# The Dark Energy Survey Six-Year Calibration Star Catalog

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### ABSTRACT

This Technical Note presents a catalog of calibrated reference stars that was generated by the Forward Calibration Method (FGCM) pipeline (Burke, Rykoff, et al., 2018) as part of the FGCM photometric calibration of the full Dark Energy Survey (DES) 6-Year data set (Y6). This catalog provides DES *grizY* magnitudes for 17 million stars with *i*-band magnitudes mostly in the range  $16 \leq i \leq 21$  spread over the full DES footprint covering 5000 deg<sup>2</sup> over the Southern Galactic Cap at galactic latitudes  $b \leq -20^{\circ}$  (plus a few outlying fields disconnected from the main survey footprint). These stars are calibrated to a uniformity of better than 1.8 mmag (0.18%) RMS over the survey area. The absolute calibration of the catalog is computed with reference to the STISNIC.007 spectrum of the Hubble Space Telescope CalSpec standard star C26202; including systematic errors, the absolute flux system is known at the  $\approx 1\%$  level. As such, these stars provide a useful reference catalog for calibrating *grizY*-

band or *grizY*-like band photometry in the Southern Hemisphere, particularly for observations within the DES footprint.

Keywords: surveys, catalogs, techniques:photometric

# 1. INTRODUCTION

### 1.1. The Dark Energy Survey

The Dark Energy Survey (DES) began observations in 2013 using the Dark Energy Camera (DECam) mounted on the Victor M. Blanco 4-meter telescope at the Cerro Tololo Inter-American Observatory (CTIO) (Sánchez & DES Collaboration 2010, Diehl et al. 2014, 2019). The DECam instrument (Flaugher et al. 2015) is a 570 megapixel CCD research camera composed of 74 individual CCDs, with active field of view of 2.7 deg<sup>2</sup> at the f/2.7 prime focus of the Blanco. Science data were collected using the DES *grizY* filters. When completed in 2019 the survey covered approximately 5000 deg<sup>2</sup> of the southern hemisphere sky with 8-10 repeated observations in each band taken over a period of 6 years (Neilsen et al. 2019), comprising the full 6-year data set (Y6). The data were processed by the DES data management system (Desai et al. 2012) at the National Center for Supercomputing Applications at the University of Illinois. A complete description of the DES image processing pipeline can be found in Morganson et al. (2018). This pipeline utilizes image quality cuts and processing based on instrumental throughput derived from dedicated dithered observations of selected star fields (see Bernstein et al. 2018).

### 1.2. Overview Of The DES Photometric Calibration

Photometric calibration of the DES broadband images is performed using the Forward Global Calibration Method (FGCM), which is described in detail in Burke, Rykoff, et al., 2018<sup>1</sup> and further updated in Abbott et al. (2021). FGCM calibrates the full survey with a forward model that incorporates the known system throughput (including positional variation in the transmission curve of filters and chromatic quantum efficiency differences in the detectors) with a model of the atmosphere. Isolated stars (with no neighbor within 2") are selected from single-epoch images, and all calibration stars are observed with a signal-to-noise greater than 10 in at least 2 observations in each of *griz*. The PSF flux is used as the calibration flux to minimize issues in photometry for faint stars due to offsets in the local background. Stars with broad range of colors (0.5 < g - i < 3.5) are used to constrain atmospheric parameters in a full multi-band calibration. A final down-sampling of stars in high density regions is performed prior to performing the calibration fit to ensure that the overall chi-squared is not dominated by the edges of the survey.

The FGCM fit is iterative, with the model based on "photometric" observations that are defined as those that have fluxes consistent with variations in the atmosphere that can be described by variations in aerosol, precipitable water vapor, and ozone, in addition to the variations in airmass predicted from the MODTRAN model (Berk et al. 1999), which is described fully in Burke, Rykoff, et al., 2018. We note that 80% of the full set of exposures are considered photometric, in that variations can be described by the atmosphere model without excess gray extinction or a significant increase in variance across the focal plane. A number of improvements to the model have been made since the original FGCM paper, including (a) treatment of aperture effects caused by variations in the wings of the PSF (see, e.g., Bernstein et al. 2018); (b) a linear

<sup>&</sup>lt;sup>1</sup> https://github.com/erykoff/fgcm/tree/v3.3.1/fgcm

approximation to the chromatic degradation of the primary mirror surface between recoatings of the mirror; (c) the GPS data is no longer used as a constraint on the atmospheric water vapor.

