SWIFT-UVOT-CALDB-01-R03
Date Original Submitted: 7th November 2005
Prepared by: Tracey Poole
Date Revised: 13th March 2007
Revision #03
Revised by: Tracey Poole; Alice Breeveld
Pages Changed: All
Comments:
Zero Points have been calculated using UVOT response curves for all filters

SWIFT UVOT CALDB RELEASE NOTE

SWIFT-UVOT-CALDB-01-R03: Zero Points

0. Summary:

This product defines the in-orbit zero point and zero point error for the 7 lenticular filters of the UVOT.

1. Component Files:

FILE NAME	VALID DATE	RELEASE DATE	VERSION

2. Scope of Document:

This document contains a description of the zero point calibration analysis performed to produce the zero point calibration products for the UVOT calibration database.

3. Changes:

This is the second release of the in-orbit zero points, replacing the first release in-orbit calibration data.
This version includes the following changes:

- the zero points have been derived for the uvot instrumental magnitude system by using the in-orbit effective area curves (uvot_caldb_effectiveareas_02b.doc), rather than by comparing directly with Johnson magnitudes
- the aperture used to measure the in-orbit count rates has changed from 6 arcseconds in the optical and 12 arcsecs in the UV, to 5 arcsecs for all filters
- the coincidence loss correction has been improved
- count rates for some standard stars have changed after reprocessing the data and ironing out exposure time problems
- some individual exposures have been removed. WD0947+857 turned out to be variable.

4. Reason For Update:

An update was undertaken to improve the zero point calibration and reduce systematic errors.

5. Expected Updates:

Further updates are expected following further observations in the ultraviolet if more suitable standard stars can be obtained.

6. Caveat Emptor:

The ground-based zero points were calculating using incorrect ground-based effective area curves. Therefore a comparison between the in-orbit zero points and the ground-based zero points in earlier versions of the CALDB is meaningless.

Due to the lack of faint spectroscopic standard stars in the UV, the UV and white zero points have been calibrated with very few stars.

7. Data Used:

Observations of 10 Landolt stars, 3 white dwarfs, and 2 Oke standard stars with known UBV magnitudes were used for the optical filter analysis. Observations of 3 faint white dwarf stars with known ultraviolet

spectra were used for UV filter analysis. Observations of 4 Landolt stars and 2 white dwarf stars were used for the white filter analysis. Where multiple observations were taken, count rates were calculated for individual exposures and then averaged. Observation details, sorted by observation date, can be seen in Table 1.

Object Name	Filter	Date	Sequence Number	Mode	Exposure Time (sec)
WD1121+145	uvw1	21/02/2005	55250008	E	584.4
sa104sw-338 & sa104sw-244	u	22/02/2005	55350004	I	1380.5
sa104sw-338 & sa104sw-244	v	22/02/2005	55350004	I	1626.1
WD1657+343	uvm2	25/02/2005	55900001	E	699.7
WD1657+343	uvw1	25/02/2005	55900002	E	570.4
WD1657+343	uvw2	25/02/2005	55900001	E	729.1
WD1657+343	v	25/02/2005	55900002	E	605.79
WD1121+145	uvm2	04/03/2005	55250010	E	671.82
WD1121+145	uvm2	04/03/2005	55250010	E	668.0
WD1121+145	uvw2	04/03/2005	55250010	E	704.5
sa101-278 & sa101-l3	b	05/03/2005	54950011	I	1523.7
sa104sw-338 & sa104sw-244	b	06/03/2005	55350009	I	1155.1
sa104sw-338 & sa104sw-244	white	06/03/2005	55350011	I	1567.4
PG1525-071B	b	07/03/2005	55750005	I	619.0
PG1525-071B	u	07/03/2005	55750003	I	1327.2
PG1525-071B	v	07/03/2005	55750001	I	1268.8
sa101-278 & sa101-l3	b	09/03/2005	54950005	I	1210.0
sa101-278 & sa101-l3	white	09/03/2005	54950006	I	1045.8
sa98offset2-646	b	11/03/2005	54700003	I	1149.7
sa104n-443 & sa104n-457	b	11/03/2005	55400005	I	508.2
sa104ne-367	b	11/03/2005	55450003	I	604.5
sa95sw-102	u	11/03/2005	54350005	I	569.9
sa98offset2-646	u	11/03/2005	54700002	I	1251.0
sa95sw-102	v	11/03/2005	54350004	I	3706.5
sa98offset2-646	v	11/03/2005	54700001	I	1290.9
WD1657+343	b	15/03/2005	55900003	I	351.0
sa104n-443 & sa104n-457	u	21/03/2005	55400012	I	2025.3
sa101-278 & sa101-l3	v	26/03/2005	54950003	I	2661.4
sa95sw-102	b	27/03/2005	54350011	I	1649.3
sa104ne-367	u	28/03/2005	55450005	I	868.6
sa104ne-367	v	05/04/2005	55450008	I	725.9
WD1657+343	u	12/04/2005	55900024	I	633.6
sa104n-443 & sa104n-457	v	19/04/2005	55400016	I	1128.0
WD1121+145	white	10/05/2005	55250021	I	53.3
WD1657+343	white	25/06/2005	55900032	I	154.9

