SWIFT-UVOT-CALDB-15-07
Date Original Submitted: 2010-11-04
Prepared by: A. A. Breeveld
Date Revised: 2023-11-14
Revision #7
Revised by: A. A. Breeveld
Sections Changed: most
Comments: Added sliding average to V and U filters and extended for UV. New correction for white filter.

SWIFT UVOT CALDB RELEASE NOTE

SWIFT-UVOT-CALDB-15: Sensitivity loss

0. Summary:

This CALDB product gives a correction for the gradual decline in sensitivity (time-dependent throughput loss; TDTL) for each filter.

1. Component Files:

FILE NAME	VALID DATE	RELEASE DATE	VERSION

2. Scope of Document:

This document includes a description of the product, expected future updates, warnings for the user, a list of data the product is based on and finally the analysis methods used to create the product.

3. Changes:

This is the seventh version of the on-orbit calibration for this product.

- New (~30) observations have been taken since the previous calibration through July 2023 for each filter, for monitoring the decline.
- No new calibration sources have been included or excluded since version 6.
- For the **b** filter the straight line fit has been extended but not changed.
- For the **v** and **u** filters, a new sliding average fit has been merged with the correction factors in the previous caldb release to follow the gradual flattening of the decline in recent years without affecting the previous calibration.
- For the **UV** filters the existing sliding average fits have been extended.
- For the **white** filter the sliding average has been updated covering all time segments since launch.

3.1. CALDB file versions:

Version 1 (swusenscorr20041120v001.fits), released on June 30th 2010 contains correction factors for all filters of 1% per year, as described in **SWIFT-UVOT-CALDB-15-01**. It uses a start time for the decline in sensitivity of day 1826 (Jan 1, 2006) for the visual filters and day 1520 (March 1, 2005) for the UV filters.
Version 2 (swusenscorr20041120v002.fits), released on June 6th, 2012, based on **SWIFT-UVOT-CALDB-15-02,** erroneously set the correction factors for all filters to 1.0 (i.e. no correction for decline in sensitivity).
Version 3 (swusenscorr20041120v003.fits), released on January 18th, 2013, corrects those errors so that the correction factors are as described in **SWIFT-UVOT-CALDB-15-02b** Section 9, and the start date for the decline for all filters is January 1st, 2005.
Version 4 (swusenscorr20041120v004.fits), submitted to Heasarc on 17th July 2015, is updated to take into account new factors for each filter, with quadratic fits fo the UV filters, as described in **SWIFT-UVOT-CALDB-15-03** (Sections 8 and 9). The start date for the decline for all filters is January 1st, 2005.
Version 5 (swusenscorr20041120v005.fits**).** Based on **SWIFT-UVOT-CALDB-15-04.** A quadratic fit was added for the v filter.
Version 5b based on the calibration done in 2018 was never released**.**
Version 6 (swusenscorr20041120v006.fits**)** submitted to Heasarc on 28th Sept 2020 with updates to UV and White filter corrections.
Version 7 (swusenscorr20041120v007.fits) **this version** submitted to Heasarc in December 2023, updated white filter correction and corrections extended for other filters.

3.2.CALDB content:

In versions 1−3 the decline in count rate was set to 1% in most filters, but in the CALDB this was implemented in a compound manner rather than linear. i.e. the correction factor was calculated as (SLOPE**DT rather than 1/(1.0-SLOPE*DT). Up until now the difference in the calculated correction has been negligibly small (e.g. after 10 years the correction was calculated as 1.105 rather than 1.111).

In version 3 this was corrected by using a series of short time intervals to approximate the linear or quadratic model, each with a power-law functional form:

C_corr = C_meas * (1.0 + OFFSET)*(1.0 + SLOPE)**DT

where DT is the time in years since the beginning of the interval. The parameters OFFSET and SLOPE are chosen to match the values of the linear or quadratic model at the beginning and end of each interval. Currently each interval has a duration of one year.

In this version (7), the CALDB file provides updated information for each filter to implement a correction for the decline in throughput, using the above formula

4. Reason For Update:

The **u** and **v** filter sensitivities need updating because the decline is flattening out. The **white** filter sensitivity curve needed slightly adjusting and has been replaced rather than extended. All other filter sensitivities needed extending to the current epoch.

5. Expected Updates:

The throughput is tested annually and may be updated if changes are seen.

6. Caveat Emptor:

7. Data Used:

Photometric standard sources (see *Table 1*) are observed regularly throughput the mission to check for any changes in throughput. For this report all data up to and including 1st August 2023 have been used.

- New (~30) observations have been taken since the previous calibration through July 2023 for each filter.
- No new calibration sources have been included or excluded since version 6.

Source	RA	Dec	v	b	u	uvw1	uvm2	uvw2	white
WD1026+453	10 29 45.3	+45 07 03.0	✓	✓	✓	✓	✓	✓	
WD1121+145	11 24 15.9	+14 13 49.0	✓	✓	✓	✓	✓	✓	✓
WD1657+343	16 58 51.3	+34 18 51.0	✓	✓	✓	✓	✓	✓	✓
SA95–42	03 53 43.66	–00 04 33.9	✓	✓	✓				
SA95–102	03 53 07.58	+00 01 10.3	✓	✓	✓				
SA98–646	06 52 02.23	–00 21 16.6	✓	✓	✓				
SA101–278	09 56 54.50	–00 29 39.0	✓	✓	✓				✓
SA101–L3	09 56 54.99	–00 30 24.8	✓	✓	✓				✓
SA104–244	12 42 34.3	–00 45 47.0	✓	✓	✓				✓
SA104–338	12 42 30.3	–00 38 33.0	✓	✓	✓				✓
SA104–367	12 43 59.0	–00 33 30.0	✓	✓	✓				✓
SA104–443	12 42 20.0	–00 25 22.0	✓	✓	✓				✓
SA104–457	12 42 54.2	–00 28 49.0	✓	✓	✓				✓
PG1525–071	15 28 11.60	–07 16 27.0	✓	✓	✓				
PG1633+099	16 35 24.0	+09 47 47.0	✓	✓	✓				
P177D	15 59 13.6	+47 36 41.8			✓	✓	✓	✓	
P041C	14 51 58.2	+71 43 17.3				✓	✓	✓	
G24–9	20 13 55.68	+06 42 44.9	✓	✓					
SDSS J0834+5336	8 34 21.22	+53 36 15.59				✓	✓	✓	✓
SDSS J1344+0324	13 44 30.12	+3 24 23.19				✓	✓	✓	✓
SDSS J1500+0404	15 00 50.71	+4 4 30.01				✓	✓	✓	✓
SDSS J2358-1034	23 58 25.80	-10 34 13.21				✓	✓	✓	✓