After the convergence of the model fit, non-photometric exposures are matched to the preliminary network of stars to produce zero-points and chromatic correction terms for every CCD/exposure in the survey, provided they have sufficient overlap with the calibration stars. We then produce the final DES Year 6 Calibration Star Catalog presented here by applying these calibration parameters to every star observation, including ones that were not used in the fit due to being in higher density regions.

## 2. CATALOG DESCRIPTION

In this Technical Note, we wish merely to provide this DES 6-Year (Y6) Calibration Star Catalog and to describe its general characteristics in order to facilitate its use as a photometric reference catalog for the calibration of other data sets using similar filter bandpasses. As noted in the previous section, in creating this reference catalog, FGCM took into account and and removed the effects of positional (across the DECam CCD mosaic) and temporal variations of the effective bandpasses for a observations on a given CCD at at given time and date; the photometry has been calibrated to the DES standard bandpasses, which are shown in Figure 1. The full catalog contains roughly 17 million stars with *i*-band magnitudes mostly in the range  $16 \leq i \leq 21$ .

In Figure 2, we show the sky density distribution of the stars in the this catalog. Nearly all fall within the official contiguous DES footprint, but we note that there are also some outlier fields that may be of interest to the user of this catalog.

In Figure 3, we plot the offset between the Gaia *G*-band synthesized magnitudes transformed from the DES *griz* magnitudes ( $G_{pred}$ ) of the stars in this catalog and their true measured Gaia *G*-band magnitude ( $G_{Gaia}$ ) from the Gaia Data Release 3 (Gaia DR3; (Gaia Collaboration 2022)). The synthesized *G*-band magnitudes were calculated in a manner similar to that in Abbott et al. (2021). For this comparison, stars were selected to have 0.5 < g - i < 1.5 and G < 20. Note that the RMS in in the difference in the synthesized and genuine *G*-band magnitudes ( $G_{pred} - G_{Gaia}$ ), averaged over an NSIDE=128 HEALPix pixel (sky area  $\approx$  0.21 sq deg), is a mere 1.8 mmag (0.018%), and the main coherent features in the map appear to be of Gaia scan patterns, not DES hexagonal pointings. Based on this plot, we estimate that the FGCM calibration star photometry is uniform across the DES footprint at the 1.8 mmag (0.18%) RMS level or better. We note that there is an offset of up to 1% at the edge of the survey toward the Galactic Bulge (comprising about 5% of the area). We have yet to determine if this is an issue with the DES calibrations, the Gaia calibrations, Galactic reddening residuals, background issues, or some combination of these. Overall, we attribute the exceptional uniformity of the calibration to the stability of DECam as well as the simplicity of the survey strategy, with all wide-field (WF) survey exposures of an equal 90 seconds.

For a calibration reference catalog to be useful, one needs to know over which magnitude ranges it covers. As we see in Figure 4, this catalog roughly covers a range in *i*-band of 16–21. Although there are a small fraction of stars with *i*-band outside this range, the vast majority lie within this range. Other bands have somewhat different ranges, due both to the typical colors of stars and to the overall sensitivity of the DES survey in these other bands.

In Figures 5, 6, and 7, we plot the color-color diagrams for this catalog. (In Figures 5 and 6, we also note some special features in these particular color-color diagrams.) Note, in each figure, we include only those stars that have more than 2 good DES observations in each of the 3 filter bandpasses represented (e.g.,  $N_{\text{good}} > 2$  for each of the *g*, *r*, and *i* bandpasses in Fig. 5). For the highest quality work, we recommend the user to implement these quality cuts when using this catalog. Note that catalog contains a full breadth of

stellar types, from hot white dwarfs  $(g-r \le 0, r-i \le 0)$  to M stars  $(g-r \approx 1.6)$ . Also note the tightness of the features in the stellar locus in each of these plots, which indicative of the photometric quality of this catalog.

