SWIFT-UVOT-CALDB-15-04
Date Original Submitted: 2010-11-04
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Revision #4
Revised by: A. A. Breeveld
Sections Changed: 3,4,7,8,9,10
Comments: Fourth update – changing V correction to a quadratic curve.

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 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 fourth update of the on-orbit calibration for this product. The sensitivity loss for the most filters is still consistent with the last version of the calibration, but for the **V** filter the correction needs to be changed from linear to quadratic.

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 the previous version of this document (**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 the new factors are 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**) this version.** Based on **SWIFT-UVOT-CALDB-15-04.**

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 4 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.

Also in version 4 different parameters were introduced for each filter, and quadratic fits for the UV filters.

In this version, the CALDB file for each filter provides information to implement the best fit linear models in *Table **2*** for the B, U and White filters, and the quadratic fits in *Table **3*** for V, UVW1, UVM2 and UVW2.

4. Reason For Update:

The V filter sensitivity is no longer consistent with the linear decline given in the previous versions.

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 March 2016 have been used.

The new white dwarf standards from SDSS (Siegel et al, ApJ, Vol 725, Issue 1, pp. 1215-1225 (2010)) have been included for the first time for the **white** filter although two didn't have enough points to be usable.

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.

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. However, not all the data have been 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 3.33.

8. Description of Analysis:

For each star, we made region and background files using the 5" aperture for the stars and 27.5 – 35" annulus for the background. We checked each exposure 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 where unsuccessful, a special set of region files devised for that particular exposure.

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. 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 LSS corrected count rates or weighted means were used in the fits and plots (except in the case of the white filter, where the background count rate can vary from exposure to exposure, affecting the resulting count rate, 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, 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 allows all stars to be plotted together, with the expected 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 plots for each filter are shown at the end of this report. Figure 1 to Figure 3 show the **optical** data and Figure 4 to Figure 6 the **uv** data. The **white** is shown in Figure 7 to Figure 10. New quadratic fits are explored in Figure 11 to Figure 13.

In each case the data were fitted with a weighted straight-line fit, shown in the plots. The parameters for the **uv** filters, **b**, **u** and **white** have not changed much since the previous release, but for the **v** filter a straight line is no longer a good fit and a quadratic is required (see Section 9 for the formulation). The linear fit parameters are shown in *Table **2*** and the quadratic fit parameters in *Table **3***.

Filter	**% loss per year**
B	0.92 ± 0.05
U	0.99 ± 0.10
White (bkgnd corrected, see section 8.1)	1.23 ± 0.09

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

Parameters:	**Param[0]**	**Param[1]**	**Param[2]**
UVW1	1.0	2.041×10^{-3}	-1.748×10^{-3}
UVM2	1.0	-2.330×10^{-3}	-1.361×10^{-3}
UVW2	1.0	1.108×10^{-3}	-1.960×10^{-3}
V	1.0	-1.798×10^{-2}	4.330×10^{-4}

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 (Figure 7), some of which can be attributed to high background count rates, i.e. the failure of the coincidence correction to cope with high backgrounds. A correction for this can be found by taking a set of data for an individual star taken with different background levels (e.g. see Figure 9). Only the white filter suffers from backgrounds high enough to cause a problem.

Using data for WD1121, the counts with higher backgrounds can be fitted using the formula:
$corrcts = cts - m \times bkgnd$, where m = -120 and cts=181.
For WD1657 the gradient m is –151 but the measured decline as a proportion of the true count rate is the same for both. Therefore we assume a correction can be applied to all the **white** measurements. The equation is:

$$Truects = \frac{Meascts}{1 - 0.67 \times bkgnd}$$

The corrected plot is shown in Figure 8. Since the background is not necessarily the same for all the exposures taken on one day, the exposures have not been averaged in every case.

9. Correcting the measured count rates:

In the previous version (4) we changed the fit to the decline for the **uv** filters from a straight line to a quadratic curve; the fit this year is not much different from the last version. The straight line fit for the **b and u** filters are also not much changed from the last version, but in the **v** filter the decline seems to be flattening off, see Figure 12. In Figure 13 we have divided the **v** data into 5 time bins and plotted a histogram of the distance of the points from the straight lines or curve in terms of standard deviations. Here you can see that the simple straight line weighted mean has been effective until the most recent (bottom) time bin. The normalised fit was not so good in the previous bin but the curve is effective all the time bins. Calculated corrections given in Table 4, show that the change to a curve gives a change of the order of 2.5% for recent observations.

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 (e.g. 0.01) given in *Table **2***.

For the case of the correction using a quadratic curve, 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***.

