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# SWIFT UVOT CALDB RELEASE NOTE

SWIFT-UVOT-CALDB-##: TELDEF Files

## 0. Summary:

The telescope definition (teldef) files are used to convert between raw and detector or sky coordinates. The format of the teldef files is described in http://heasarc.gsfc.nasa.gov/docs/swift/sdc/teldef_doc/

## 1. Component Files:

The table below shows the teldef files used for current data. For the seven lenticular filters (first seven rows), there are four additional teldef files with earlier valid dates, used for older data.

| FILE NAME | VALID DATE | RELEASE DATE | VER SION |
|---|---|---|---|
| *swuwh20070828v001.teldef* | 2007-08-28 | 2005-07-15 | 101 |
| *swuvv20070828v001.teldef* | 2007-08-28 | 2005-07-15 | 101 |
| *swubb20070828v001.teldef* | 2007-08-28 | 2005-07-15 | 101 |
| *swuuu20070828v001.teldef* | 2007-08-28 | 2005-07-15 | 101 |
| *swuw120070828v001.teldef* | 2007-08-28 | 2005-07-15 | 101 |
| *swum220070828v001.teldef* | 2007-08-28 | 2005-07-15 | 101 |
| *swuw220070828v001.teldef* | 2007-08-28 | 2005-07-15 | 101 |
| *swumagni20041120v103.teldef* | 2004-11-20 | 2006-10-24 | 103 |

| | | | |
|---|---|---|---|
| *swugu0160_20041120v103.teldef* | 2004-11-20 | 2006-10-24 | 103 |
| *swugu0200_20041120v103.teldef* | 2004-11-20 | 2006-10-24 | 103 |
| *swugv0955_20041120v103.teldef* | 2004-11-20 | 2006-10-24 | 103 |
| *swugv1000_20041120v103.teldef* | 2004-11-20 | 2006-10-24 | 103 |

## 2. Scope of Document:

This document describes the determination of the following four quantities which are needed to create a teldef file.

(1) Boresight: This is the position in raw pixels where the target (i.e. the RA and Dec position given in the spacecraft attitude file) appears. Because of spacecraft drift, one can only calculate a mean boresight, and deviations of several arcseconds from this position are not uncommon.

(2) Detector Rotation Angle: This is the angle that the detector makes with the spacecraft roll angle given in the attitude file. It determines the angle needed to rotate a raw or detector image to North-up orientation (sky image). This angle is expected to be identical for all UVOT observing modes.

(3) Distortion Map: This is a matrix of correction vectors needed to undistort the raw image to obtain a linear plate scale. The optical fiber taper connecting the microchannel plate to the detector introduces distortions that can reach 68 pixels at the edge of the UVOT field. The distortion correction is expected to be independent of time or observing mode.

(4) Plate Scale: The scale in arc seconds/pixel in the UVOT detector and sky images. The choice of plate scale is somewhat arbitrary since the distortion map can be modified to provide any plate scale. However, the astrometric information in the header must be consistent with the chosen plate scale.

There are currently 40 teldef files; four for the grism modes (UV/Visible, clocked/nominal) one for the magnifier, and five for each of the seven lenticular filters.

## 3. Changes

The updates to the teldef files include the following:

(1) There are now a separate set of teldef files for each lenticular filter. In particular, the UVW2 filter has been found to have a plate scale of 0.5043 "/pixel rather than the 0.502 "/pixel of the other filters, and the *u* filter has a boresight that differs by about 3" from the other filters.

(2) As part of the process of returning Swift to operation after the gyro problem in August 2007, a change was made to the spacecraft alignment matrix for the star tracker. The change is equivalent to a -10 arc minute rotation about the spacecraft x-axis. A corresponding change was made to the teldef files for each of the Swift instruments to compensate for the change on the spacecraft.

(3) The UVOT boresights for the white filter and the 6 lenticular filters were recalibrated in May 2009. The positions of boresights changed in a gradual and monotonic fashion throughout the mission. New teldef files for each filter were generated at five epochs between Nov 2004 and May 2009.