WD1026+453*	b	07/07/2005	55761006	I	63.6
sa95-42*	b	07/07/2005	55763001	I	329.1
G24-9	b	07/07/2005	55762002	I	643.0
WD1026+453*	u	07/07/2005	55761005	I	36.0
WD1026+453	uvm2	07/07/2005	55761004	E	361.6
sa95-42	v	07/07/2005	55763002	I	501.6
G24-9	v	07/07/2005	55762001	I	1016.5
WD1026+453	uvw1	05/10/2005	55761007	I	376.3
WD1026+453	uvw2	10/11/2005	55761009	I	391.6
WD1657+343	u	14/01/2006	55900035	I	82.6
WD1657+343	white	14/01/2006	55900035	I	66.7

Table 1 - Table containing the observations used to calculate the in-orbit zero points. All of the sequence numbers in column 4 are missing their first three digits of 000. In column 5, I represents Image mode, and E represents Event mode. * indicates that there was considerable TOSSLOSS (http://heasarc.gsfc.nasa.gov/docs/swift/analysis/uvot_digest.html#timing) in one of more of the exposures within the observation; these problem exposures were removed.

8. Description of Analysis:

The same method for calculating the zero points for optical and ultraviolet filters have been used for this revision, so that the zero points are defined in terms of the UVOT response.

8.1. Obtaining an Observational Count Rate

Observations of 10 Landolt stars, 2 Oke standard stars with known UBV magnitudes, and 3 white dwarfs with known ultraviolet spectra (from HST and IUE) were considered. The spectra of the 2 Oke stars were known from HST data, and the spectra of the 10 Landolt stars were identified by fitting the Landolt star b-v and u-b colours (Landolt 1992, AJ, 104, 340) with known spectra from the Pickles models (http://www/ifa.hawaii.edu/users/pickles/AJP/hilib.html).

Raw count rates for each star were extracted using an aperture radius of 10 pixels (5 arcsec) for all filters, and then corrected for coincidence loss. The background region was set to an annulus with an inner radius of 55 pixels (27.5 arcsec), and an outer radius of 70 pixels (35 arcsec). The background extraction method was set depending upon the background level: below a background level of 10 ph/pix a MEAN background method was used unless there was a bright source in the background region then a CLIPPED MEAN (using a sigma clipping

method at 3 sigma) background method was used; above a background level of 10 ph/pix a CLIPPED MEAN background was used.

The raw observed count rate and background count rate for each observation was then corrected with the theoretical coincidence loss equation of,

$$C_{theory} = \frac{-\ln(1 - C_{raw} ft)}{ft(1 - df)},$$

Where C_{theory} is the theoretically coincidence loss corrected count rate, C_{raw} is the raw observed count rate, ft is the frame time (0.0110322s for full frame), and df is the deadtime fraction (0.0157720 for full frame). N.B. This count rate C_{raw} is calculated using an exposure time which is *not* corrected for deadtime. If the count rate is calculated using the deadtime-corrected exposure time recorded in the keyword EXPOSURE, then it must be multiplied by *(1-df)* to get C_{raw}.
This theoretical coincidence loss is then corrected by multiplying by the in-orbit empirical formula for a 10 pixel (5 arsec) aperture,

$$f(x) = 1.0 - 0.0663428x + 0.0900434x^2 - 0.0237695x^3 - 0.0336789x^4,$$

where $x = C_{raw} ft$.

