SWIFT-UVOT-CALDB-15-06
Date Original Submitted: 2010-11-04
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Revision #6
Revised by: A. A. Breeveld
Sections Changed: most
Comments: Changing to sliding average for UV and white filters.

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 sixth version of the on-orbit calibration for this product. The sensitivity loss for the optical filters is still consistent with the last version of the calibration, but the **UV filters** and **white** calibration has changed.

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 6 (swusenscorr20041120v006.fits**) this version** submitted to Heasarc on 28th Sept 2020.

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 (6), the CALDB file for each filter provides information to implement the best fit linear models in *Table 2* for the B, U, a quadratic fit in *Table 3* for V, and smoothed sliding average fits for White, UVW1, UVM2 and UVW2.

4. Reason For Update:

The **UV** filter sensitivities need updating because the decline is flattening out.

5. Expected Updates:

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

6. Caveat Emptor:

7. Data Used:

Several photometric standard sources (see *Table 1*) have been observed from time to time throughput the mission to check for any changes in throughput. For this report all data up to and including August 2020 have been used.

- More data points have been added during the last two years to August 2020 particularly in the UV.
- Some sources have been included for the first time:
  UV new sources: P177D, P041C, SDSS J134430.11 and SDSS J235825.80 (the latter two from Siegel et al, (2010) ApJ, Vol 725, Issue 1, pp. 1215-1225);
  Optical new sources: SA98-646 and SA104-457 (used for the original calibration but until recently too few points to measure the decline).
- PG1525-071B has been *excluded* for all filters this time because it is in a crowded field and consistently shows peculiar results.
- A new sliding average fit has been used for the **UV** and **white** filters to more closely follow the gradual flattening of the decline curve since day ~4,500 during 2017.

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 is uvot2fits 3.8 and the most up-to-date is uvot2fits 3.34.

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.

The raw coordinates of each source measurement were checked to see whether they fell on the position of any of the small areas of low sensitivity. All these measurements have been excluded.

Using UVOTMAGHIST (with LSSfile=CALDB), 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 those with LSS correction (LSS_RATE) 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 were 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 was used to correct the starting value. This allowed 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 were 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 for the **v** filter is illustrated in *Figure 10*.

For **b** and **u** the normalised data were fitted with a weighted straight-line fit, shown in the *Figures 1-3* and *Table 2*, and also the stars were fitted individually and then the results averaged (Pink line in *Figures 1-3*). For the **b** and **u** filters the straight line fits well, but a quadratic curve is required for **v** (*Table 3*). For the **white** and **UV** filters, a smoothed sliding average has been used for the first time in this version (2020).

Filter	**loss per year**
B	0.0092 ± 0.0005
U	0.0099 ± 0.0010
White (bkgnd corrected, see section 8.1)	0.0123 ± 0.0009

Table 2 The observed change in throughput per year using a linear fit.

Parameters:	Param[0]	Param[1]	Param[2]
UVW1	1.0	−0.0125844	−0.00021754
UVM2	1.0	−0.0149401	−5.80281e-05
UVW2	1.0	−0.0177331	−0.00016490
V	1.0	−0.0184223	0.000469391

Table 3 Fitting a quadratic curve gives these parameters where the (normalised) count rate (c) at a time t (yrs) is given by $c=param[2]t^2+param[1]t+param[0]$, where t is zero on 1st Jan 2005

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:

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

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:

In each case the normalised data have been fitted with a weighted straight-line fit or a quadratic curve, shown in the figures. The fits for **v**, **b, u** this year are all still consistent within 1.5 % of the previous CALDB correction, (swusenscorr20041120v005.fits), but the **uv** and **white** filters need to be changed, see *Table 4*

For **b** and **u**: to correct the measured count rate C_{meas} to the corrected C_{corr} in the linear case the following equation should be used:

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

where *t* is the time in years since launch and R is the rate of decline given *in Table 2*.

For **v** the following should be used:

$$C_{corr} = \frac{C_{meas}}{(1 + param[1] \times t + param[2] \times t^2)}$$

where *t* is the time in years and *param*[1] and *param*[2] are given *in Table 3*.

For **white**, **uvw1**, **uvm2** and **uvw2**, the smoothed sliding average correction is given as an array.