Table 1 Standard sources for monitoring throughput. (Note: PG1525-071 data are no longer included)

All the relevant data on these sources were downloaded from the Swift archive at HEASARC. Important keywords in each sky file and also the *uct.hk files were checked for any problems like ‘shift and toss’ loss, which could affect exposure times.

Not all the data were processed with the same version of uvot2fits and the keywords were not all available for the earlier versions. The oldest reprocessing of data used here was uvot2fits 3.8 and the most up-to-date was uvot2fits 3.36

8. Description of Analysis:

For each star, region and background files were made using 5" aperture for the sources and 27.5 – 35" annulus for the background. Each exposure was checked visually for any problems e.g. aspect correction not being applied correctly, or the images being smudged by drift. Where necessary the aspect correction was redone, or the exposure was discarded.

For the first time in this version, the `FTOOLS` were able to automatically check if the raw coordinates of the source fell on the position of any of the small areas of low sensitivity (see uvotcaldb_sss_02b.pdf). Any sources failing the SSS check have been excluded. The most aggressive screening was used in `uvotmaghist`:

```
uvotmaghist lssfile=CALDB sssfile=CALDB ssstype=HIGH
```

The fully corrected count rates (and errors) of the sources were extracted for each exposure and recorded in an excel spreadsheet. The co-incidence corrected count rates (COI-SRC_RATE) and LSS corrected (LSS_RATE) count rates, errors and background were recorded. Weighted means were calculated for those cases where there was more than one extension, i.e., when several exposures were taken on the same day. The weighted means were used in the TDTL fits and plots (in the case of the white filter the count rates were first corrected for the background count rate which can vary from exposure to exposure, see below).

The count rates are normalised using the mean count rate for each star in each filter in exposures taken within the first 500 days, assuming a start date of Jan 1st 2005 (time 00:00), close to when observations began. For stars not observed until after day 500, a factor taken from the initial fit is used to correct the starting value. This allows all stars to be plotted together, with the expected throughput value for the beginning of the mission for each star being 1.0. Where the fitted line does not go exactly through 1.0, the points are re-normalised to ensure this parameter is 1.0. Standard stars only observed at the beginning of the mission, and not re-visited, have not been included.

The TDTL plots for each filter are shown at the end of this report. *Figures 1-3* show the **optical** data and *Figures 4-6* the **UV** data. The **white** is shown in *Figures 7-9*. The preference for a quadratic curve rather than linear for the **v** filter is illustrated in *Figure 10*.

8.1. White filter:

There is a large scatter in the **white** data, some of which can be attributed to high background count rates, i.e. the failure of the coincidence correction to cope with high backgrounds. The correction for this was devised in 2010 using early data from two white dwarfs only, and re-measured in 2018 using data from all the standard stars. The count rates were corrected first for TDTL, then plotted against background count rate (see *Figures 8 and 9*). Only the white filter suffers from backgrounds high enough to cause a problem.

A correction for the loss of counts with background was devised from these data:

$$Truects = \frac{Meascts}{1-0.509 \times bkgnd} \qquad (1)$$

where *bkgnd* is in cts/s/arcsec^2 (COI_BKG_RATE). Since the background is not necessarily the same for all the exposures taken on one day, the exposures have to be treated separately, and then averaged. The TDTL for white was re-calculated after making this correction. Corrected count rates are used in *Figure 7.*

9. Correcting the measured count rates for TDTL:

For **b** (*Figure 2)* the normalised data are fitted with a weighted straight-line fit. The data for each individual star are also fitted with a weighted straight-line fit, and then the results averaged. The straight-line fit for this calibration is consistent with the previous release and is therefore unchanged.
To correct the measured count rate C_{meas} to the corrected C_{corr} the following equation should be used:

$$\boldsymbol{C_{corr}} = \frac{\boldsymbol{C_{meas}}}{\boldsymbol{(1-R\times t)}} \qquad (1)$$

where *t* is the time in years since launch and *R* is the rate of decline (For **b** R=0.0092).

For the **u** (*Figure 3*) filter a straight line fitted well until the last few years but now the rate of the decline is slowing slightly. The correction has therefore been extended beyond the straight-line using a sliding average.

A quadratic curve was required for **v** (*Figure 1*) but the as with **u**, the decline is slowing faster than predicted by the fitted curve, meaning that the latest correction would be ~1.5% off without an update. The correction has therefore been extended beyond the quadratic fit using a sliding average.

For the **white** and **UV** filters (*Figure 4–7*), a smoothed sliding average has been used as in the previous release. The sliding average has been extended for the **UV** filters, but completely replaced for the **white** filter because an error was found in the normalisation of one of the sources at early times that has affected the correction by a few percent.

For all filters the correction is kept constant after a certain point when there is insufficient data to know how the correction will change.

