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WFC3/UVIS Photometric Transformations

Kailash Sahu, Susana Deustua and Elena Sabbi

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ABSTRACT

We provide photometric transformation coefficients for converting magnitudes from the native WFC3/UVIS filter passbands to Johnson/Cousins UBVRI passbands in ABMAG, STMAG and VEGAMAG system. The transformation coefficients have been calculated both for UVIS1 and UVIS2 chips, for stars of various spectral types and a range black-body temperatures using synthetic stellar/black-body models. We also provide a recipe which can be used to derive transformation coefficients using SYNPHOT. Our recommendation, however, is that the users should refer to WFC3 photometric results in a system based on the WFC3 filters themselves, and we warn that the transformations should be used with extreme caution since they can have limited precision.

1. Introduction

The WFC3/UVIS filters do not have an exact counterpart in any other 'standard' filter set and we recommend users to refer to WFC3 photometric results in a system based on the WFC3 filters themselves. Sensitivity curves can be used to translate physical quantities from theoretical models into the WFC3 observational system.

Nevertheless, the transformation of observed magnitudes to a standard system is sometimes the only way to properly compare data taken with different instruments. Here we provide the coefficients to translate WFC3/UVIS photometry to other well known photometric systems. Coefficients are provided for transformations between both UVIS1 and UVIS2 chips, based on synthetic photometry. We also provide a recipe to derive the required transformation coefficients using the SYNPHOT task 'calcphot' in IRAF/PyRAF. We warn that all of these transformations should be used with extreme caution for reasons described below. Before proceeding with the actual transformations, it is useful to review some of the basics of the photometric systems, most of which are also described in Section 7.2 of the WFC3 Handbook (Dressel et al. 2014).

2. Photometric Systems, Units, and Zeropoints

The WFC3 filters naturally define their own native photometric system. The magnitude of a given object observed in a WFC3 filter is simply given in "instrumental magnitudes" as WFC3MAG = -2.5log [count rate (e^-/sec)]. It is sometimes convenient to convert the measured brightness of a source into a common photometric system, three of the most common systems in use being VEGAMAG, STMAG, and ABMAG. However, transformation to other such photometric systems generally has large uncertainties and is dependent not only on the uncertainty in the system throughput of the instrument, but also on the color range, surface gravity, and metallicity of the source stars considered (e.g., see Sirianni et al. 2005, for a detailed discussion).

The VEGAMAG system is defined such that the bright AOV star α-Lyrae (i.e., Vega) has a magnitude of 0 at all wavelengths. The VEGAMAG system is the default SYNPHOT magnitude system, and the magnitude of a star with flux f in this system is simply $-2.5\log(f/f_{Vega})$, where f_{Vega} is the calibrated spectrum of Vega in SYNPHOT. As this system depends on the calibration of the standard star, it is also subject to errors and changes in that calibration. The STMAG and ABMAG systems are different in that they define an equivalent flux density for a source of predefined shape that would produce the observed count rate. In the STMAG system, the flux density is expressed per unit wavelength, and in the ABMAG system, the flux density is express per unit frequency. The reference spectra are flat as a function of wavelength and frequency in each respective case. The definitions of the systems are:

- STMAG = $-2.5 \text{ Log } f_\lambda - 21.10$ (where f_λ is expressed in erg $cm^{-2}sec^{-1}Å^{-1}$),
- ABMAG = $-2.5 \text{ Log } f_\nu - 48.60$ (where f_ν is expressed in erg $cm^{-2}sec^{-1}Hz^{-1}$)

The offsets in these equations, e.g., −21.10 and −48.60, are also frequently referred to as zero points. However, these are a part of the definition of the photometric system. For example, in the STMAG system, the zero point of −21.10 is set so an object with this brightness will have a flux density of 1 erg $cm^{-2}sec^{-1}Å^{-1}$. For a flat reference spectrum, the flux density in the equations above may be computed by multiplying the count rate by the PHOTFLAM or PHOTFNU keywords found in the image header.

Further information on the VEGAMAG system can be found in Bohlin & Gilliland (2004), the ABMAG system in Oke (1964) and the STMAG system in Korneef et al. (1986).