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

	Loss (%) using CALDB v.005	**Loss (%) using CALDB v.006**
uvw1 @ 5 years	3.4	4.6
uvw1 @ 10 years	15.4	14.6
uvw1 @ 14 years	31.4	26.4
uvm2 @ 5 years	4.6	5.8
uvm2 @ 10 years	15.9	15.0
uvm2 @ 14 years	29.9	24.7
uvw2 @ 5 years	4.3	5.4
uvw2 @ 10 years	18.5	18.4
uvw2 @ 14 years	36.9	34.4
v @ 5 years	7.9	7.9
v @ 11 years	13.7	13.7
v @ 14 years	16.7	16.8

Table 4 The magnitude (in percent) of the correction which would be applied using this version or the previous version.

10. Figures:

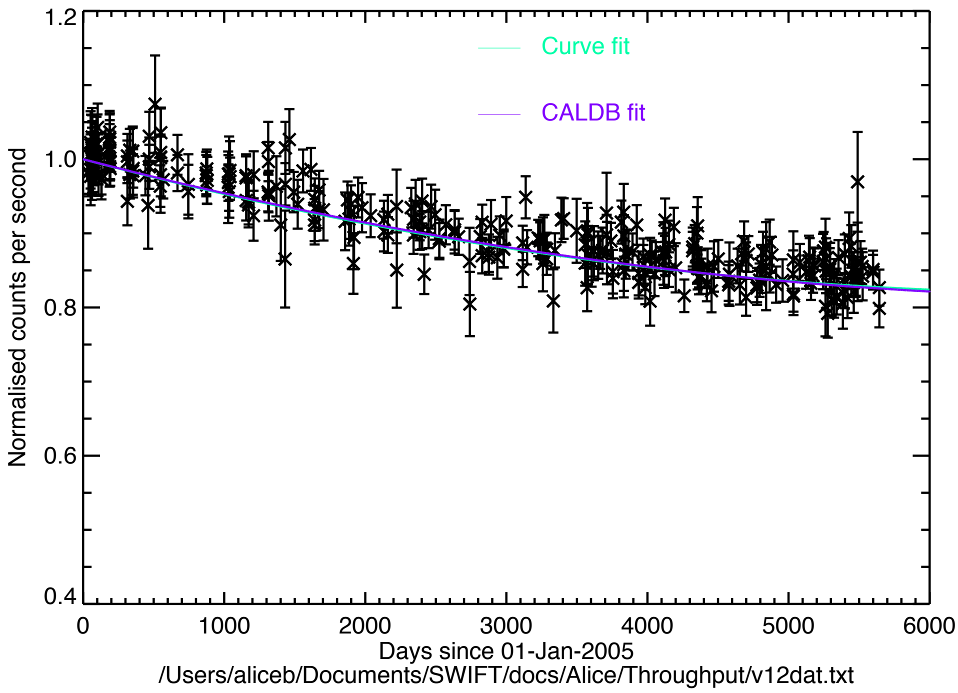

Figure 1 Count rates of standard stars in v filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a quadratic and compared with CALDB v.005. (The two curves are more-or-less on top of one another)