In addition to the recommendation that the user apply a quality cut on the number of good observations a star has in each filter (preferably  $N_{\text{good}} > 2$  for a given filter bandpass), we also provide a caveat that, although the vast majority of stars in the catalog have highly precise and accurate calibrated magnitudes, a small fraction have relatively large statistical errors. This is highlighted for each filter bandpass in Figures 8– 12. Depending on the use, one may wish to either weight the stars accordingly, or even just cull those stars with high statistical errors. As seen in the log-linear histograms in Figure 13, over 90% of the stars have statistical errors in their photometry of  $\sigma_g < 0.02$  (and similar or better in the other filter bands).

So, typically how many good observations were obtained for each star in each filter? The DES is composed of two parts: a wide-field (WF) survey covering  $\approx 5000 \text{ deg}^2$ , plus a set of ten 2.7 deg<sup>2</sup> deep transient fields (TFs; also known as the "supernova fields") that were observed roughly once a week throughout the DES seasons (typically August–February) (Diehl et al. 2019, Hartley et al. 2020). The goal was to cover the WF portion of the survey with a total of 10 dithered "tilings" in *g*,*r*,*i*,*z* (and, in the end, 8 for *Y*). Of course, due to the dither pattern, some stars might be observed more than 10 times, and others fewer than 10. Only photometric observations<sup>2</sup> are counted as "good" for the  $N_{good}$  tabulation. In addition, there are further cuts to individual observations that are deemed outliers. In Figure 14, we plot the histogram of  $N_{good}$  using a linear y-axis and cut off at  $N_{good} = 12$ . This is appropriate for stars in the WF survey. In Figure 15, we plot the histogram of  $N_{good}$  using a logarithmic y-axis and cut off at  $N_{good} = 12$ . This is appropriate for stars in the TFs. Note that there are some stars with nearly 1400 good observations in *z*-band.

So far, we have been focused on the uniformity and precision of this catalog. Another question that remains is how accurately is it tied to a system of physical units (e.g., ergs s<sup>-1</sup> cm<sup>-2</sup> Hz<sup>-1</sup>) traced to the *System Internationale* (SI)? The DES ties itself to the SI by tying itself to the AB magnitude system (Oke & Gunn 1983, Fukugita et al. 1996); so another way to put this question is, "How well is the DES tied to the AB magnitude system?" To tie this catalog of calibration stars (and hence the DES Year 6 data) to the AB system, FGCM used the synthetic DES *grizY* AB magnitudes of the star C26202 – a star that lies in the DES itself and is faint enough not to be saturated in photometric DES science images – to zeropoint the whole FGCM DES Year 6 calibration star catalog to the AB system. These synthetic magnitudes were calculated by integrating the official DES passband throughputs (Fig. 1) with one of standard spectra for C26202 from the Hubble Space Telescope (HST) CalSpec database (Bohlin et al. 2014) – in this case, the then-current spectrum C26202.STISNIC.007.

In Table 1 we summarize our results. For each DES band, we tabulate the synthetic AB magnitude of the C26202.STISNIC.007 spectrum (the input values to FGCM), the measured AB magnitudes for C26202 from the final catalog of calibrated stars from FGCM (FGCM mag), the statistical error for the AB magnitude output by FGCM (FGCM  $\sigma_{mag}$ ), the number of good DES observations of C26202 ( $N_{good}$ ), how much the FGCM output magnitude differs from the synthetic DES AB magnitude of C26202.STISNIC.007 (AB offset), an estimate of how well the FGCM output magnitude is tied to the synthetic DES AB magnitude of C26202.STISNIC.007 ( $\sigma_{AB,stat}$ ), and a rough estimate of how well the synthetic DES AB magnitude of C26202.STISNIC.007 itself may be tied to the CalSpec AB system ( $\sigma_{AB,sys}$ ). Note that the absolute value of the AB offset is  $\leq 3 \text{ mmag}$  ( $\leq 0.3\%$ ) for all bands, and that the AB offset is within  $2\sigma_{AB,stat}$  for all

<sup>&</sup>lt;sup>2</sup> As previously noted, 80% of the exposures are considered "photometric" in that the variations are modeled by our atmosphere model.