3. Photometric Zero Points

The photometric zero point of a telescope/instrument/filter combination is a convenient way to characterize the overall sensitivity of the system. By most definitions, the zero point represents the magnitude of a star-like object that produces one count per second within a given aperture (see Maiz Apellaniz 2007). The total system throughput for a given 'observation mode' represents the combined throughput of several individual components, including: the *HST* Optical Telescope Assembly (OTA), the WFC3 pick-off mirror, the reflectivity of the 2 UVIS mirrors, the filter throughput, the transmission of the UVIS inner and outer windows, and the quantum efficiency (QE) of the detector/chip. For *HST* instruments such as WFC3, the zero points depend on the absolute flux calibration of *HST* white dwarf spectra, and therefore they will change whenever that calibration is improved.

Example 1: Zero point calculation with the SYNPHOT task 'calcphot':

--> calcphot 'wfc3,uvis1,f606w,cal' spectrum='rn(bb(10000),band(v),1,counts)' form=vegamag

```
PACKAGE = synphot
   TASK = calcphot

obsmode = wfc3,uvis1,f606w,cal  Instrument observation mode
spectrum= rn(bb(10000),band(v),1,counts)Synthetic spectrum to calculate
form    =              vegamag  Form for output data
(func   =              effstim) Function of output data
(vzero  =                     ) List of values for variable zero
(output =                 none) Output table name
(append =                   no) Append to existing table?
(wavetab=                     ) Wavelength table name
(result =                     ) Result of synphot calculation for form
(refdata=                     ) Reference data
(mode   =                    a)

output:
Mode = band(wfc3,uvis1,f606w,cal)
   Pivot       Equiv Gaussian
 Wavelength         FWHM
   5887.39        1546.133    band(wfc3,uvis1,f606w,cal)
Spectrum:  rn(bb(10000),band(v),1,counts)
    VZERO           VEGAMAG     Mode: band(wfc3,uvis1,f606w,cal)
       0.           26.41755
```

The photometric zero point can be determined using several techniques. Using SYNPHOT, a user can renormalize a spectrum to 1 count/sec in the appropriate WFC3 bandpass and output the zero point in the selected magnitude system (assuming that updated throughput tables are included in the local SYNPHOT installation). Example 1 renormalizes a 10,000 K blackbody for WFC3/UVIS1 in the F606W filter, and outputs the zero point in the VEGAMAG system. Note that an additional 'cal' switch has been added to the HST 'obsmode' to correct for the flat field of a given filter/chip.

The photometric keywords in the header of WFC3 images reflect the best solutions at the time the data was downloaded. The zeropoints published on the WFC3 Web page www.stsci.edu/hst/wfc3/phot_zp_lbn will ideally match the values produced on-the-fly using SYNPHOT, but these pages can become out-of-date as new calibrations are defined. Likewise, the zeropoints published in WFC3 ISR 2009-31 are also out-of-date and should no longer be used. For these reasons, users are strongly encouraged to use SYNPHOT to get the most up-to-date photometric zeropoints.

4. Photometric Transformation Coefficients

As discussed above, there are some advantages in deriving the transformation coefficients, in spite of the uncertainties discussed above. A major part of the uncertainties comes from the system throughputs and atmospheric transmission coefficients of the ground-based site considered, rather than the source characteristics. As a result, transformation coefficients based on synthetic stellar models are generally adequate for most part.

In Table 1, we provide transformation coefficients for synthetic stellar and black-body models (The numbers in columns 3 to 5 are quantities that need to be added for the required transformations). We also provide below a recipe to derive the transformation coefficients using the SYNPHOT task 'calcphot'. Since some of the calibration files are likely to change, we recommend users to derive the transformation coefficients using the recipe provided here. This will ensure that the most recent transformation coefficients are calculated taking the most recent and updated sensitivities into account.

Example 2 computes the color term from Cousins-I to UVIS1,F814W in the ABMAG system. The results correspond to row 31, column 3 in Table 1.

Example 2: Color term calculation with the SYNPHOT task 'calcphot'.