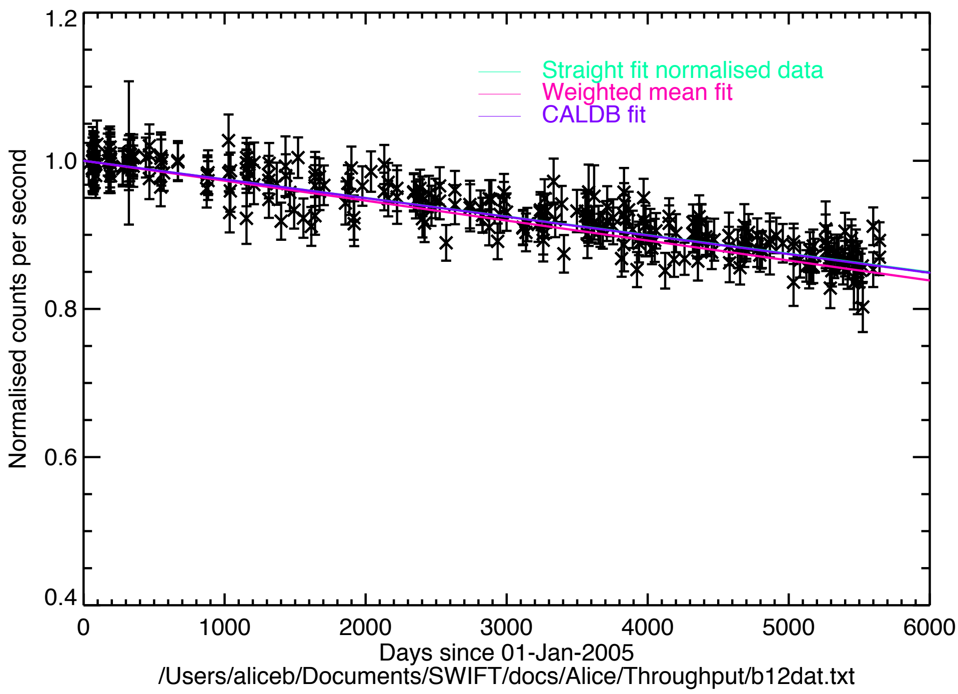

Figure 2 Count rates of standard stars in b filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a straight line and compared with CALDB v.005. (The green and purple lines are on top of one another)

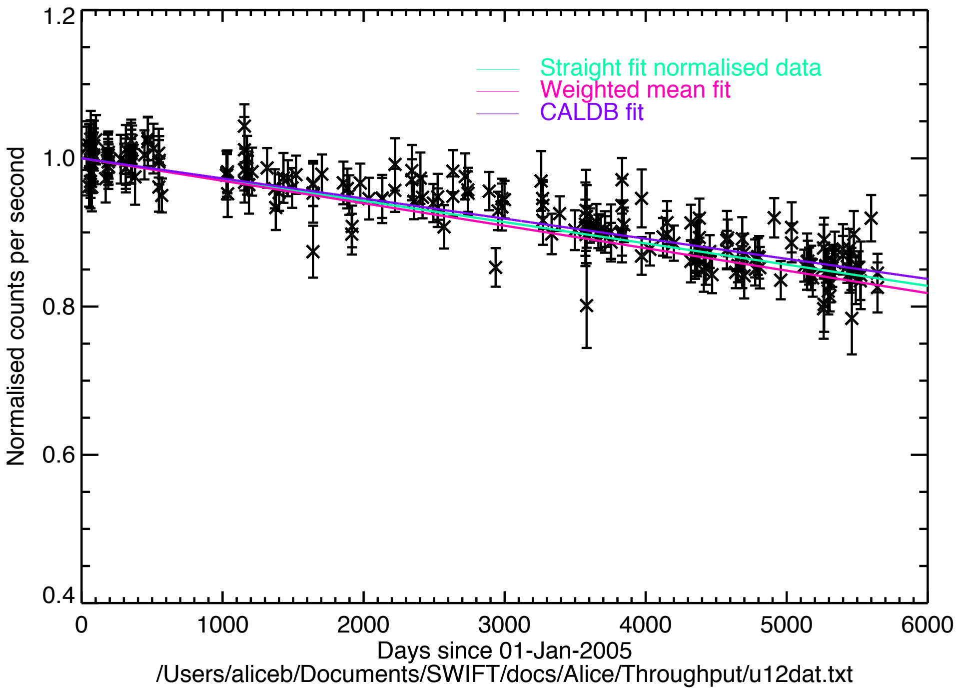

Figure 3 Count rates of standard stars in u filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a straight line and compared with CALDB v.005.