(4) New teldef files were created in January, 2024, for the 6 lenticular filters and the white filter. The new files have the names swuXX20230101v001.teldef in which XX is replaced with the filter identification (vv, bb, uu, w1, m2, w2, or wh). The boresights were adjusted using aspect solutions from the first six months of 2023. The adjustments were sized to compensate for the mean aspect correction in the detector x- and y-axes. The new teldef files should be used for processing any UVOT observation with any of the 6 lenticular filters or the white filter in 2023 or later.

## 4. Reason For Update:

The automatic aspect correction in the UVOT pipeline has allowed a more accurate study of the UVOT boresight, and its variation with time and with different filters. There are now five teldef files for each lenticular filter, covering four timespans during the mission.

## 5. Expected Updates:

(1) Changes of the UVOT boresight with time will continue to be monitored.
(2) The adopted detector rotation angles for the grism nominal modes and the magnifier are incorrect by about 0.5 degrees. No study of the time dependence of the grism teldef file has yet been performed. The introduction of aspect correction for the grism images (using the *uvotgraspcorr* routine) should allow a more accurate grism teldef file to be made, similar to what has been done for the lenticular filters.

## 6. Caveat Emptor:

The boresight continues to change with time and the current teldef files are expected to need revision in the future.

The grism teldef files do not account for the additional distortion introduced by the grism.

## 7. Data Used:

| ***ObsID*** | ***Target*** | ***Date*** | ***Filter*** | ***ExpTime*** |
|---|---|---|---|---|
| ***Boresight*** | | | | |
| 00055550007 | PG1311+129 | Feb 3, 2005 | V | 493 |
| 00056350002 | UZFOR | Feb 2, 2005 | U | 5973 |
| 00067042028 | M83 | Feb 1, 2005 | V | 536 |
| 00670470029 | FOCUS6 | Feb 1, 2005 | V | 699 |
| ***Rotation/Plate Scale*** | | | | |
| 00054500040 | Sally's Field | Apr 15, 2005 | V | 2374 |
| 00103906000 | GRB050128 | Jan 28, 2005 | V | 3595 |
| 00054100001 | SMCNorth | Mar 13, 2005 | V | 1018 |
| 00054500041 | Sally's Field | Apr 15, 2005 | Magnifier | 1977 |
| ***Grism*** | | | | |

| ObsID | Target | Date | Filter | ExpTime |
|---|---|---|---|---|
| 00030022049 | NGC 5548 | Apr 26, 2005 | V Grism | 1026 |
| 00055050021 | GD 108 | Mar 15, 2005 | V Grism | 1167 |
| 00054001001 | BPM 16274 | Mar 17, 2005 | V Grism | 683 |
| 00055800013 | Sco-X1 | Apr 4, 2005 | V Grism | 494 |
| 00055200012 | WD1057+719 | May 25, 2005 | U Grism | 1298 |
| 00035170003 | V574 Pup | May 25, 2005 | U Grism | 3760 |
| 00054250008 | WD0320-530 | May 12, 2005 | U Grism | 1174 |
| 00055503012 | GD 153 | Apr 5, 2005 | U Grism | 1172 |