In all cases the rate of decline is determined starting from 1st Jan 2005, so this should be the starting date for the CALDB.

	Loss (%) using caldb	**Loss (%) using straight line fit**	**Loss (%) using quadratic curve (from Table 3)**
v @ 5 years	7.65	7.45	7.91
v @ 11 years	16.83	16.39	14.54

Table 4 The magnitude (in percent) of the correction which would be applied for each of the possible scenarios: first column, the current CALDB correction; second column, changing the parameter for a new straight line fit; third column, using a curve to fit.

10. Figures:

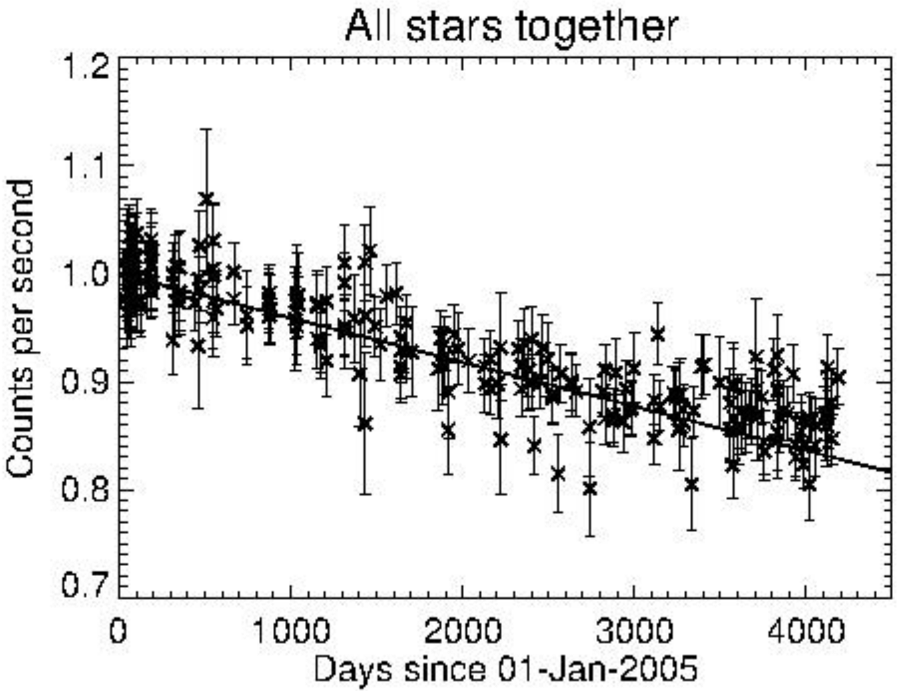

Figure 1 Count rates of standard stars in v filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005. Compare with the curved fit in Figure 12

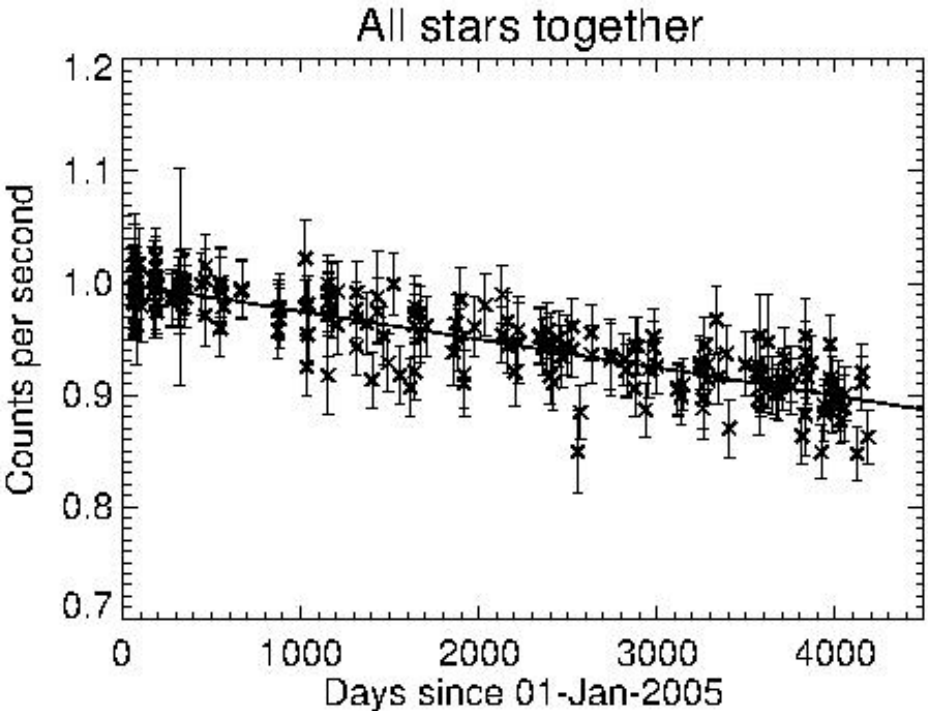

Figure 2 Count rates of standard stars in b filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005.