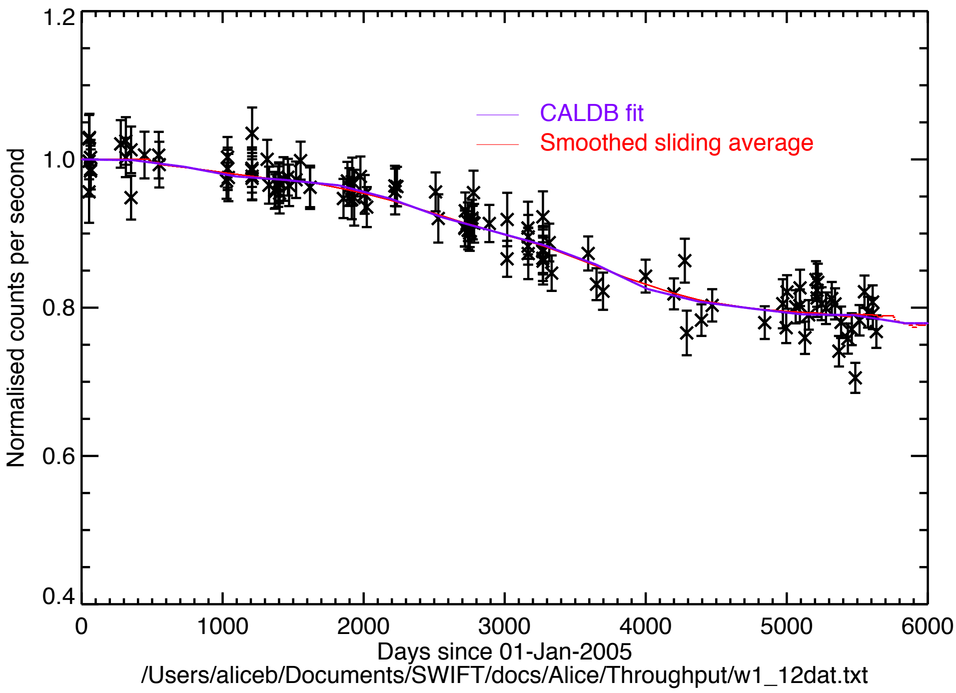

Figure 4 Count rates of standard stars in uvw1 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a smoothed sliding average and compared with CALDB v.006.

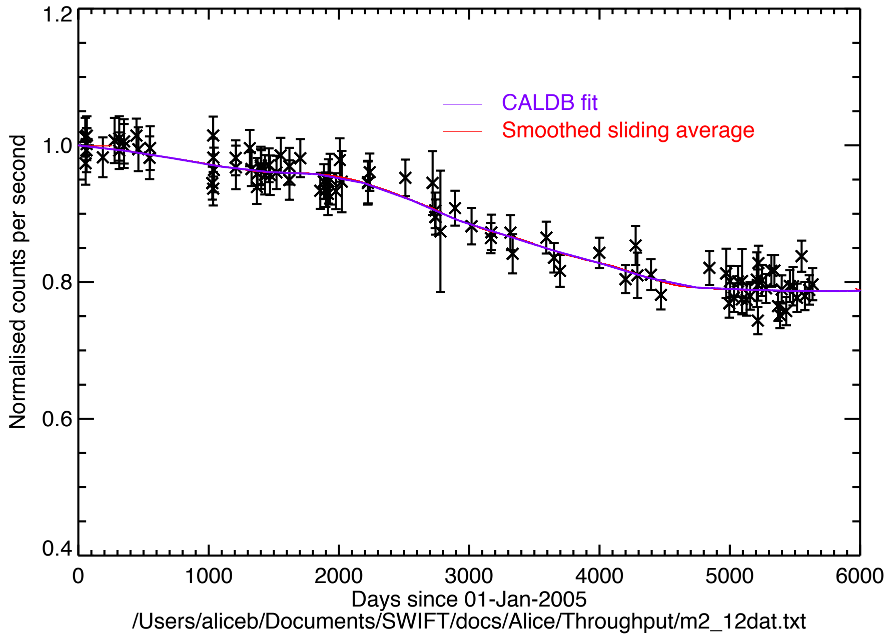

Figure 5 Count rates of standard stars in uvm2 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a smoothed sliding average and compared with CALDB v.006.

