0	00010382005
GRB180314a	06 37 03.68	-24 29 46.0	00814129001
GRB180314a	06 37 03.68	-24 29 46.0	00814129008
GRB180314a	06 37 03.68	-24 29 46.0	00814129009
Mrk1393	15 08 53.95	-00 11 49.0	00088254001
Mrk1393	15 08 53.95	-00 11 49.0	00088254002
GRB180329b	05 31 36.91	-23 41 25.8	00819490001
GRB180329b	05 31 36.91	-23 41 25.8	00819490002
GRB180404b	03 33 34.23	-50 12 54.2	00821902001
GRB180404a	05 34 11.64	-37 10 03.9	00821881009
V1432 Aql	19 40 11.42	-10 25 25.7	00088611001
GRB180418a	11 20 29.21	+24 55 59.2	00826428002
GRB180418a	11 20 29.21	+24 55 59.2	00826428007
GRB180510b	05 11 52.64	-62 19 26.3	00831816010
GRB180618a	11 19 45.84	+73 50 13.5	00842475001
GRB180620a	18 39 35.09	+23 14 23.2	00843122001
GRB180620b	23 50 05.09	-57 57 43.9	00843211005
GRB180624a	21 12 23.38	-02 20 16.7	00844192000
GRB180626a	16 14 18.12	+14 45 25.5	00844615001

Table 3 – *continued* - Sources and observations selected to derive the best-fit boresight for the time period between the second semester of 2017 and the first semester of 2019. The table includes source name, RA and Dec of the optical source position, and sequence number for each observation.

Source name	Right Ascension	Declination	Observation ID
	Semester 2018B		
GRB180706a	12 06 34.34	+66 02 13.6	00846395001
2MASXJ20033401p7013367	20 03 33.99	+70 13 36.9	00088567001
V515 And	00 55 19.90	+46 12 57.0	00088625001
XY Ari	02 56 08.18	+19 26 34.1	00088613001
RXJ1856.4-3754	18 56 35.11	-37 54 30.5	00051950237
RXJ1856.4-3754	18 56 35.11	-37 54 30.5	00051950238
GRB180720b	00 02 06.87	-02 55 05.2	00848890006
GRB180728a	16 54 15.53	-54 02 40.2	00850471000
GRB180728a	16 54 15.53	-54 02 40.2	00850471001
GRB180728a	16 54 15.53	-54 02 40.2	00850471014
GRB180728a	16 54 15.53	-54 02 40.2	00850471034
GRB180728a	16 54 15.53	-54 02 40.2	00850471035
GRB180728a	16 54 15.53	-54 02 40.2	00850471037
AXMic	21 17 15.26	-38 52 02.5	00010784001
AXMic	21 17 15.26	-38 52 02.5	00010784002
AXMic	21 17 15.26	-38 52 02.5	00010784003
AXMic	21 17 15.26	-38 52 02.5	00010784004
AXMic	21 17 15.26	-38 52 02.5	00010784006
AXMic	21 17 15.26	-38 52 02.5	00010784007
AUMic	20 45 09.53	-31 20 27.2	00010785001
AUMic	20 45 09.53	-31 20 27.2	00010785005
AUMic	20 45 09.53	-31 20 27.2	00010785007
AUMic	20 45 09.53	-31 20 27.2	00010785008
AUMic	20 45 09.53	-31 20 27.2	00010785009
PKS1302-102	13 05 33.01	-10 33 19.4	00094058003
IC3599	12 37 41.19	+26 42 27.5	00010375013
IC3599	12 37 41.19	+26 42 27.5	00010375015
IC3599	12 37 41.19	+26 42 27.5	00010375017
2MASXJ12475784m5829599	12 47 57.84	-58 29 59.9	00081129001
Mrk684	14 31 04.78	+28 17 14.1	00081165001
AT2018cow	16 16 00.22	+22 16 04.8	00010724106
AT2018cow	16 16 00.22	+22 16 04.8	00010724107
Mrk507	17 48 38.42	+68 42 16.6	00081212004
PKS1143m696	11 45 53.62	-69 54 01.8	00081100001
GRB181010a	03 30 16.89	-23 02 15.4	00866434001
GRB181010a	03 30 16.89	-23 02 15.4	00866434002
PKS0442m28	04 44 37.70	-28 09 54.4	00080964002
GRB181020a	00 55 55.77	-47 22 51.9	00867987000
NVSSJ062335p644538	06 23 35.12	+64 45 36.5	00088793002
V1005ORI	04 59 34.83	+01 47 00.6	00094120004
GRB181202a	18 42 56.38	+27 57 35.0	00874334001
GRB181202a	18 42 56.38	+27 57 35.0	00874334004

Table 3 – *continued* - Sources and observations selected to derive the best-fit boresight for the time period between the second semester of 2017 and the first semester of 2019. The table includes source name, RA and Dec of the optical source position, and sequence number for each observation.

Source name	Right Ascension	Declination	Observation ID
	Semester 2019A		
GRB190106a	01 59 31.16	+23 50 43.9	00882252010
GRB190114a	04 22 10.58	+02 11 28.3	00883600001
GRB190114a	04 22 10.58	+02 11 28.3	00883600003
GRB190114c	03 38 01.16	-26 56 46.9	00883832001
GRB190114c	03 38 01.16	-26 56 46.9	00883832002
GRB190114c	03 38 01.16	-26 56 46.9	00883832012
GRB190114c	03 38 01.16	-26 56 46.9	00883832014
GRB190106a	01 59 31.16	+23 50 43.9	00882252012
GRB190106a	01 59 31.16	+23 50 43.9	00882252013
GRB190106a	01 59 31.16	+23 50 43.9	00882252016
GRB190106a	01 59 31.16	+23 50 43.9	00882252017
GRB190202a	11 06 00.63	+09 22 36.7	00887217003
GRB190204a	23 25 54.58	+54 52 35.1	00887579000
GRB190204a	23 25 54.58	+54 52 35.1	00887579004
GRB190211a	13 06 38.45	+41 58 04.9	00888648001
Mrk1393	15 08 53.95	-00 11 49.0	00088254003
V2400 Oph	17 12 47.00	-24 13 32.0	00088610002
IGR J16547m1916	16 54 43.73	-19 16 31.0	00088622001
GRB190311a	14 08 15.71	+53 30 02.9	00892607001
GRB190311a	14 08 15.71	+53 30 02.9	00892607004
2MASXJ13542913p1328068	13 54 43.40	+13 25 48.0	00081154001
2MASSIJ1830231p731310	18 30 23.16	+73 13 10.7	00088548001
GRB190324a	03 18 27.74	-47 12 52.6	00894718001
GRB190324a	03 18 27.74	-47 12 52.6	00894718009
PQ Gem	07 51 17.32	+14 44 23.8	00088615001
RXJ2044d0p2833	20 44 05.89	+28 32 07.0	00081251001
ESO374mG025	10 03 23.59	-37 23 44.9	00081062001
ESO533 50	22 34 49.82	-25 40 36.9	00080286001