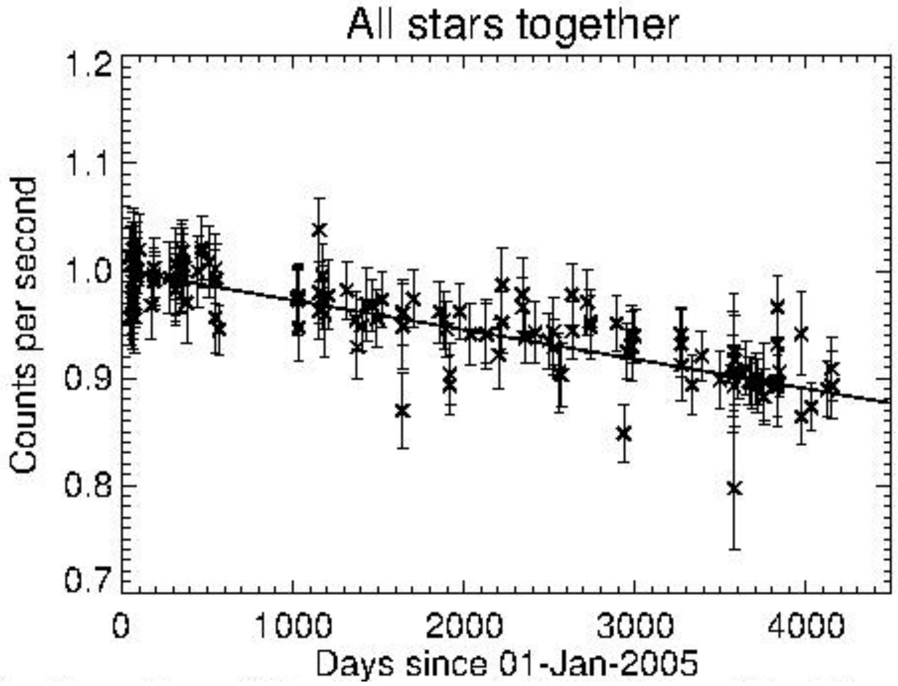

Figure 3 Count rates of standard stars in u filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005.

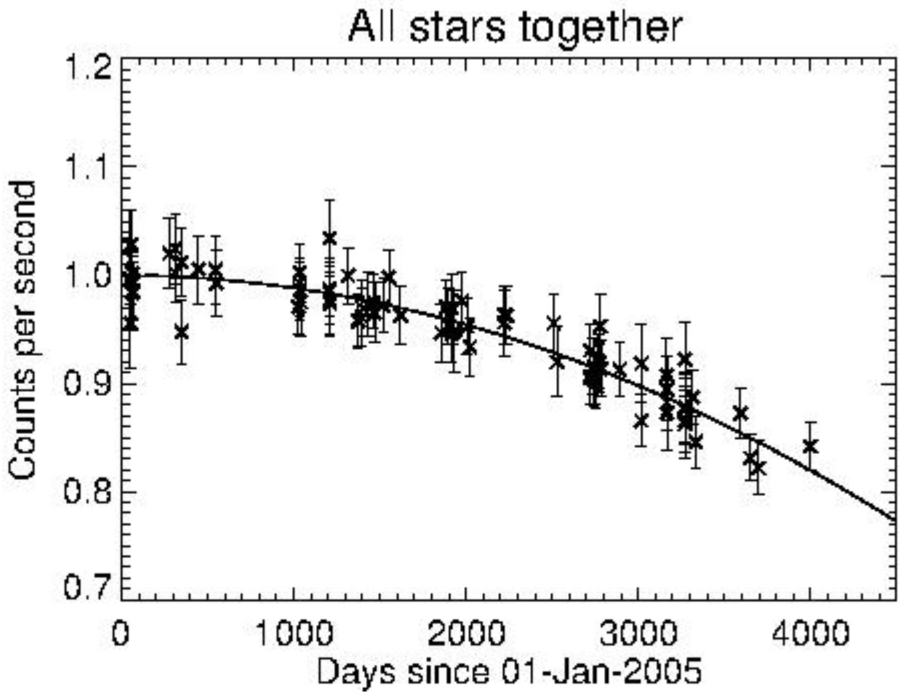

Figure 4 Count rates of standard stars in uvw1 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005.