Finally, the corrected background count rate is subtracted producing a final in-orbit observed count rate of $C_{obs}(I)$, where i is the number of standard stars used.

The observations of sa95-42 were discarded in the b filter due to large TOSS LOSS (http://heasarc.gsfc.nasa.gov/docs/swift/analysis/uvot_digest.html#timing). There was a large readout streak running through the background region of sa98offset2-646 in the u filter observations so this was also discarded.

The spectra of WD1026+453 had to be extrapolated beyond 5700Å which will affect the V filter. The optical spectrum (3150-8000Å) of WD1121+145 was uncertain therefore this source was removed from the V and B filter analysis. The spectra of SA95-42 and G24-9 range from 3200-8000Å, which will affect all the UV filters and the U filter.

8.2. Obtaining Zero Points for each UVOT filter

The zero points for all the UVOT filters were then calculated by standardising the count rates to a Vega spectrum (Bohlin & Gilliland, 2004, ApJ, 127, 3508). The expected count rate of each observed star ($C_{exp}(i)$) was calculated by convolving the known spectra of the observed stars with the in-orbit filter effective areas (see uvot_caldb_effectivearea_02b.doc). In the same way the spectra of Vega was convolved to produce an expected Vega count rate ($C_{exp}(vega)$). The zero points ($Z_{pt}(i)$) for each source in each filter were then calculated using

$$Z_{pt}(i) = M_{vega} + 2.5\log\left(C_{\exp}(vega)\frac{C_{obs}(i)}{C_{\exp}(i)} \right)$$

Where M_{vega} is the standard Vega magnitude for each filter (set to 0.0 for the UVOT system). The final zero point (Z_{pt}) for each filter was calculated by averaging over all the observations in that filter.

Figures 1 to 7 show the data used to produce the zero points for the optical and ultraviolet UVOT filters respectively. The error bars produced in the plots include the Poisson error in the raw observed count rate, and also include the errors associated with the stellar spectra used. The predicted errors on the Landolt stars for the V, B and U filters were calculated using an estimate of the systematic error between the Landolt and Johnson system (Menzies et al, 1991, MNRAS, 248, 642) added in quadrature with the Landolt colour term errors (Landolt, 1992). The predicted errors of the Landolt stars for the white filter were calculated to have a 4% error due to the scatter of possible Pickle model fits, and this was added in quadrature with the Landolt colour term errors (Landolt, 1992). The predicted errors on the white dwarf and Oke stars were calculated using a HST error of 2% (Bohline 2006, astroph/0608716) or an IUE error of 3% (Massey & Fitzpatrick, 2000, ApJs, 126, 517).

Table 2 shows the latest in-orbit UVOT zero points (as from 12th February 2007). The RMS error on the average zero point (a measure of

the data scatter) and the standard error for each zero point (a measure of the error on the mean) is also given in the Table 2.

The dotted lines on the plots show the RMS of the average. The error bars on the data points (the average is included in Table 2) are comparable to this RMS in the optical, showing that there is no significant additional systematic error. The errors are not comparable in the ultraviolet and white, but the scatter in the results does not necessarily reflect the inherent error because of the small number of standard stars used. For this reason, for the UV and white zero points, we recommend using the average error bar error from Table 2 to be sure to include all uncertainties. The errors on the zero points included in the CALDB file are shown in bold.

Filter	Zero Point	RMS Error	Standard Error	Average Error Bars
v	17.89	0.04	**0.013**	0.03
b	19.11	0.05	**0.016**	0.05
u	18.34	0.06	**0.020**	0.07
uvw1	17.49	0.02	0.013	**0.03**
uvm2	16.82	0.02	0.015	**0.03**
uvw2	17.35	0.02	0.012	**0.03**
white	20.29	0.05	0.023	**0.04**

Table 2 - In-orbit non-colour zero points. The recommended errors to use with the zero points are in bold.