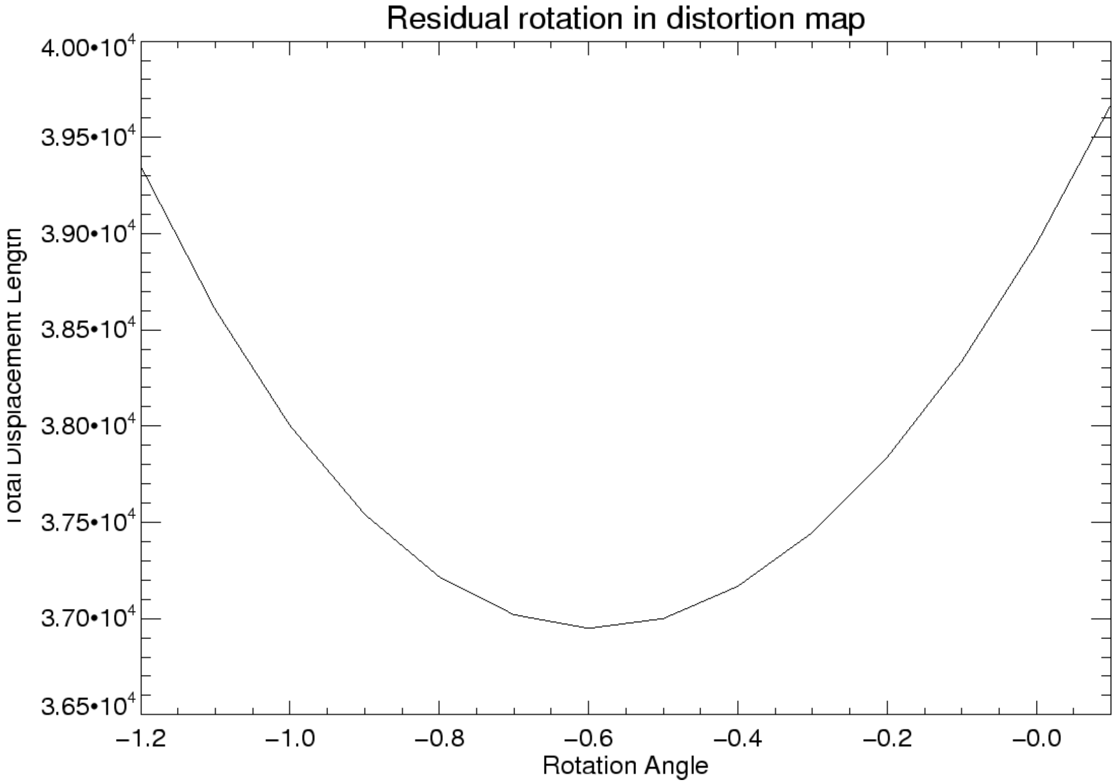
## 8. Description of Analysis:

The raw UVOT image includes a distortion introduced by alignment variation in the optical fiber taper connecting the microchannel plate to the detector. The telescope definition (teldef) file in the pipeline both corrects for this distortion and adds astrometric parameters into the FITS header based on the telescope attitude.

### (1) **Distortion Map**

The distortion was mapped during the ground-based calibration using a target mask with a grid of pinholes, and is documented in the Swift UVOT Instrument Science Report 206-R01 by Sally Hunsberger, dated March 13, 2003. The ground-based distortion map was supplied as a set of 1952 correction vectors, with the size of the correction reaching 68 pixels near the edge of the detector. In the current teldef file, the distortion vectors are mapped onto a 256 x 256 grid using thin spline smoothing. As described below, two modifications were made to the ground-based-distortion corrections.

The main change to the ground-based distortion map was that a rotation of 0.6 degrees about the center of the image was applied to each displacement vector. This change was suggested by comparison of over 1500 star position (as derived from Sextractor) in the V image of the




“Sally's Field" (00054500040) target in the Magellanic Clouds, with sources in the Magellanic Cloud Photometric Survey catalog (Zaritsky et al. 2002, AJ, 123, 855). If the boresight had been located at the center of the image, then this 0.6-degree rotation would simply had been incorporated into the astrometric keywords. However, the boresight position is offset from the center by about 69 pixels in the lenticular filters (see Table 1). Thus this rotation was instead applied to each of the displacement vectors in the distortion map to create a new map.

Figure 1: Total displacement as a function of rotation angle in the ground-based distortion map.

Table 1
Astrometric Parameters for the Teldef Files

| ***Mode*** | ***Clocking*** | ***CALDB File*** | ***Raw X*** | ***Raw Y*** | ***Scale "/pix*** | ***Rotation*** |
|---|---|---|---|---|---|---|
| Image | | swugen20041120v103 | 956 | 1035 | 0.502 | -118.8 |
| Magnifier | | swumagni20041120v103 | 840 | 888 | 0.1259 | -118.25 |
| U Grism | 200 | swugu0200_20041120v101 | 1476 | 704 | 0.557 | -118.25 |
| U Grism | 160 | swugu0160_20041120v101 | 1532 | 601 | 0.564 | -118.8 |
| V Grism | 1000 | swugv1000_20041120v101 | 1548 | 668 | 0.564 | -118.25 |
| V Grism | 955 | swugv0955_20041120v101 | 1592 | 537 | 0.564 | -118.8 |

There is some evidence that this 0.6 deg rotation was present in the ground-based calibration setup, perhaps due to an extra rotation of the pinhole mask. Figure 1 shows that the integrated displacement (the sum of all the displacement vectors) is minimized for a rotation angle of 0.6 deg.