In all cases the TDTL is determined starting from 2005-01-01T00:00. The CALDB uses a series of short time intervals to approximate the correction curve, each with a power-law functional form:
C_corr = C_meas * (1.0 + OFFSET)*(1.0 + SLOPE)**DT

Table 2 Comparing the percentage loss in sensitivity corrected with the previous CALDB correction (v.006) and this version (v.007). Values that are different from the previous version are highlighted in yellow.

	Days since launch	Loss (%) using CALDB v.006	Loss (%) using CALDB v.007
V @ 5 years	1825	7.9	7.9
@ 10 years	3650	13.7	13.7
@ 15 years	5475	17.2	16.6
@ 18 years	6570	18.3	16.6
B @ 5 years	1825	4.6	4.6
@ 10 years	3650	9.2	9.2
@ 15 years	5475	13.8	13.8
@ 18 years	6570	16.6	16.6
U @ 5 years	1825	5.0	5.0
@ 10 years	3650	9.9	9.9
@ 15 years	5475	14.9	14.9
@ 18 years	6570	17.8	15.3
uvw1 @ 5 years	1825	3.5	3.5
@ 10 years	3650	14.2	14.2
@ 15 years	5475	21.0	21.0
@ 18 years	6570	22.1	22.7
uvm2 @ 5 years	1825	4.2	4.2
@ 10 years	3650	15.4	15.4
@ 15 years	5475	21.3	21.3
@ 18 years	6570	21.2	22.1
uvw2 @ 5 years	1825	4.2	4.2
@ 10 years	3650	19.6	19.6
@ 15 years	5475	27.4	27.4
@ 18 years	6570	29.1	29.2
white @ 5 years	1825	5.6	5.2
@ 10 years	3650	11.3	10.7
@ 15 years	5475	14.9	14.6
@ 18 years	6570		15.3

10. Figures:

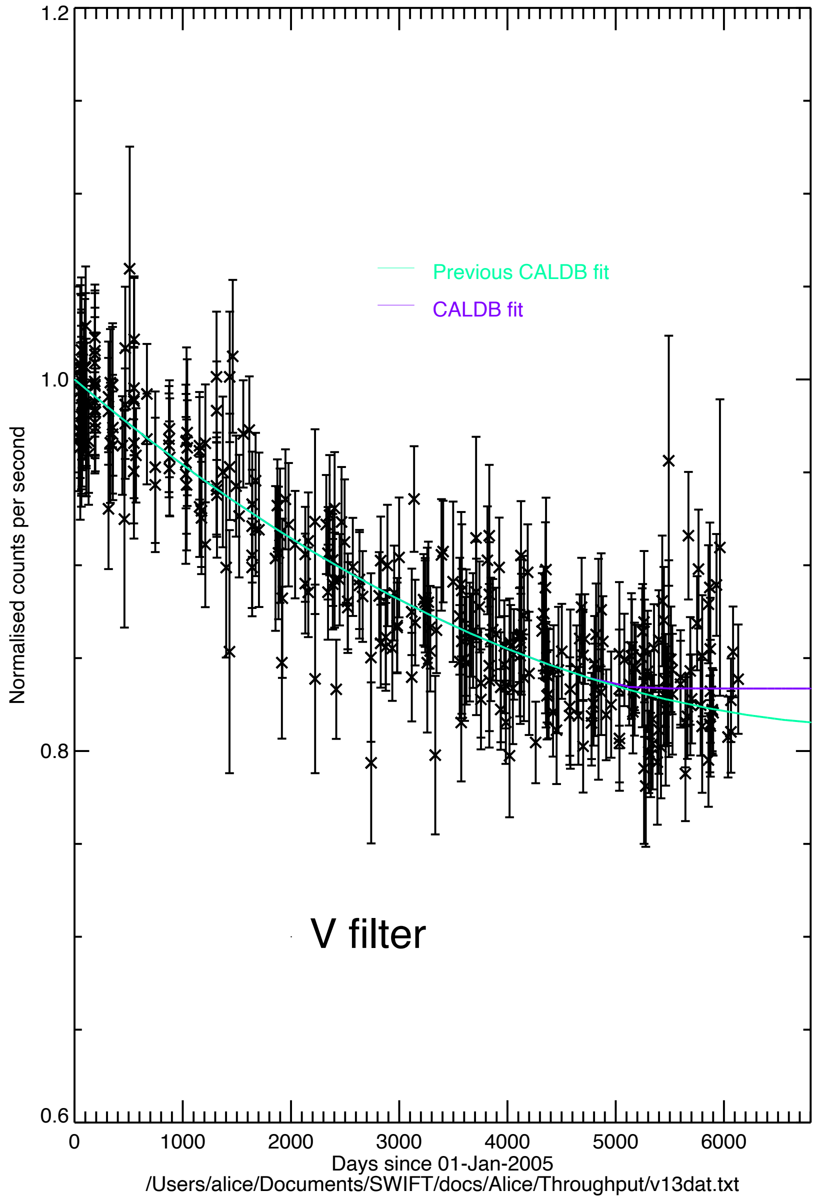

Figure 1 Count rates of standard stars in the v filter, against days since 1st Jan 2005, normalised to the count rates within the first 500 days. Purple line: quadratic curve until day 4745 then merged with a sliding average fit to follow the observed flattening of the decline. Green line: CALDB v.006.