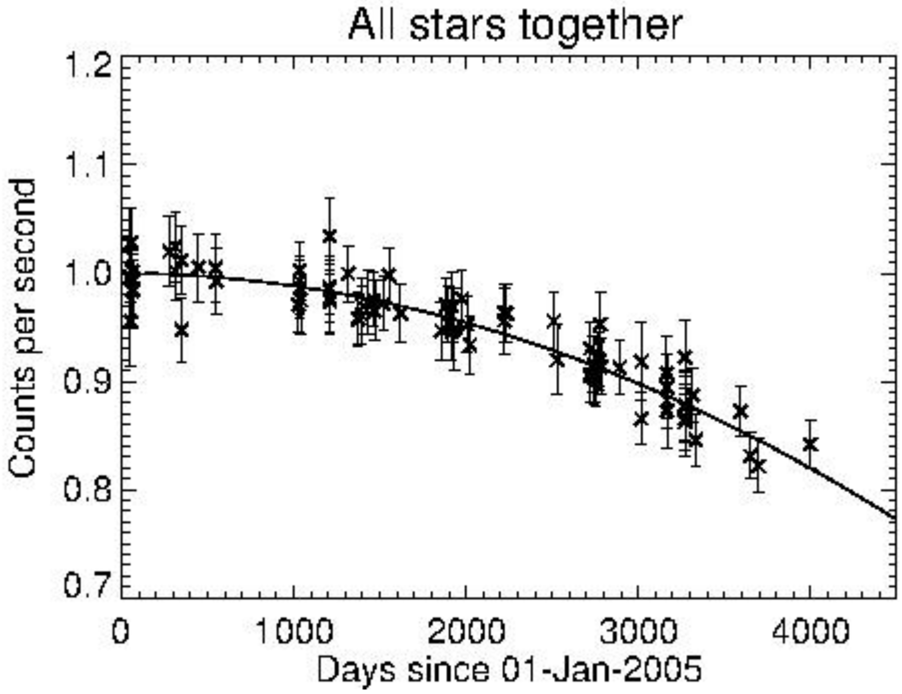

Figure 5 Count rates of standard stars in uvm2 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005.

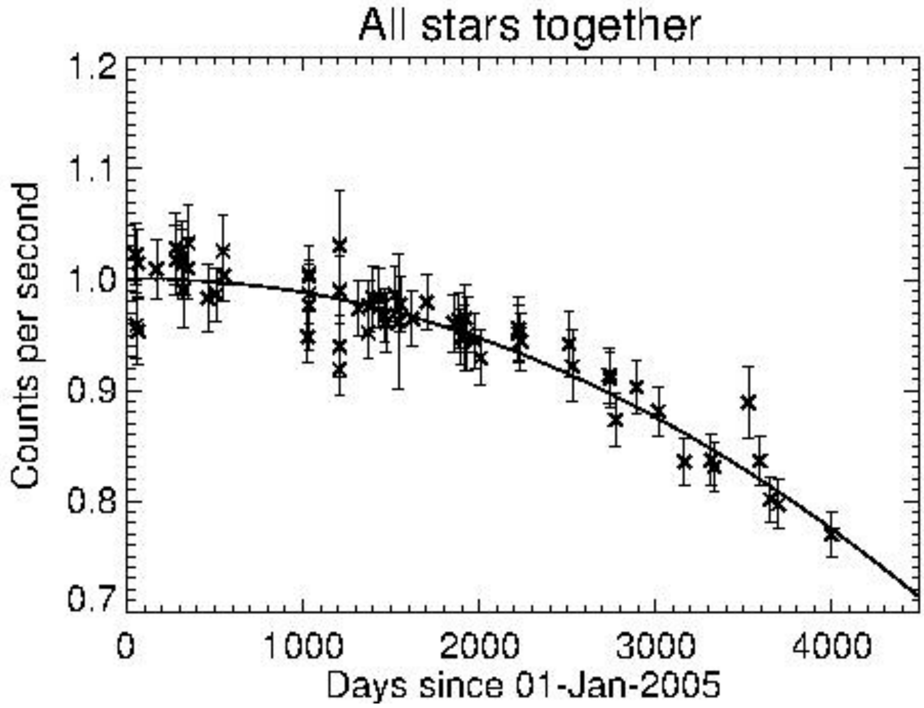

Figure 6 Count rates of standard stars in uvw2 filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005.