A second small change to the ground-based distortion map was to delete two of the 1952 points (listed in Table 2) which had a large discrepancy with neighboring points. Figure 2 shows that removing these two points allowed for an improved global astrometric solution, though the effect is localized to a very small area of the detector. (It is evident only in the central star in Figure 2 and a few stars below it.)

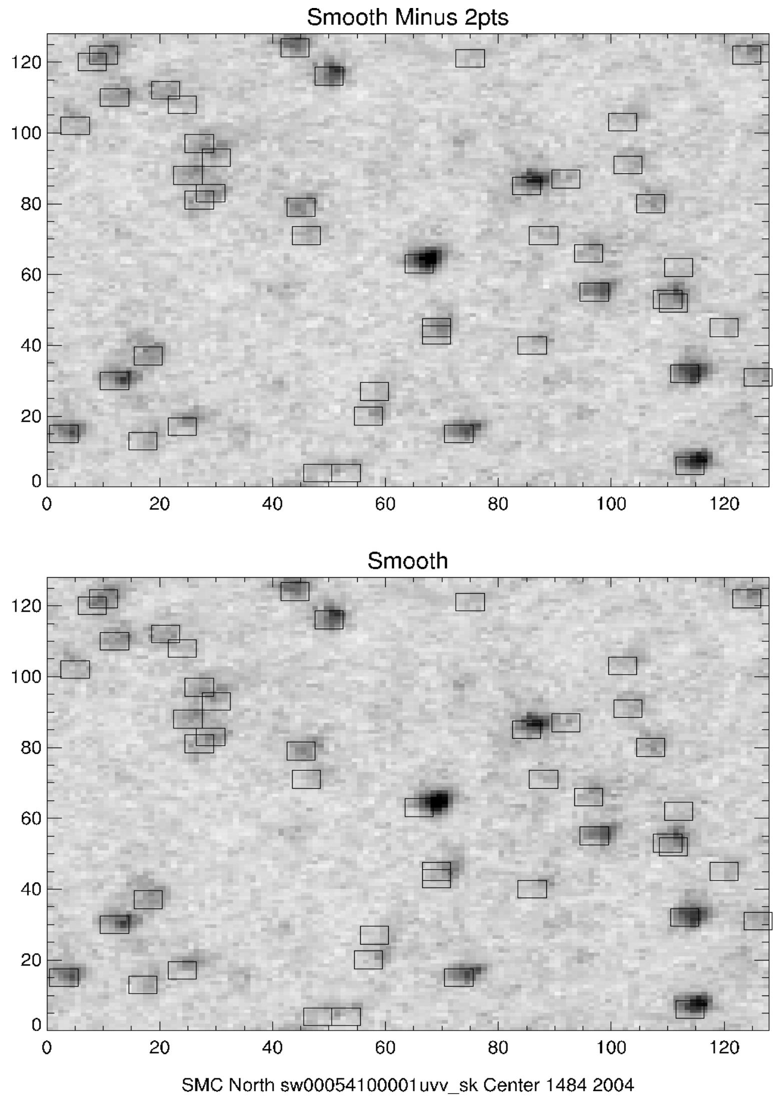



**Figure 2: The effect of removing 2 deviant points from the teldef file**

## Table 2
## Deleted Distortion Map Points

| *Old X* | *Old Y* | *New X* | *New Y* |
|---|---|---|---|
| 1901.47 | 571.68 | 1870.72 | 547.58 |
| 1942.13 | 592.62 | 1909.16 | 570.66 |

## (2) Astrometric Parameters

### 1. Direct Images

All the teldef files use the same distortion map, but the boresight, plate scale and detector rotation angle were determined using flight images Table 1 shows the determination of these values in 2006, but note that there are now time-dependent and filter-dependent determinations for the lenticular filters.