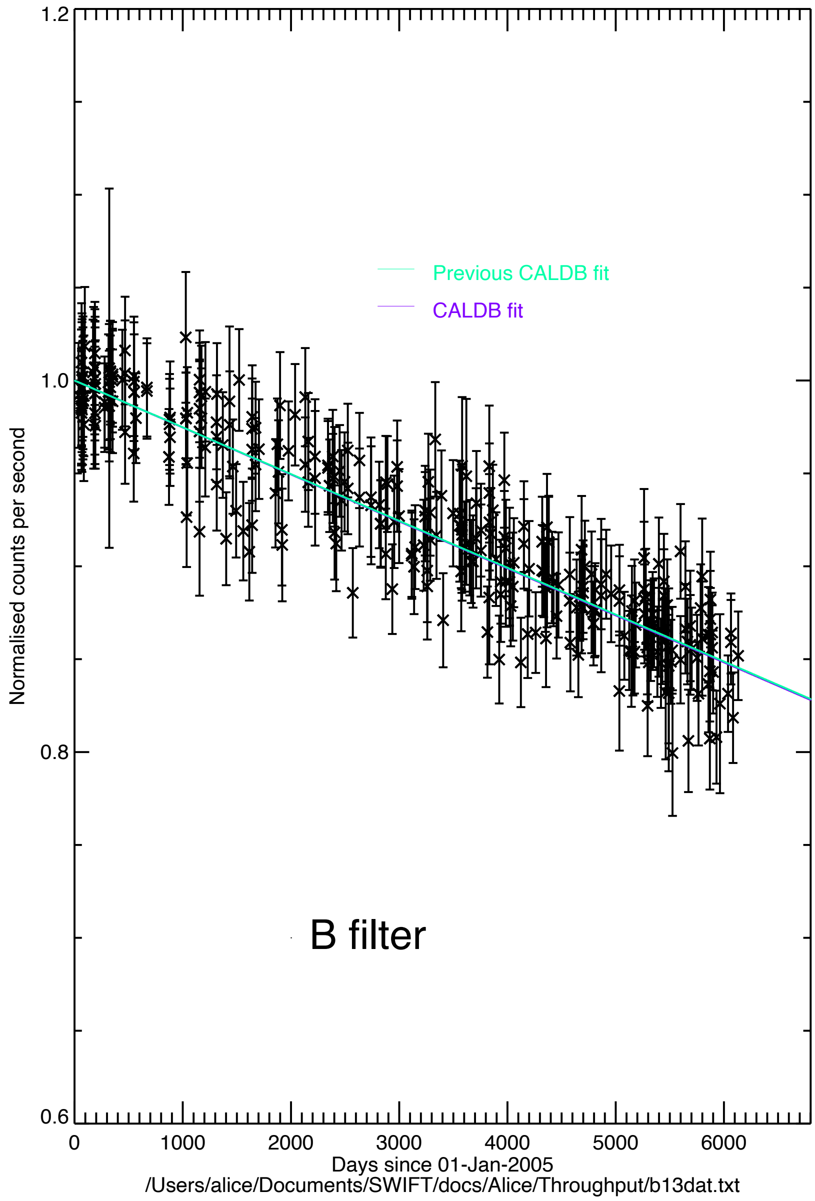

Figure 2 Count rates of standard stars in the b filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a straight line and compared with CALDB v.006. (The green and purple lines are on top of one another)

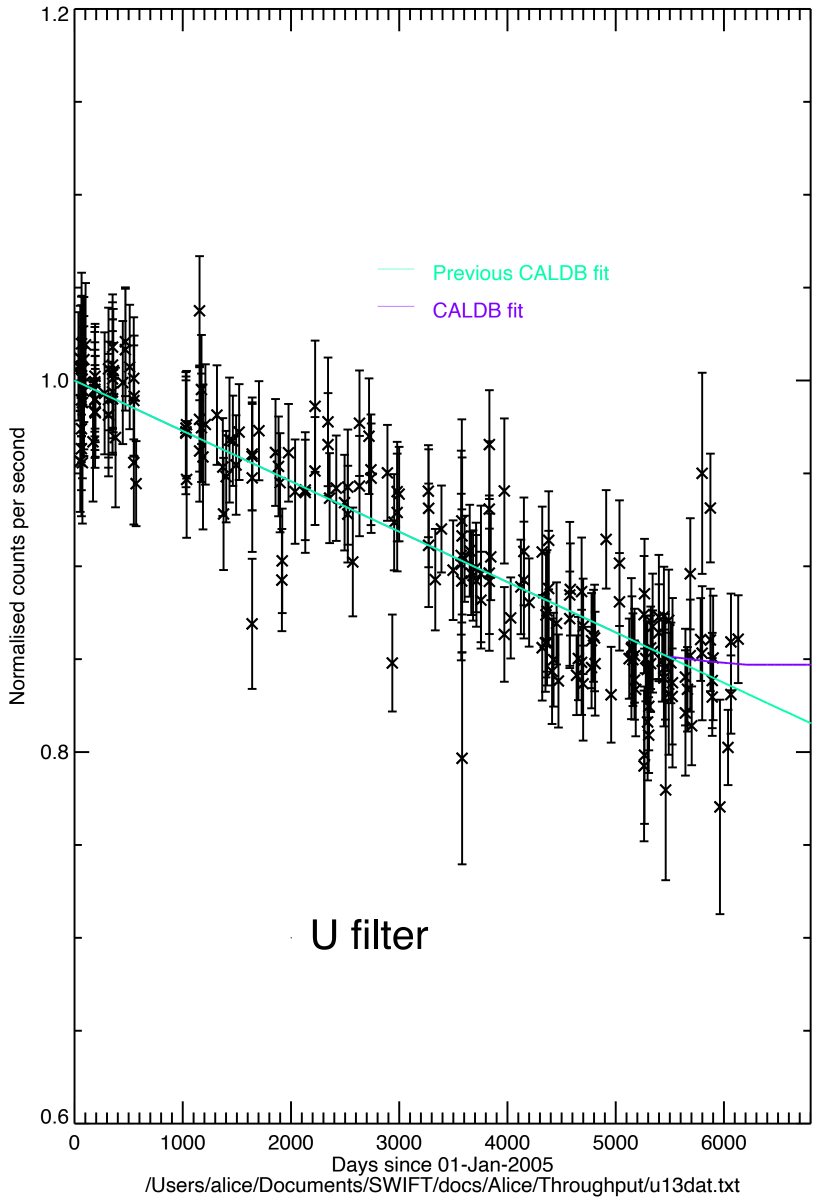

Figure 3 Count rates of standard stars in the u filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, Purple line: straight line until day 5475 then merged with a sliding average fit to follow the observed flattening of the decline. Green line: CALDB v.006.