--> calcphot 'band(i)-band(uvis1,f814w)' spectrum='bb(5000)' form=abmag

```
obsmode =        band(i)-band(wfc3,uvis1,f814w)
spectrum=        bb(5000))Synthetic spectrum to calculate
form    =        ABMAG  )Form for output data
(func   =        effstim) Function of output data
(vzero  =           ) List of values for variable zero
(output =        none) Output table name
(append =        no) Append to existing table?
(wavetab=          ) Wavelength table name
(result =          ) Result of synphot calculation for form
(refdata=          ) Reference data
(mode   =         a)

Output:
Mode = band(I) - band(wfc3,uvis1,f814w)
   Pivot       Equiv Gaussian
 Wavelength         FWHM
   7874.84        897.6057    band(I)
   8029.52         1562.04    band(wfc3,uvis1,f814w)
Spectrum:  bb(5000)
    VZERO    ABMAG(band(I)) - ABMAG(band(wfc3,uvis1,f814w))
       0.           0.004665
```

Table 1: Photometric Transformation Coefficients for Synthetic Stellar and Black-Body Models

Spectrum	Color	ABMAG	STMAG	VEGAMAG
BB(2500)	I-(uvis1,f814w)	0.092	0.050	0.092
BB(2500)	V-(uvis1,f606w)	0.629	0.473	0.708
BB(2500)	V-(uvis1,f555w)	-0.158	-0.089	-0.188
BB(2500)	B-(uvis1,f475w)	0.882	0.691	0.893
BB(2500)	U-(uvis1,f336w)	-1.094	-0.947	-0.670
BB(2500)	I-(uvis2,f814w)	0.089	0.048	0.088
BB(2500)	V-(uvis2,f606w)	0.629	0.473	0.708
BB(2500)	V-(uvis2,f555w)	-0.157	-0.088	-0.188
BB(2500)	B-(uvis2,f475w)	0.881	0.690	0.892
BB(2500)	U-(uvis2,f336w)	-1.094	-0.947	-0.670
BB(3000)	I-(uvis1,f814w)	0.055	0.013	0.055
BB(3000)	V-(uvis1,f606w)	0.450	0.294	0.528
BB(3000)	V-(uvis1,f555w)	-0.154	-0.085	-0.185
BB(3000)	B-(uvis1,f475w)	0.696	0.505	0.707

BB(3000)	U-(uvis1,f336w)	-0.857	-0.710	-0.433
BB(3000)	I-(uvis2,f814w)	0.053	0.013	0.052
BB(3000)	V-(uvis2,f606w)	0.450	0.294	0.528
BB(3000)	V-(uvis2,f555w)	-0.154	-0.085	-0.185
BB(3000)	B-(uvis2,f475w)	0.695	0.504	0.706
BB(3000)	U-(uvis2,f336w)	-0.857	-0.710	-0.433
BB(4000)	I-(uvis1,f814w)	0.020	-0.022	0.020
BB(4000)	V-(uvis1,f606w)	0.247	0.091	0.325
BB(4000)	V-(uvis1,f555w)	-0.126	-0.057	-0.156
BB(4000)	B-(uvis1,f475w)	0.455	0.264	0.467
BB(4000)	U-(uvis1,f336w)	-0.564	-0.417	-0.140
BB(4000)	I-(uvis2,f814w)	0.019	-0.022	0.018
BB(4000)	V-(uvis2,f606w)	0.247	0.091	0.325
BB(4000)	V-(uvis2,f555w)	-0.125	-0.057	-0.156
BB(4000)	B-(uvis2,f475w)	0.454	0.264	0.466
BB(4000)	U-(uvis2,f336w)	-0.564	-0.417	-0.139
BB(5000)	I-(uvis1,f814w)	0.005	-0.038	0.004
BB(5000)	V-(uvis1,f606w)	0.141	-0.015	0.219
BB(5000)	V-(uvis1,f555w)	-0.094	-0.025	-0.125
BB(5000)	B-(uvis1,f475w)	0.309	0.118	0.320
BB(5000)	U-(uvis1,f336w)	-0.395	-0.247	0.030
BB(5000)	I-(uvis2,f814w)	0.004	-0.037	0.003
BB(5000)	V-(uvis2,f606w)	0.141	-0.015	0.219
BB(5000)	V-(uvis2,f555w)	-0.094	-0.025	-0.125
BB(5000)	B-(uvis2,f475w)	0.308	0.118	0.320
BB(5000)	U-(uvis2,f336w)	-0.394	-0.247	0.030
BB(6000)	I-(uvis1,f814w)	-0.003	-0.046	-0.004
BB(6000)	V-(uvis1,f606w)	0.078	-0.078	0.157
BB(6000)	V-(uvis1,f555w)	-0.067	0.001	-0.098
BB(6000)	B-(uvis1,f475w)	0.212	0.021	0.224
BB(6000)	U-(uvis1,f336w)	-0.286	-0.139	0.139
BB(6000)	I-(uvis2,f814w)	-0.004	-0.044	-0.004
BB(6000)	V-(uvis2,f606w)	0.078	-0.078	0.157
BB(6000)	V-(uvis2,f555w)	-0.067	0.001	-0.098
BB(6000)	B-(uvis2,f475w)	0.212	0.021	0.223
BB(6000)	U-(uvis2,f336w)	-0.285	-0.138	0.139
BB(8000)	I-(uvis1,f814w)	-0.011	-0.053	-0.012
BB(8000)	V-(uvis1,f606w)	0.010	-0.146	0.088
BB(8000)	V-(uvis1,f555w)	-0.028	0.041	-0.059
BB(8000)	B-(uvis1,f475w)	0.094	-0.097	0.106
BB(8000)	U-(uvis1,f336w)	-0.156	-0.009	0.269
BB(8000)	I-(uvis2,f814w)	-0.011	-0.052	-0.012
BB(8000)	V-(uvis2,f606w)	0.010	-0.146	0.088
BB(8000)	V-(uvis2,f555w)	-0.028	0.041	-0.059
BB(8000)	B-(uvis2,f475w)	0.094	-0.096	0.106