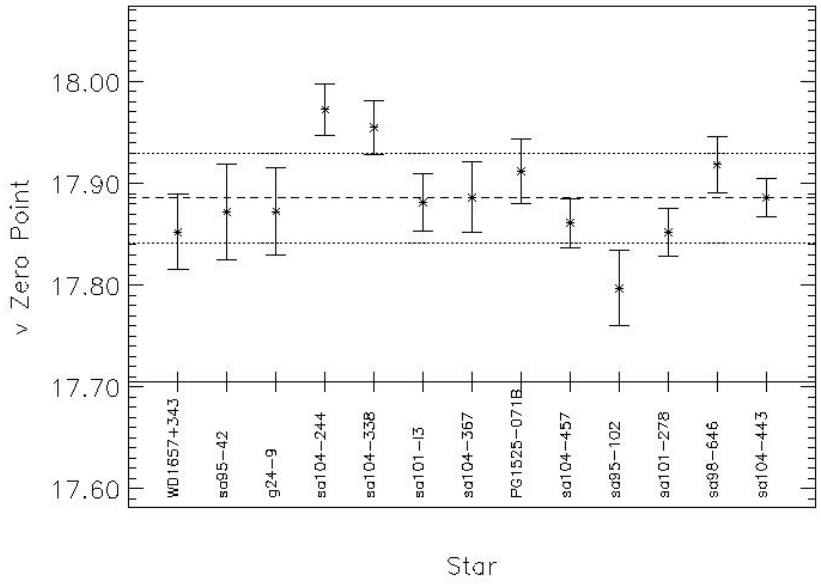

Figure 1 – v filter zero point data. Each data point represents the zero point as calculated according to the measurement of one standard star. The quoted zero point (in Table 2) is the average of these and is shown with a dashed line. The dotted lines show the RMS.

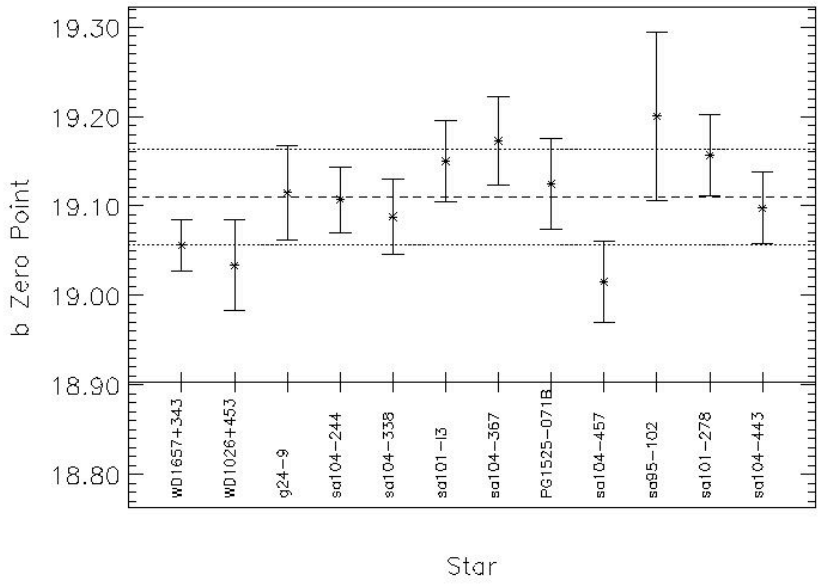

Figure 2 - b filter zero point data. Each data point represents the zero point as calculated according to the measurement of one standard star. The quoted zero point (in Table 2) is the average of these and is shown with a dashed line. The dotted lines show the RMS.