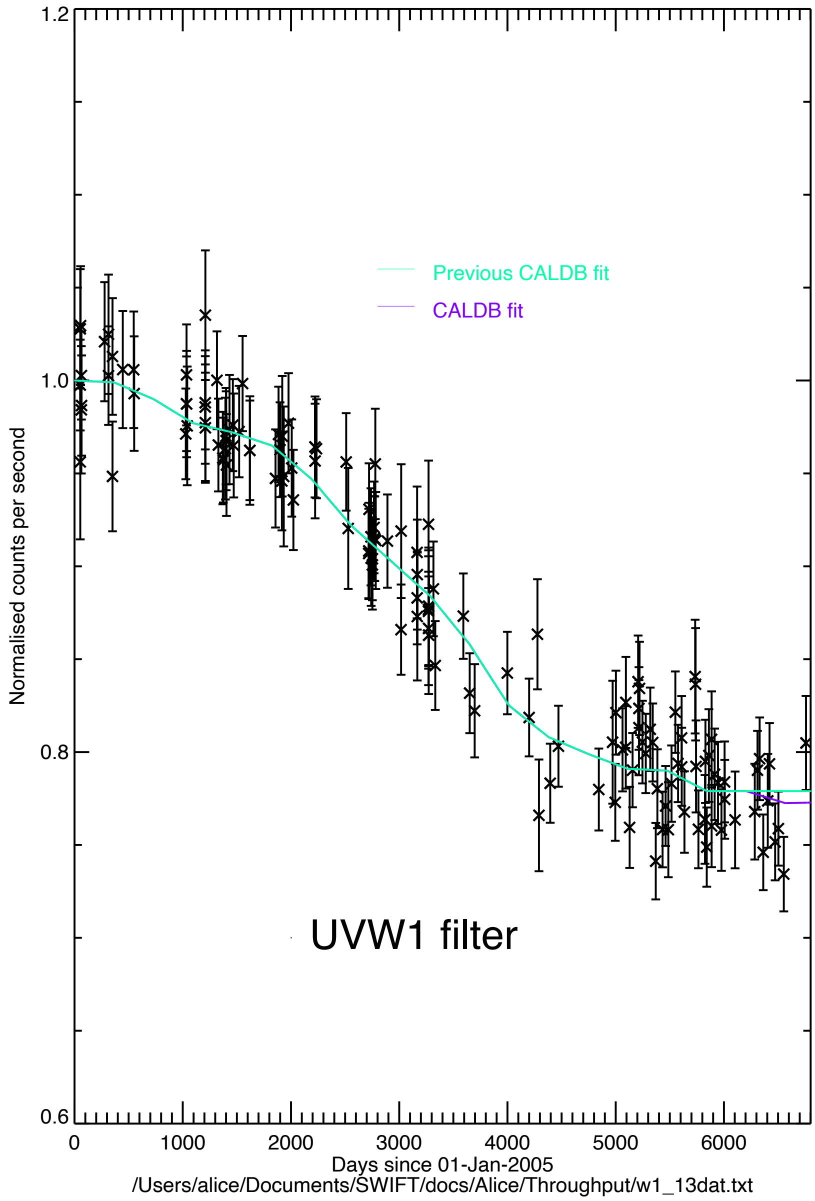

Figure 4 Count rates of standard stars in the uvw1 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a smoothed sliding average (Purple line) and compared with CALDB v.006 (Green line).