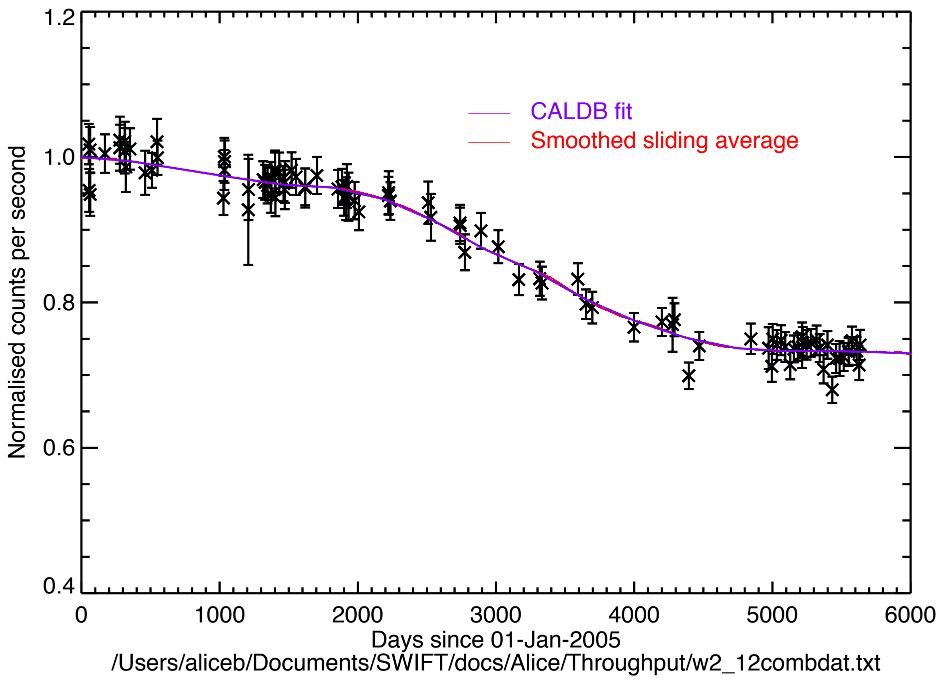

Figure 6 Count rates of standard stars in uvw2 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a smoothed sliding average and compared with CALDB v.006.

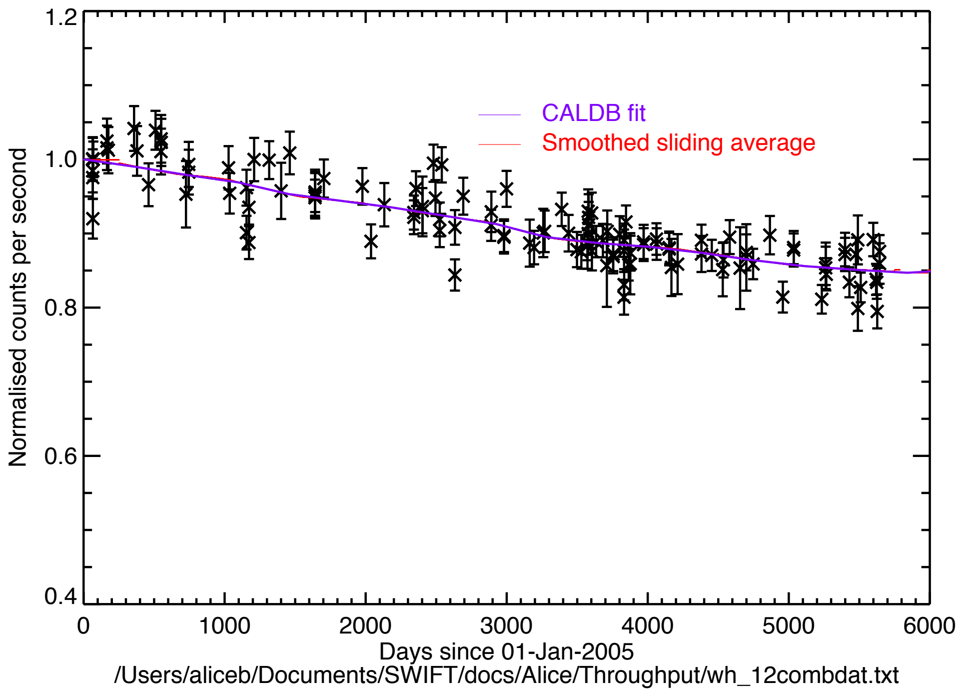

Figure 7 Count rates standard stars in the white filter, corrected for background count rate (using equation 1) and normalised to the count rates within the first 500 days, against days since 1st Jan 2005, fitted with a smoothed sliding average and compared with CALDB v.006.