BB(8000)	U-(uvis2,f336w)	-0.156	-0.009	0.269
BB(10000)	I-(uvis1,f814w)	-0.015	-0.057	-0.015
BB(10000)	V-(uvis1,f606w)	-0.025	-0.181	0.053
BB(10000)	V-(uvis1,f555w)	-0.003	0.066	-0.033
BB(10000)	B-(uvis1,f475w)	0.027	-0.164	0.039
BB(10000)	U-(uvis1,f336w)	-0.083	0.064	0.342
BB(10000)	I-(uvis2,f814w)	-0.014	-0.055	-0.015
BB(10000)	V-(uvis2,f606w)	-0.025	-0.181	0.053
BB(10000)	V-(uvis2,f555w)	-0.003	0.066	-0.033
BB(10000)	B-(uvis2,f475w)	0.027	-0.164	0.039
BB(10000)	U-(uvis2,f336w)	-0.083	0.064	0.342
O5V	I-(uvis1,f814w)	-0.019	-0.061	-0.020
O5V	V-(uvis1,f606w)	-0.111	-0.267	-0.032
O5V	V-(uvis1,f555w)	0.080	0.149	0.049
O5V	B-(uvis1,f475w)	-0.154	-0.345	-0.142
O5V	U-(uvis1,f336w)	0.111	0.259	0.536
O5V	I-(uvis2,f814w)	-0.018	-0.059	-0.019
O5V	V-(uvis2,f606w)	-0.111	-0.267	-0.032
O5V	V-(uvis2,f555w)	0.080	0.148	0.049
O5V	B-(uvis2,f475w)	-0.154	-0.344	-0.142
O5V	U-(uvis2,f336w)	0.111	0.258	0.536
B5V	I-(uvis1,f814w)	-0.011	-0.053	-0.011
B5V	V-(uvis1,f606w)	-0.091	-0.247	-0.013
B5V	V-(uvis1,f555w)	0.053	0.122	0.022
B5V	B-(uvis1,f475w)	-0.083	-0.273	-0.071
B5V	U-(uvis1,f336w)	-0.110	0.037	0.314
B5V	I-(uvis2,f814w)	-0.010	-0.050	-0.011
B5V	V-(uvis2,f606w)	-0.091	-0.247	-0.013
B5V	V-(uvis2,f555w)	0.053	0.122	0.022
B5V	B-(uvis2,f475w)	-0.082	-0.273	-0.071
B5V	U-(uvis2,f336w)	-0.110	0.037	0.314
A5V	I-(uvis1,f814w)	-0.008	-0.050	-0.008
A5V	V-(uvis1,f606w)	-0.050	-0.206	0.028
A5V	V-(uvis1,f555w)	0.003	0.072	-0.028
A5V	B-(uvis1,f475w)	0.066	-0.124	0.078
A5V	U-(uvis1,f336w)	-0.330	-0.183	0.095
A5V	I-(uvis2,f814w)	-0.008	-0.048	-0.008
A5V	V-(uvis2,f606w)	-0.050	-0.206	0.028
A5V	V-(uvis2,f555w)	0.003	0.071	-0.028
A5V	B-(uvis2,f475w)	0.066	-0.124	0.078
A5V	U-(uvis2,f336w)	-0.330	-0.183	0.095
F5V	I-(uvis1,f814w)	-0.007	-0.049	-0.007
F5V	V-(uvis1,f606w)	0.037	-0.119	0.116
F5V	V-(uvis1,f555w)	-0.038	0.031	-0.069
F5V	B-(uvis1,f475w)	0.188	-0.003	0.200