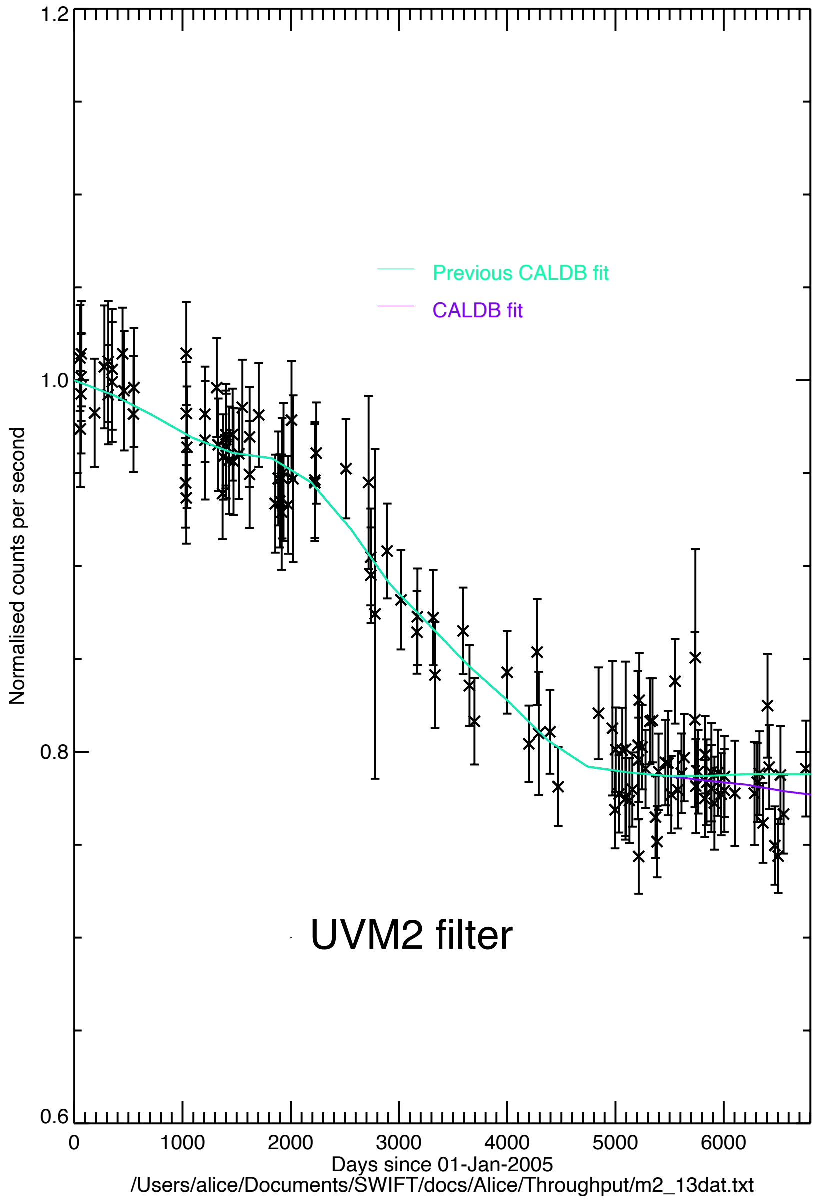

Figure 5 Count rates of standard stars in the uvm2 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a smoothed sliding average (Purple line) and compared with CALDB v.006 (Green line).

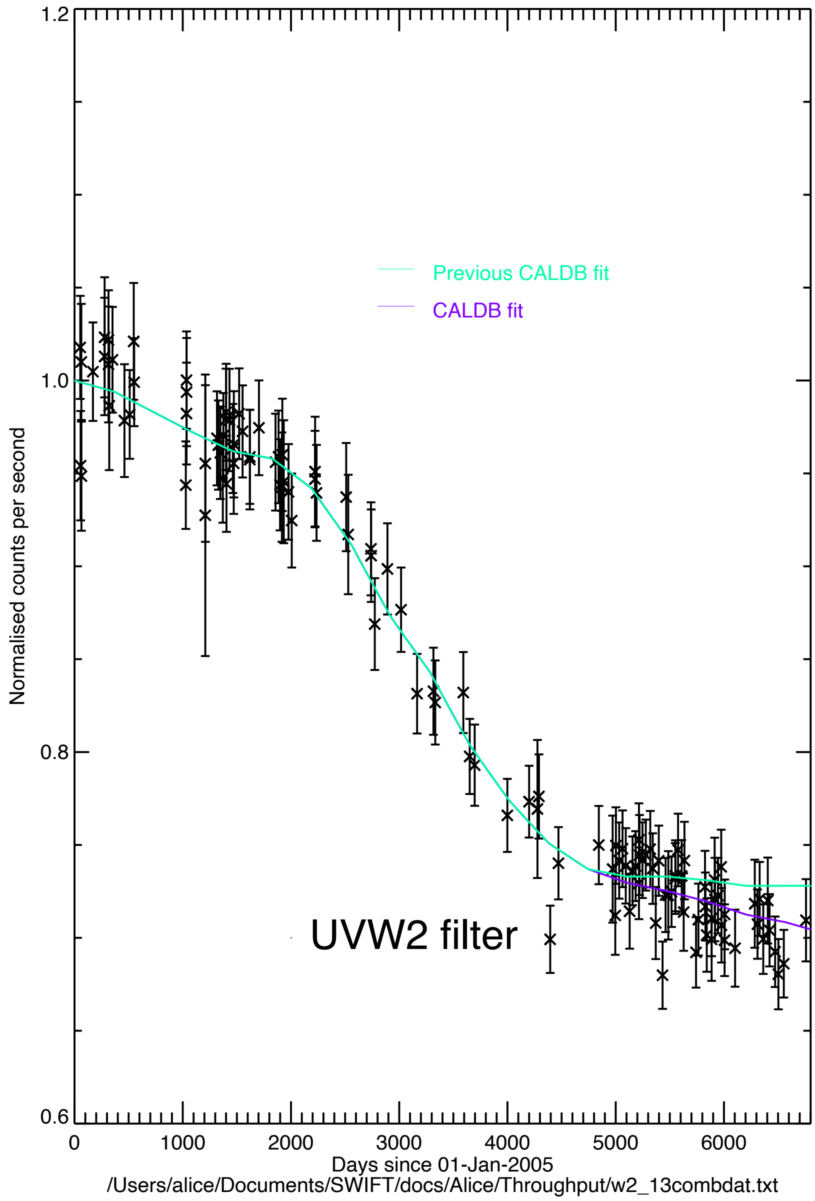

Figure 6 Count rates of standard stars in the uvw2 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a smoothed sliding average (Purple line) and compared with CALDB v.006 (Green Line).