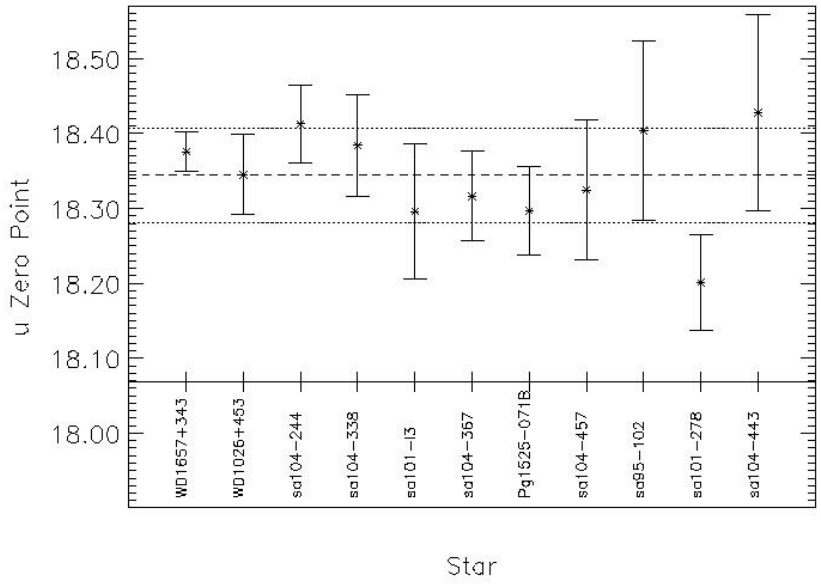

Figure 3 - u filter zero point data. Each data point represents the zero point as calculated according to the measurement of one standard star. The quoted zero point (in Table 2) is the average of these and is shown with a dashed line. The dotted lines show the RMS.

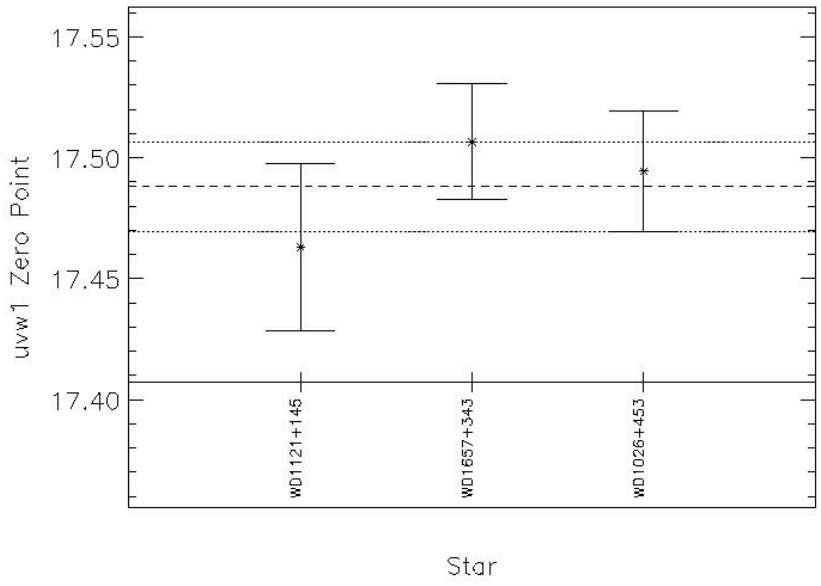

Figure 4 - uvw1 filter zero point data. Each data point represents the zero point as calculated according to the measurement of one standard star. The quoted zero point (in Table 2) is the average of these and is shown with a dashed line. The dotted lines show the RMS.

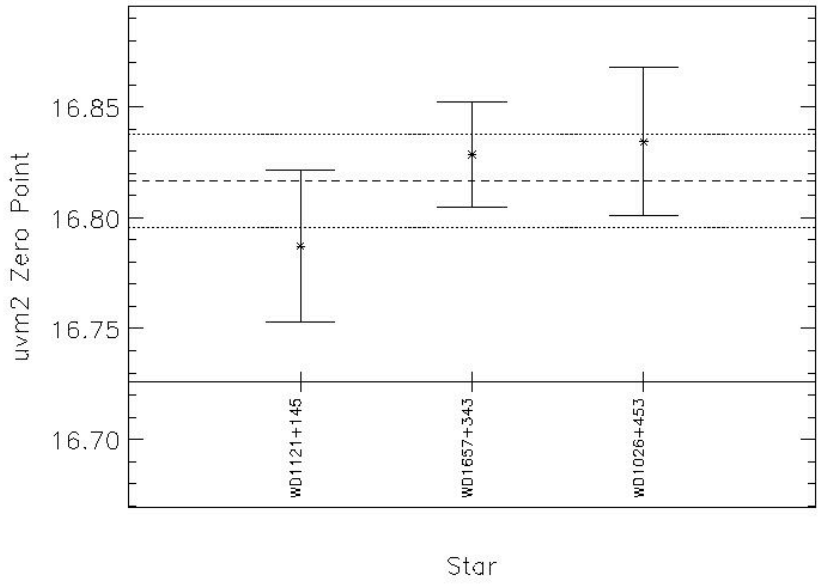

Figure 5 - uvm2 filter zero point data. Each data point represents the zero point as calculated according to the measurement of one standard star. The quoted zero point (in Table 2) is the average of these and is shown with a dashed line. The dotted lines show the RMS.