The acquisition error of the Swift pointing system is typically a few arc seconds. That is, the position of the target at the start of an exposure varies from exposure to exposure by a few arc seconds from the "average" position. The errors are not completely random. In particular, the errors for exposures taken during a single snapshot are correlated. The boresight for UVOT is chosen to be this average position on the detector plane. Consequently, it minimizes the average acquisition error.

The boresight for the direct images was first estimated in Feb 2005 by Martin Still using the following four images from Feb 1-3, 2005.

| ***ObsID*** | ***RA*** | ***Dec*** | ***Raw X*** | ***Raw Y*** |
|---|---|---|---|---|
| 00055550007 | 198 | 13 | 955 | 1035 |
| 00056460002 | 53 | -25 | 960 | 1033 |
| 00067042028 | 352 | 59 | 956 | 1036 |
| 00067047029 | 7 | -59 | 955 | 1035 |

The RawX, RawY values give the measured pixel position of the target center. The median of these values was taken to give a mean boresight at (RawX, RawY) = (956, 1035) as shown in Table 1.

The pointings listed in Section 7 were then used to derive the plate scale and detector rotation. The GSC2.2 catalog was used for all the star positions except for the Magellanic Cloud pointings where the Magellanic Cloud Survey was preferred. No attempt was initially made to determine different astrometric parameters for different filters. The accuracy of the direct filter teldef file was assessed using a V image of the “Sally's Field" (00054500040) target in the Magellanic Clouds, where a total of 1587 sources can be matched with stars in the Magellanic Cloud Photometric Survey catalog with a mean error of 0.323".

The derived plate scale of 0.502"/pixel differs slightly from the plate scale of 0.500"/pixel measured in the ground-based calibration. The choice of a plate scale for the sky images is somewhat arbitrary because the plate scale varies across the raw image due to the distortion. It would have been possible to apply an expansion to the distortion map to provide sky images with a plate scale of exactly 0.500"/pixel, but we have chosen to keep the original output plate scale.

**Variations with Time and Filter**

In July 2006 it was discovered that the plate scale on the UVW2 images was slightly larger (~ 0.5043"/pixel) than that of the other lenticular filters. This effect was originally observed on UVW2 images of GRB060319 and March 2005 images of the SMCNorth field, and is likely related to the different material used in the UVW2 filter to obtain the proper UV transmittance. The UVW2 teldef files were modified to include an additional expansion so that UVW2 sky images would match the 0.502"/pixel plate scale of the other filters.

As part of the process of returning Swift to operation after the gyro problem in August 2007, a change was made to the spacecraft alignment matrix for the star tracker. The change is equivalent to a -10 arc minute rotation about the spacecraft x-axis. A corresponding change was made to the teldef files for each of the Swift instruments to compensate for the change on the spacecraft. Since the rotation was about an axis very near the UVOT boresight, this should not significantly affect the direction of the UVOT boresight. Subsequent measurements of the boresight before and after the change show that the new teldef file correctly adjusts the UVOT alignment matrices and that the UVOT boresight changed by <0.5".