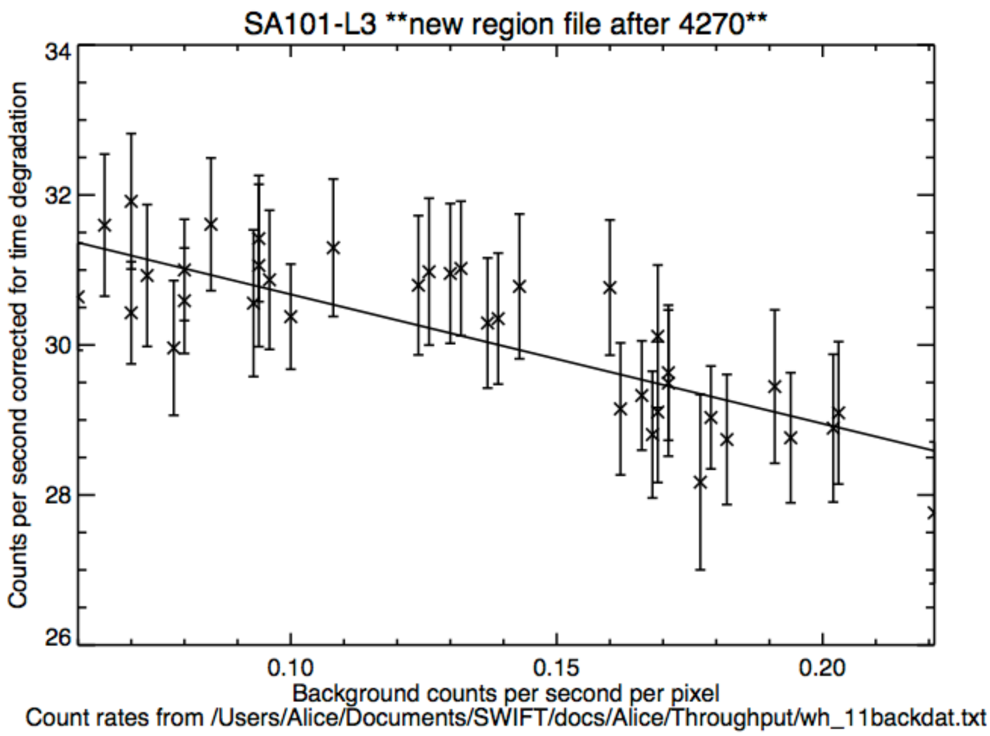

Figure 8 An example using SA101-L3 showing how count rates in the white filter are strongly affected by the background level

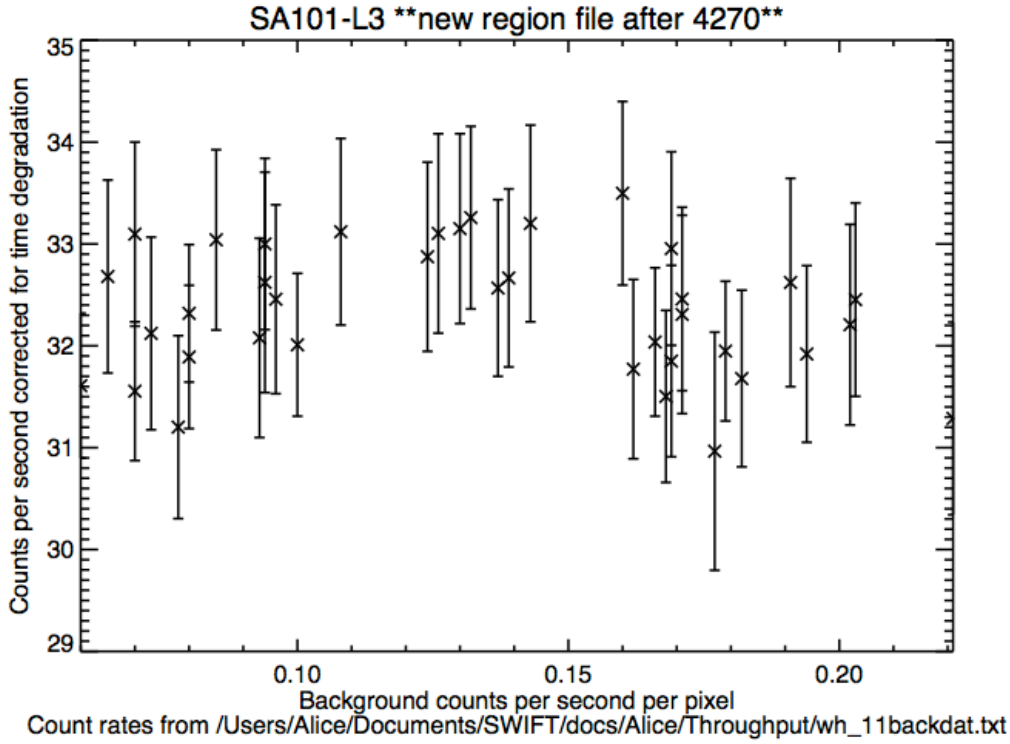

Figure 9 An example using SA101-L3 showing the count rates corrected for high background in the white filter.