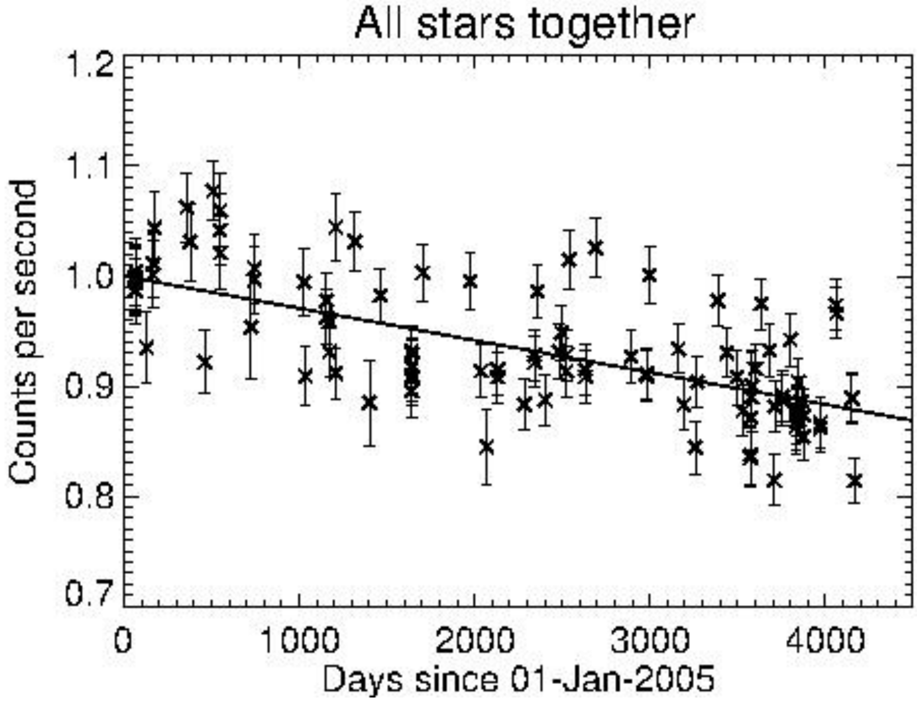

Figure 7 Count rates of standard stars in white filter, normalised to the count rates within the first 500 days, against days since 1st Jan 2005.

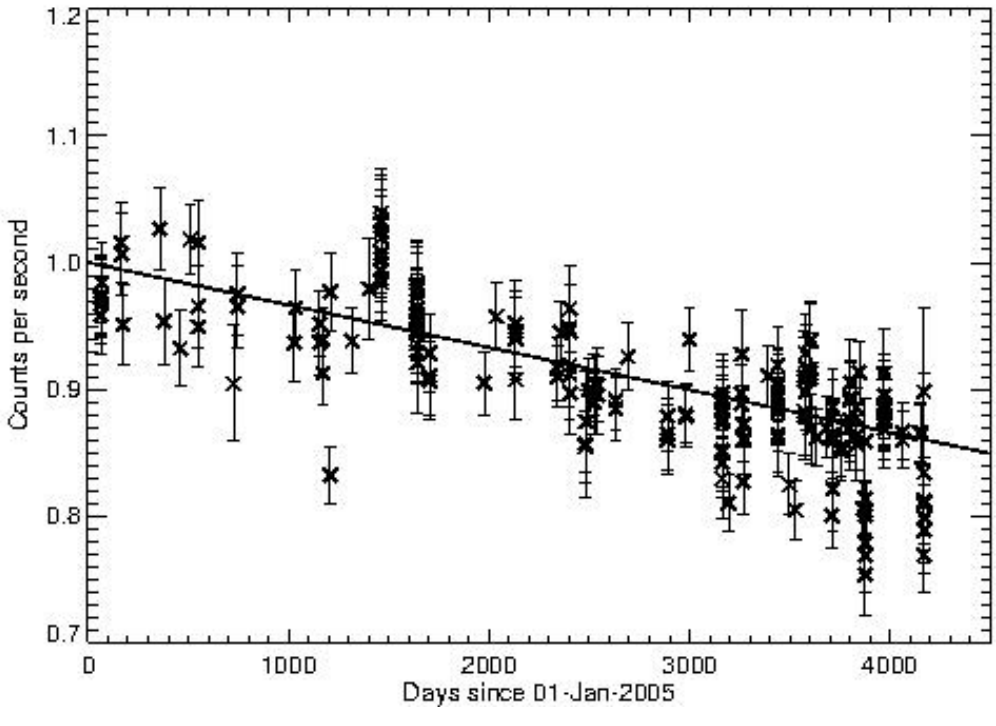

Figure 8 White data corrected for background count rate.