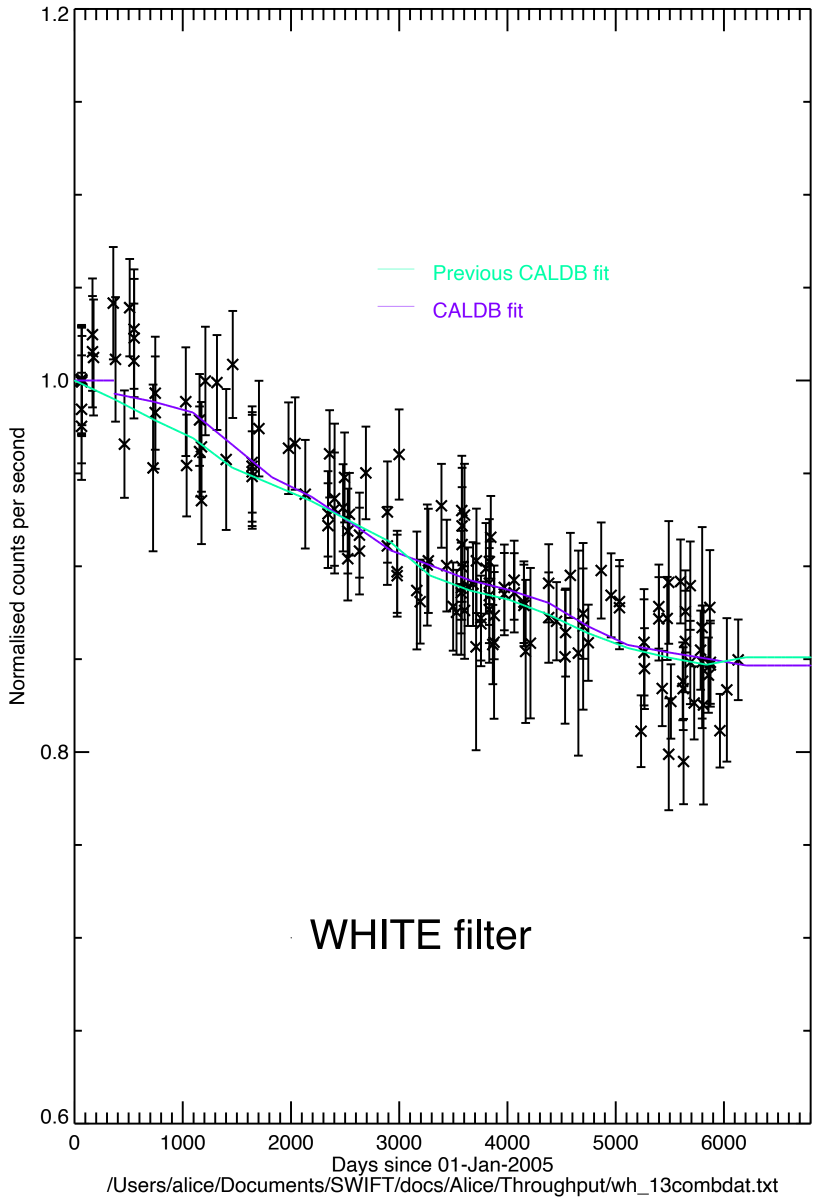

Figure 7 Count rates of standard stars in the white filter, corrected for background count rate (using equation 1) and normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a smoothed sliding average (Purple line) and compared with CALDB v.006 (Green line).

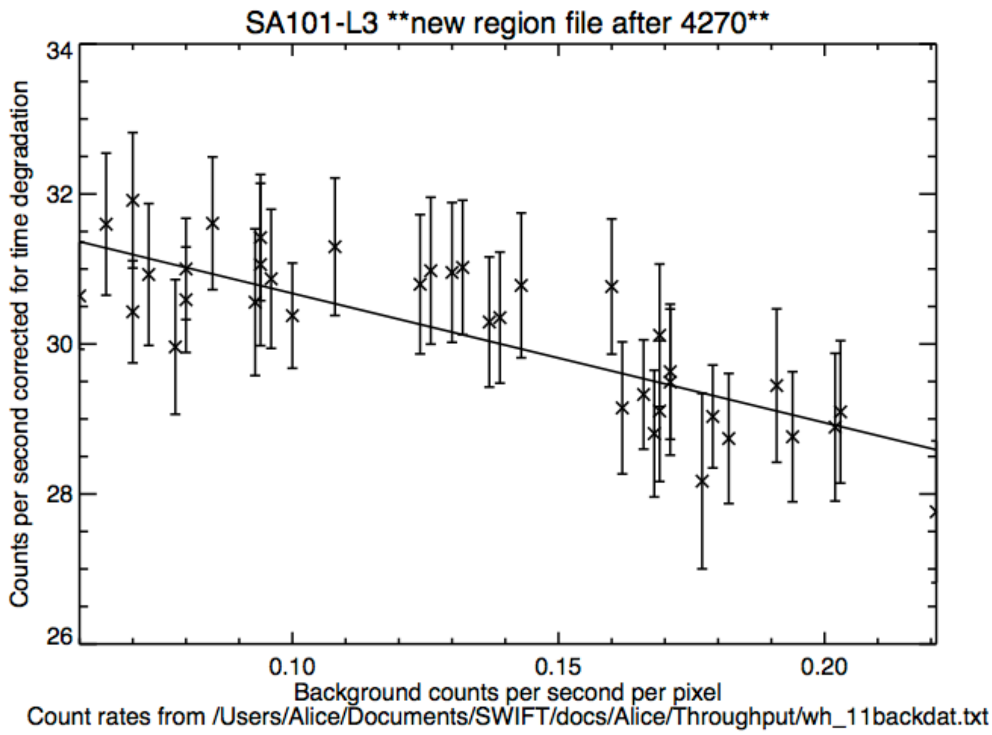

Figure 8 An example using SA101-L3 showing how count rates in the white filter are strongly affected by the background level