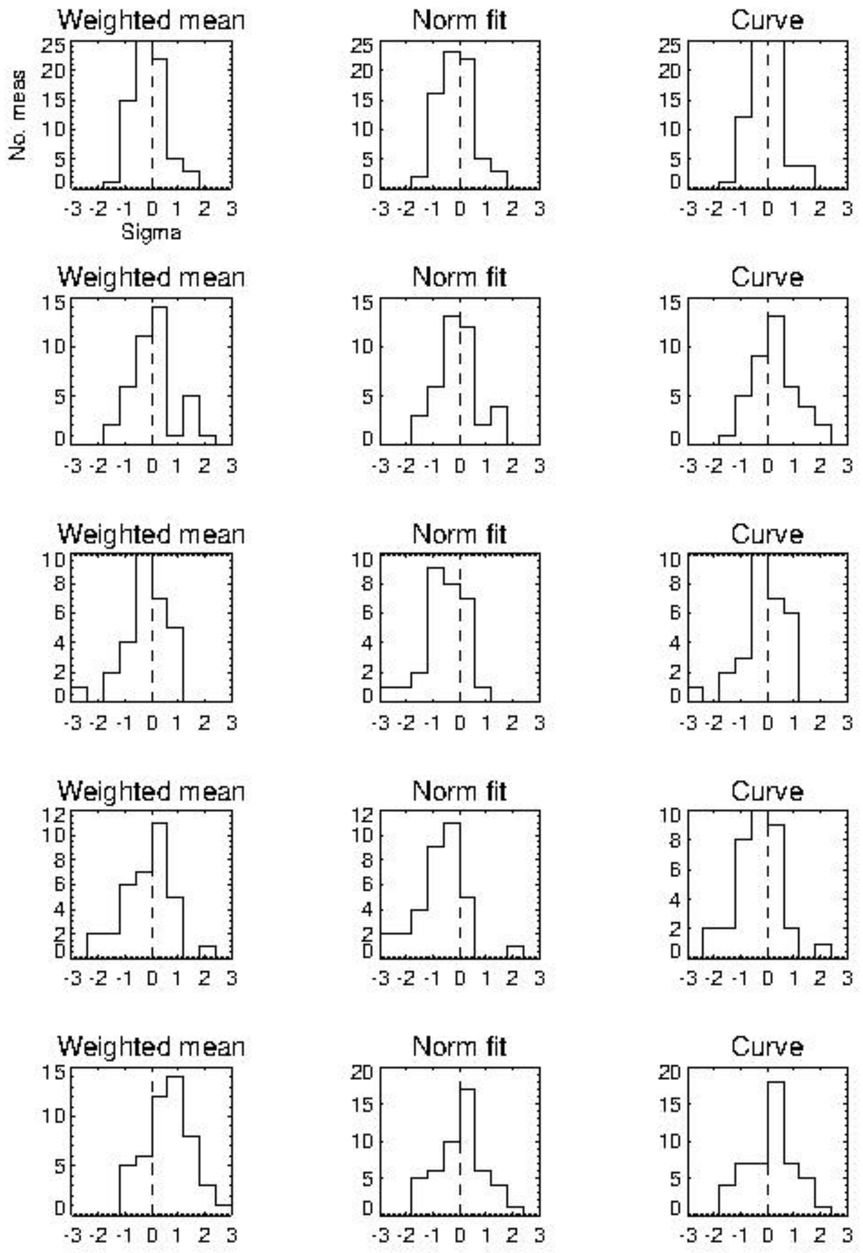

Figure 10 V filter: histograms showing the distance in standard deviations of each measurement from the weighted mean fit (left column), the normalised fit (middle) or the curve (right hand column). The data were divided into 5 time bins with the earliest one at the top.