F5V	U-(uvis1,f336w)	-0.281	-0.134	0.143
F5V	U-(uvis1,f336w)	-0.281	-0.134	0.143
F5V	V-(uvis2,f606w)	0.037	-0.119	0.116
F5V	V-(uvis2,f555w)	-0.038	0.031	-0.069
F5V	B-(uvis2,f475w)	0.188	-0.003	0.200
F5V	U-(uvis2,f336w)	-0.281	-0.134	0.144
G5V	I-(uvis1,f814w)	-0.002	-0.044	-0.002
G5V	V-(uvis1,f606w)	0.080	-0.076	0.159
G5V	V-(uvis1,f555w)	-0.055	0.014	-0.086
G5V	B-(uvis1,f475w)	0.288	0.098	0.300
G5V	U-(uvis1,f336w)	-0.284	-0.137	0.140
G5V	I-(uvis2,f814w)	-0.002	-0.043	-0.003
G5V	V-(uvis2,f606w)	0.080	-0.076	0.159
G5V	V-(uvis2,f555w)	-0.055	0.014	-0.086
G5V	B-(uvis2,f475w)	0.288	0.098	0.300
G5V	U-(uvis2,f336w)	-0.284	-0.137	0.140
M2V	I-(uvis1,f814w)	0.058	0.016	0.058
M2V	V-(uvis1,f606w)	0.297	0.141	0.375
M2V	V-(uvis1,f555w)	-0.136	-0.067	-0.167
M2V	B-(uvis1,f475w)	0.547	0.357	0.559
M2V	U-(uvis1,f336w)	-0.900	-0.753	-0.476
M2V	I-(uvis2,f814w)	0.056	0.015	0.055
M2V	V-(uvis2,f606w)	0.297	0.141	0.375
M2V	V-(uvis2,f555w)	-0.136	-0.067	-0.167
M2V	B-(uvis2,f475w)	0.546	0.356	0.558
M2V	U-(uvis2,f336w)	-0.900	-0.753	-0.475
Ellip. galaxy	B-(uvis1,f475w)	0.420	0.229	0.432
Ellip. galaxy	B-(uvis2,f475w)	0.419	0.229	0.431
Ellip. galaxy	I-(uvis1,f814w)	0.042	0.000	0.042
Ellip. galaxy	I-(uvis2,f814w)	0.041	0.000	0.040
Ellip. galaxy	U-(uvis1,f336w)	-0.461	-0.314	-0.037
Ellip. galaxy	U-(uvis2,f336w)	-0.461	-0.314	-0.036
Ellip. galaxy	V-(uvis1,f555w)	-0.087	-0.019	-0.118
Ellip. galaxy	V-(uvis1,f606w)	0.194	0.038	0.273
Ellip. galaxy	V-(uvis2,f555w)	-0.087	-0.019	-0.118
Ellip. galaxy	V-(uvis2,f606w)	0.194	0.038	0.273
S0 galaxy	B-(uvis1,f475w)	0.418	0.227	0.429
S0 galaxy	B-(uvis2,f475w)	0.417	0.226	0.429
S0 galaxy	I-(uvis1,f814w)	0.041	-0.001	0.041
S0 galaxy	I-(uvis2,f814w)	0.040	-0.001	0.039
S0 galaxy	U-(uvis1,f336w)	-0.322	-0.175	0.102
S0 galaxy	U-(uvis2,f336w)	-0.322	-0.175	0.102
S0 galaxy	V-(uvis1,f555w)	-0.092	-0.023	-0.122
S0 galaxy	V-(uvis1,f606w)	0.191	0.035	0.269
S0 galaxy	V-(uvis2,f555w)	-0.092	-0.023	-0.122