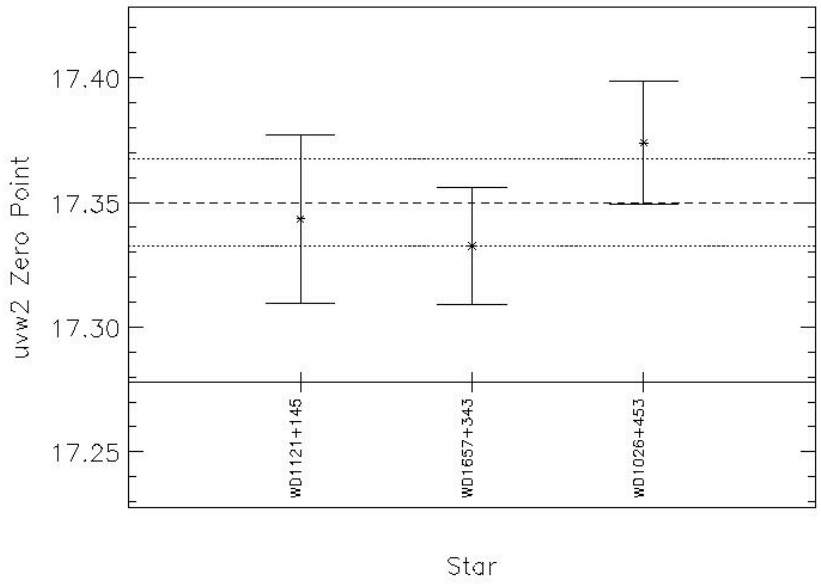

Figure 6 - uvw2 filter zero point data. Each data point represents the zero point as calculated according to the measurement of one standard star. The quoted zero point (in Table 2) is the average of these and is shown with a dashed line. The dotted lines show the RMS.

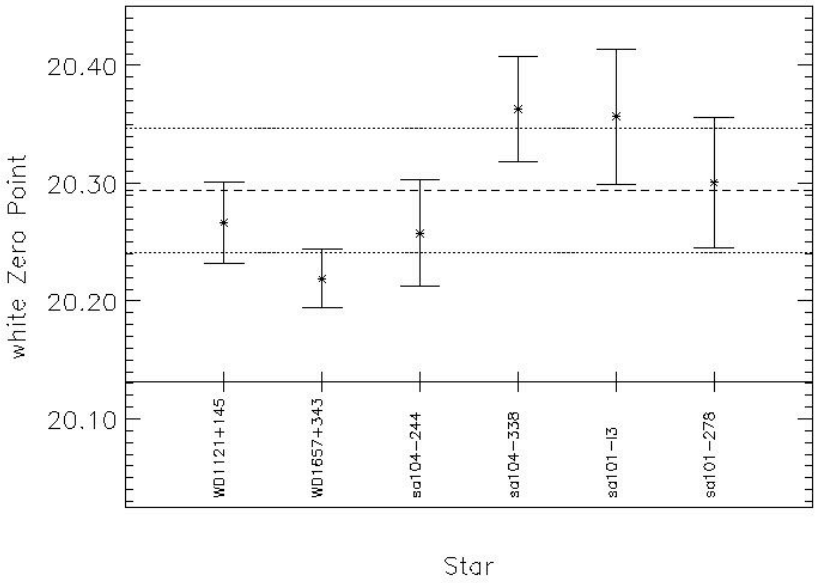

Figure 7 – white filter zero point data. Each data point represents the zero point as calculated according to the measurement of one standard star. The quoted zero point (in Table 2) is the average of these and is shown with a dashed line. The dotted lines show the RMS.