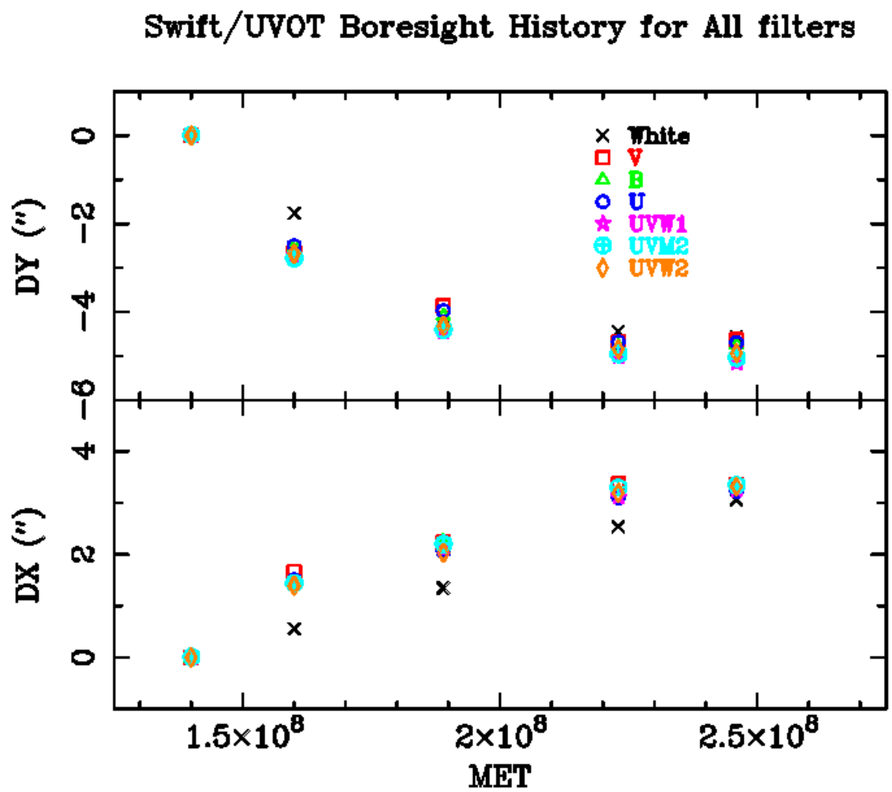



*Figure 3: UVOT boresight history for all seven filters*

The positions of boresights changed in a gradual monotonic fashion throughout the mission. Figure 3 shows the boresight drift for all seven filters, based on thousands of automatic aspect solutions. The boresight values depend on filter, but they show similar changes as a function of time. Figure 2 shows the history for all 7 filters after offsetting the values so that they are all 0 at MET of 140,000,000. Except for the white filter, the histories are very similar. It is not known why the results for the white filter are different.

The UVOT boresights for the white filter and the six lenticular filters were recalibrated in May 2009. Therefore, new teldef files for each filter were generated at five epochs between Nov 2004 and May 2009. The discrete boresight changes of about 1" at these epochs approximate the gradual, continuous changes of the UVOT boresights.

## 2. Magnifier

The magnifier is rarely used, and the astrometric parameters were derived from a single image (00054500041) of the Large Magellanic Clouds. Again, the detector angle, plate scale and boresight position were adjusted to minimize the deviations between the star centroids and positions in the Magellanic Cloud Survey. As expected, the plate scale of the magnifier (Table 1) is approximately four times smaller than in the lenticular filters. However, the rotation angle implemented in the CALDB file (-118.25 deg, Table 1) was determined before the 0.6 deg rotation of the distortion map was implemented. Thus the current CALDB magnifier teldef file gives a median error of 0.94 arcsec for 149 sources in the Magellanic Cloud field. This error would be reduced to 0.40 arcsec if the same rotation angle (-118.8 deg) used for the lenticular filter were used. This mistake will be corrected in a future CALDB release.

## 3. Grisms

The same method to derive the astrometric parameters for the direct images was also used for the grisms. However, the Sextractor positions cannot be directly used, because grism images consist of both zero and first (and higher) orders, and because even the zeroth order are dispersed. In addition, measurements are best done on the detector image (with a constant grism angle) rather than the sky image. Therefore a few star positions were measured manually (by centroiding the maximum pixel) on the detector image, and used to derive an astrometric solution. Two grism images were used for each grism mode (UV or V grism, clocked or nominal) so that eight images are listed in Section 7.

The accuracy of the astrometric solution for the grism is poorer with a mean error of about 1" for the nominal (unclocked) modes. A small part of this error is due to the difficulty of centroiding the zero orders, which are elongated and dependent on spectral type. However, the most likely cause appears to be additional distortion in the grism mode beyond what is given in the detector distortion map. More accurate astrometric solutions were possible for the clocked grism modes, but this may be only because the zero orders appear on a smaller area of the detector. The additional distortion in the grism has now been mapped (using the uvotgraspcorr tool) and the grism teldef file will be updated in a future CALDB release.