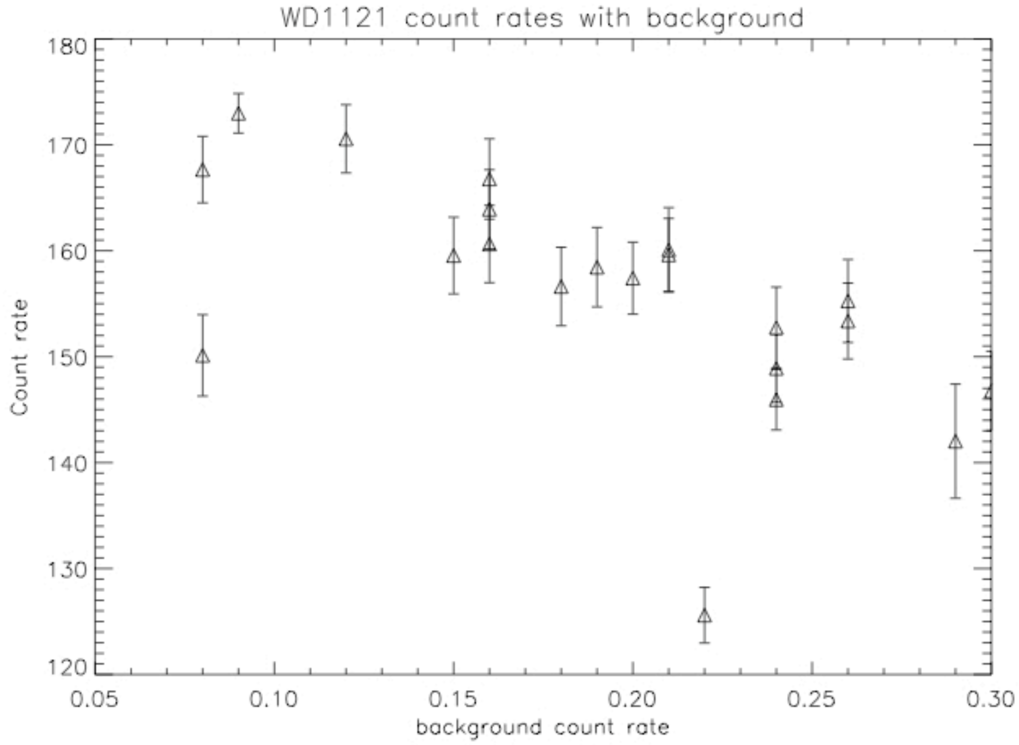

Figure 9 showing how count rates in the white filter are strongly affected by the background level.

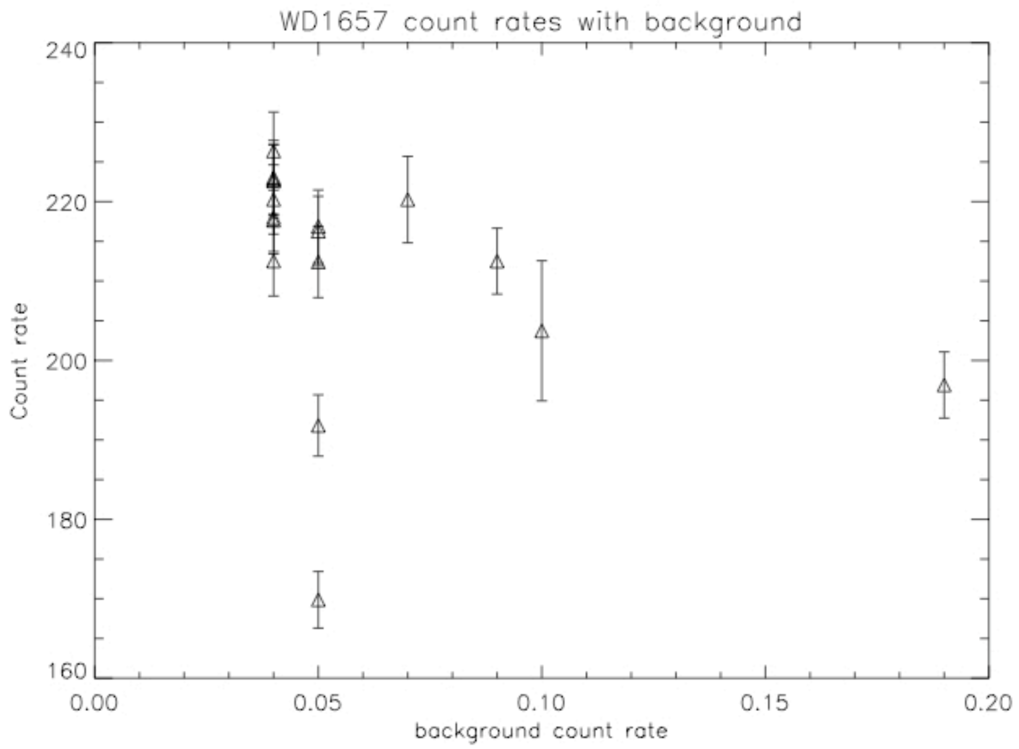

Figure 10 showing how count rates in the white filter are strongly affected by the background level.