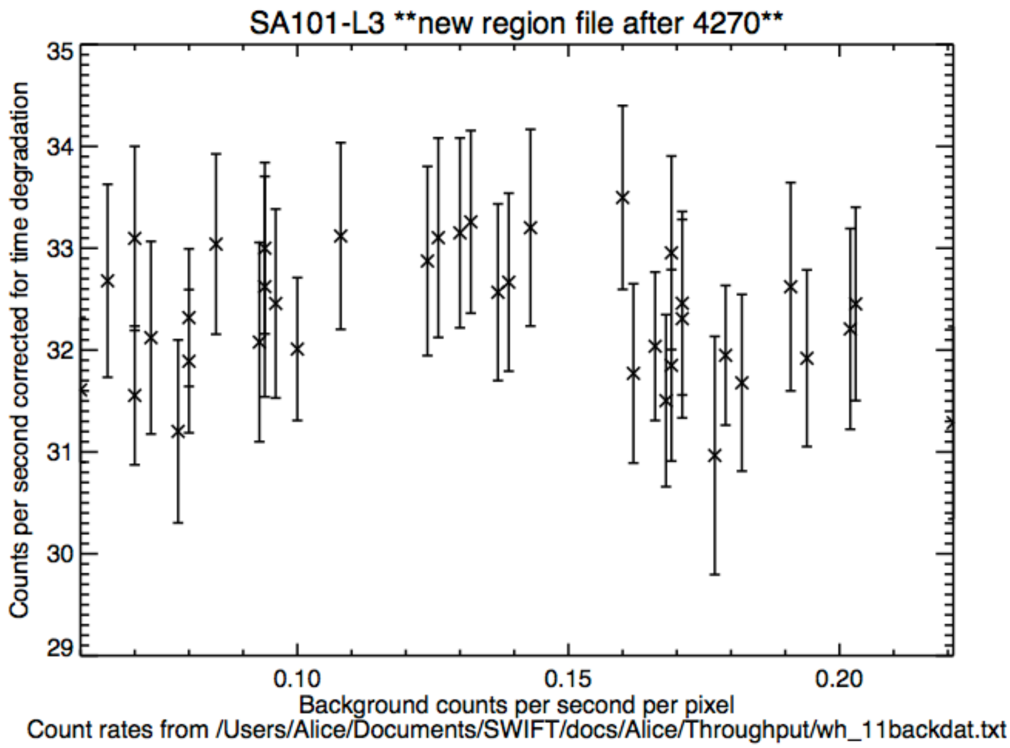

Figure 9 An example using SA101-L3 showing the count rates corrected for high background in the white filter.

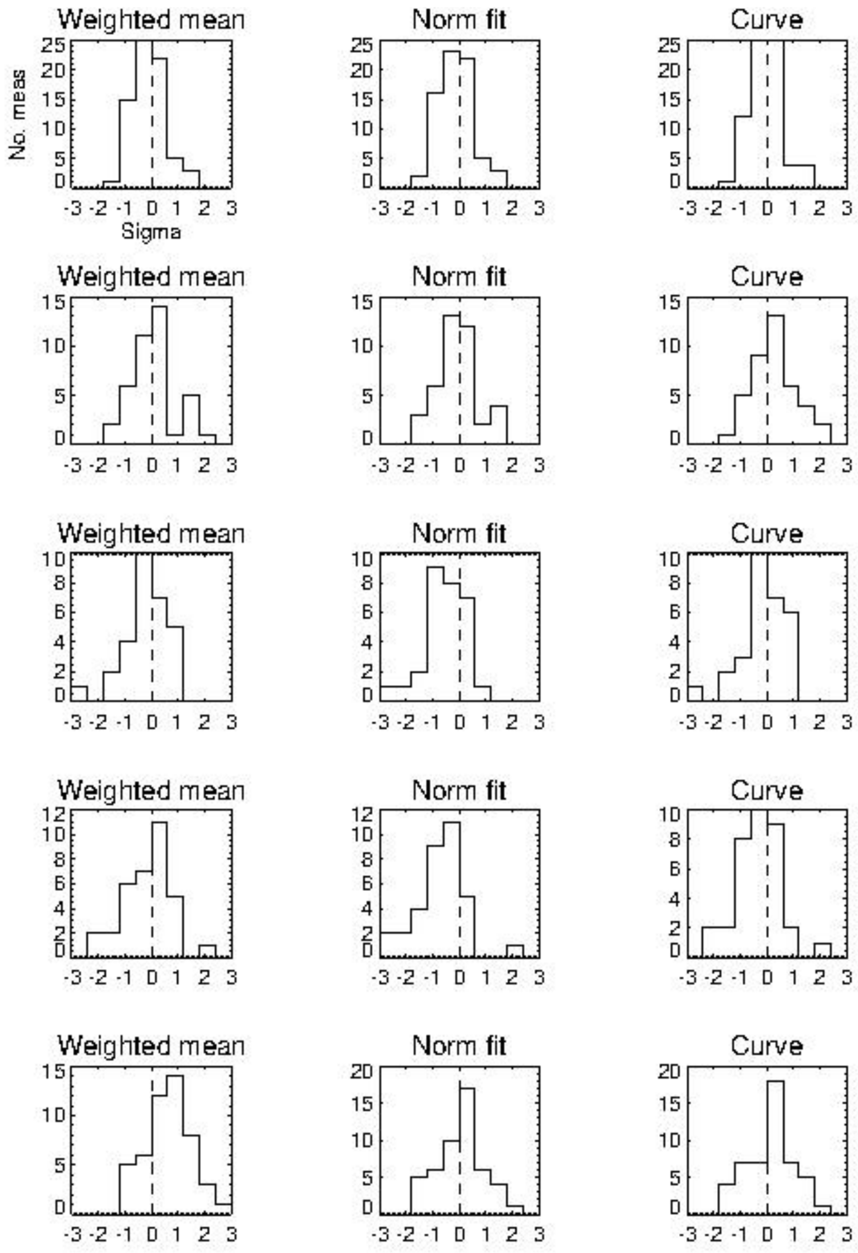

Figure 10 V filter: histograms showing the distance in standard deviations of each measurement from the weighted mean fit (left column), the normalised fit (middle) or the curve (right hand column). The data were divided into 5 time bins with the earliest one at the top.