S0 galaxy	V-(uvis2,f606w)	0.191	0.035	0.269
Sa galaxy	B-(uvis1,f475w)	0.322	0.131	0.334
Sa galaxy	B-(uvis2,f475w)	0.322	0.131	0.333
Sa galaxy	I-(uvis1,f814w)	0.026	-0.016	0.026
Sa galaxy	I-(uvis2,f814w)	0.025	-0.016	0.024
Sa galaxy	U-(uvis1,f336w)	-0.423	-0.276	0.001
Sa galaxy	U-(uvis2,f336w)	-0.423	-0.276	0.002
Sa galaxy	V-(uvis1,f555w)	-0.084	-0.015	-0.115
Sa galaxy	V-(uvis1,f606w)	0.191	0.035	0.269
Sa galaxy	V-(uvis2,f555w)	-0.084	-0.015	-0.115
Sa galaxy	V-(uvis2,f606w)	0.191	0.035	0.269
Sb galaxy	B-(uvis1,f475w)	0.343	0.152	0.355
Sb galaxy	B-(uvis2,f475w)	0.342	0.152	0.354
Sb galaxy	I-(uvis1,f814w)	0.037	-0.005	0.037
Sb galaxy	I-(uvis2,f814w)	0.036	-0.005	0.035
Sb galaxy	U-(uvis1,f336w)	-0.239	-0.092	0.185
Sb galaxy	U-(uvis2,f336w)	-0.239	-0.092	0.185
Sb galaxy	V-(uvis1,f555w)	-0.082	-0.013	-0.112
Sb galaxy	V-(uvis1,f606w)	0.183	0.027	0.262
Sb galaxy	V-(uvis2,f555w)	-0.081	-0.013	-0.112
Sb galaxy	V-(uvis2,f606w)	0.183	0.027	0.262
Sc galaxy	B-(uvis1,f475w)	0.061	-0.130	0.072
Sc galaxy	B-(uvis2,f475w)	0.060	-0.130	0.072
Sc galaxy	I-(uvis1,f814w)	0.057	0.015	0.057
Sc galaxy	I-(uvis2,f814w)	0.068	0.028	0.067
Sc galaxy	U-(uvis1,f336w)	-0.120	0.028	0.305
Sc galaxy	U-(uvis2,f336w)	-0.119	0.028	0.305
Sc galaxy	V-(uvis1,f555w)	0.044	0.112	0.013
Sc galaxy	V-(uvis1,f606w)	0.186	0.030	0.265
Sc galaxy	V-(uvis2,f555w)	0.044	0.113	0.013
Sc galaxy	V-(uvis2,f606w)	0.187	0.031	0.265

Notes:
1. The UBVRI filter system in Table 1 corresponds to Johnson UBV and Cousins RI bands.
2. BB(2500) refers to black body with temperature 2500K, etc.
3. The stellar models used here are from Castelli and Kurucz models, with solar metallicity and T and log z values as appropriate. In STScI, these stellar models are in the directory crgridck04$ckp01. The names of the files corresponding to different stellar models can be found at
http://www.stsci.edu/hst/observatory/crds/astronomical_catalogs.html
http://www.stsci.edu/hst/observatory/crds/castelli_kurucz_atlas.html
The galaxy models are in the directory crgrid$kc96, which corresponds to

/grp/hst/cdbs/grid/kc96. For example, the model Ellip. galaxy spectrum can be refereed to as crgrid$kc96/Ellip._template.fits in synphot.
More detailed information on the files can be found at
http://www.stsci.edu/hst/HST_overview/documents/synphot/AppA_Catalogs.html#57
The files are also available for download, details are available at
http://www.stsci.edu/hst/observatory/crds/cdbs_throughput.html

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