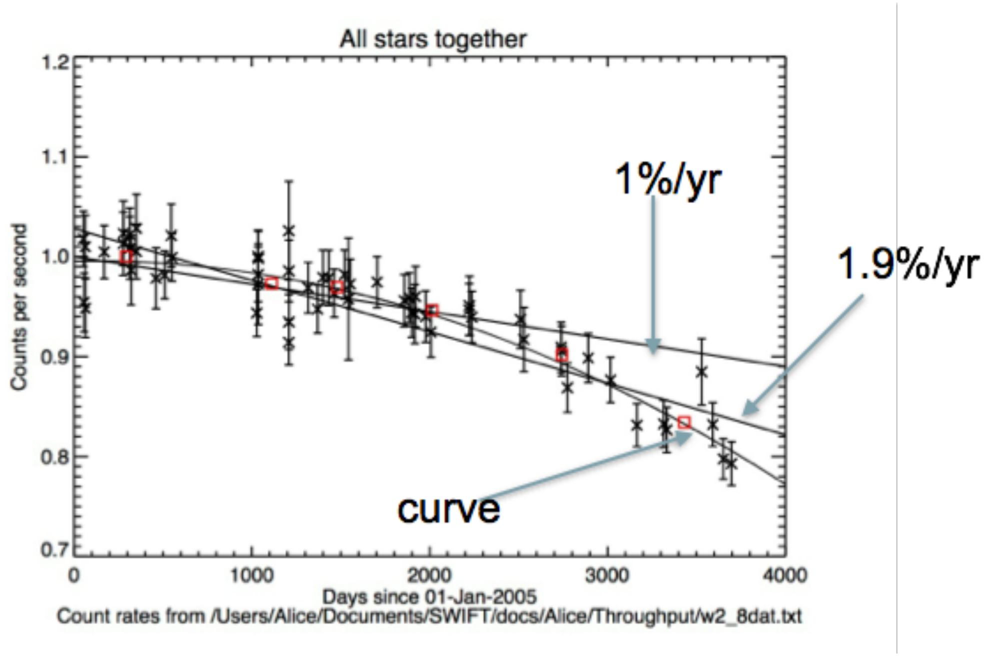

Figure 11 uvw2 with the original Caldb value of 1% a year decline compared with the 1.9% straight line fit, or the quadratic curve.

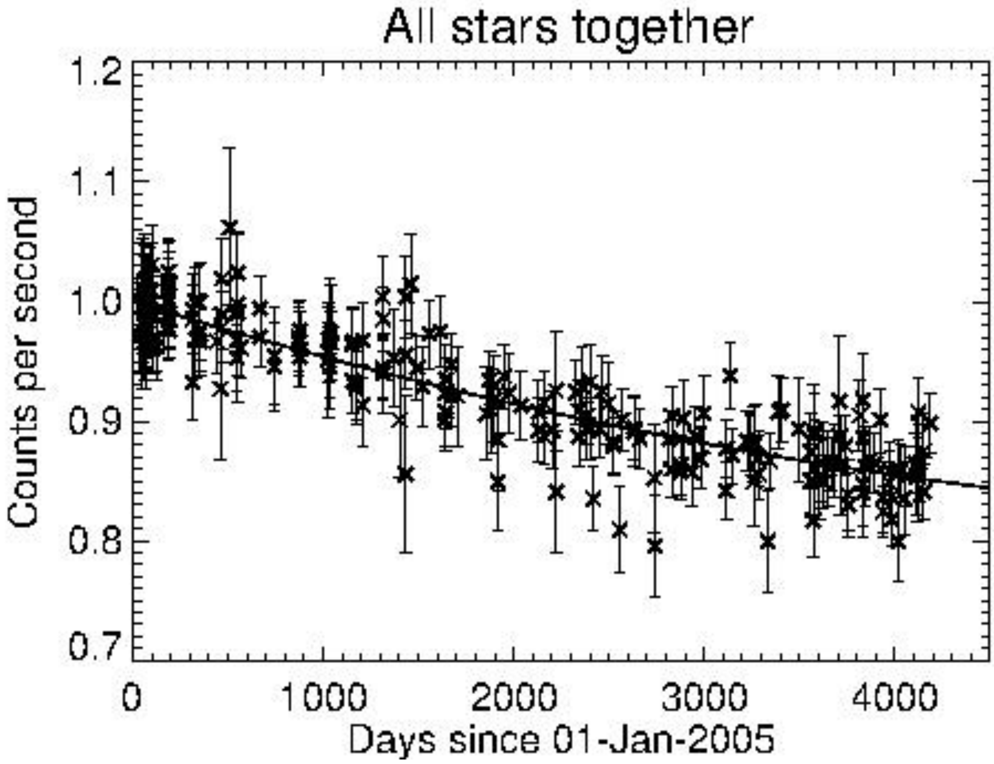

Figure 12 V filter data fitted with a curve rather than a straight line.

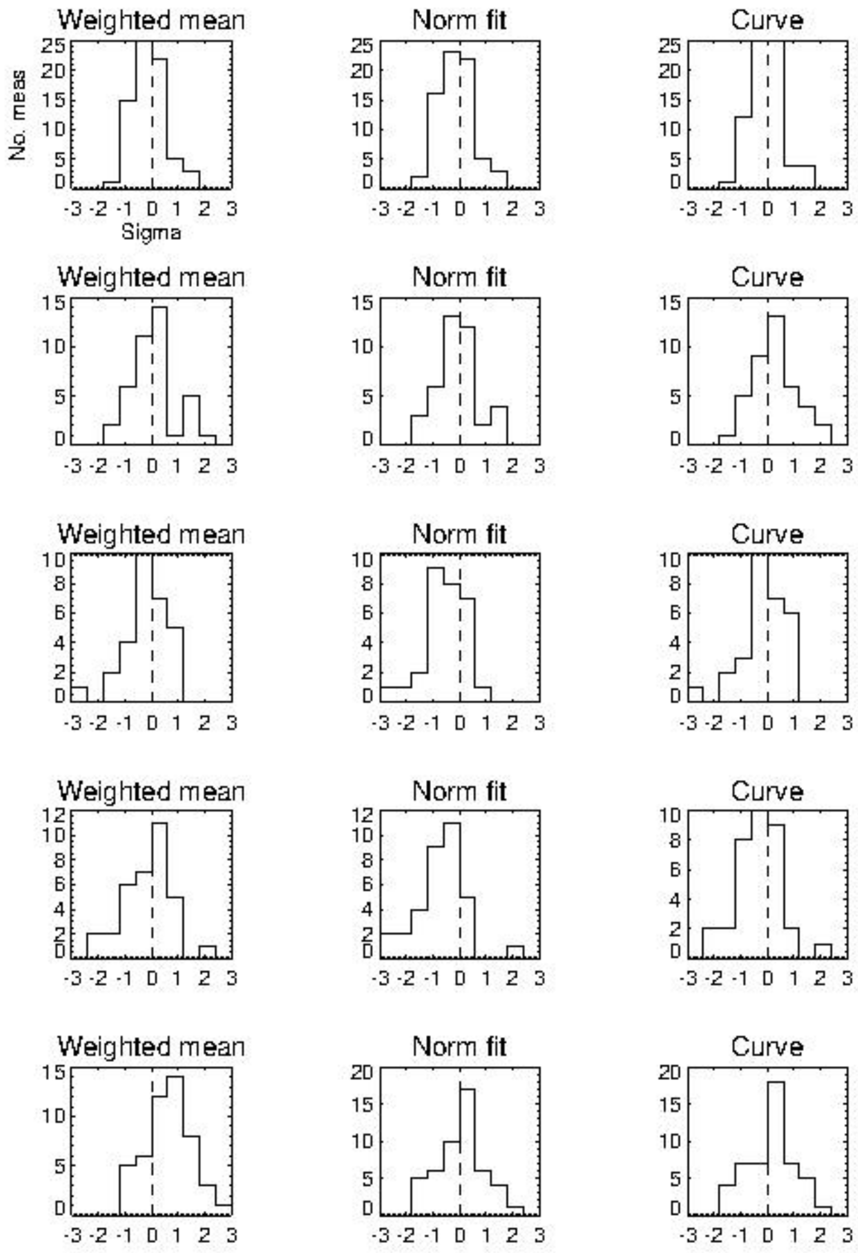

Figure 13 V filter: histograms showing the distance in standard deviations of each measurement from two types of straight line fit: the weighted mean (left column) and the normalised (middle) or thirdly the curve (right hand column). The data were divided into 5 time bins with the earliest one at the top.