5 DES passbands, indicating that this catalog is well tied to the synthetic DES AB photometry of C26202. That said, estimates of how well C26202.STISNIC.007 (or the majority of other CalSpec stars) is tied to the AB system is roughly at the 11-12 mmag level (1.1-1.2% level), as is shown in the final column of Table 1 ( $\sigma_{AB,sys}$ ), and this is confirmed by the differences in the synthetic DES AB magnitudes from other versions of the HST CalSpec spectra (see, e.g., § 4.2.2 and Appendix C of Abbott et al. 2021). Those seeking sub-percent absolute calibrations should note this caveat.

Finally, Table 2 provides a listing of the first 25 entries from the DES Y6 FGCM calibration star catalog sorted by RA. The columns include a running FGCM\_ID (out of order here, since here we show the catalog after sorting it by ascending RA), the RA and DEC in degrees in J2000.0 coordinates, a FLAG to note if the star in question was used in the FGCM modeling fit (0) or if the star was randomly excluded from the fit to help with statistical measures (16)<sup>3</sup>, the calibrated DES AB magnitudes of the star in each DES band (*g*, *r*, *i*, *z*, *Y*), the statistical errors in those calibrated magnitudes ( $\sigma_{g,r,i,z,Y}$ ), and the number of good DES observations that went into those calibrated magnitudes ( $N_{g,r,i,z,Y}$ ). The full machine-readable table can be found at https://des.ncsa.illinois.edu/releases/other.

<sup>&</sup>lt;sup>3</sup> Roughly 10% of stars at high Galactic latitudes were reserved, and somewhat fewer at low Galactic latitudes. Both FLAG = 0 and FLAG = 16 stars are useful as calibration stars.



**Figure 1.** A plot of the DES standard bandpass curves (grizY) used in DES DR2 (Abbott et al. 2021). The bandpasses represent the total system throughput, including atmospheric transmission (air mass = 1.2) and the average instrumental response across the science CCDs. Machine-readable tables of the DES standard bandpasses can be found at https://des.ncsa.illinois.edu/releases/dr2/dr2-products



**Figure 2.** A (logarithmically scaled) sky density Aitoff projection of the full DES Y6 FGCM calibration star catalog, plotted in equatorial coordinates (black grid). The light purple grid lines indicate contours of galactic latitude, *b*. Note that the main contiguous footprint lies within  $b \leq -20 \ deg$ , although there are a handful of fields outside this main footprint.



**Figure 3.** *Left:* A map of the per-pixel average offset between Gaia G-band fluxes synthesized from DES *griz* fluxes and the measured Gaia G-band fluxes (HEALPix NSIDE=128). We note that there is an offset of up to 1% at the edge of the survey toward the Galactic Bulge (comprising about 5% of the area). We have yet to determine if this is an issue with the DES calibrations, the Gaia calibrations, Galactic reddening residuals, background issues, or some combination of these. *Right:* Histogram of the per-pixel offset between these maps.



Figure 4. Histogram of the distribution of magnitudes for the standard star catalog in each of the 5 DES filter bands.

Table 1.	Comparison	of DES	synthetic A	AB mag	nitudes	and DES	observed
FGCM P	SF magnitud	es for the	HST CA	LSPEC	Standar	d C26202	,

band	STISNIC.007 [mag]	FGCM mag [mag]	FGCM $\sigma_{mag}$ [mag]	Ngood	AB offset [mag]	$\sigma_{AB,{ m stat}}{}^a$ [mag]	$\sigma_{AB,\mathrm{sys}}{}^{b}$ [mag]
g	16.695913	16.6949	0.0001	119	+0.0010	0.0018	0.011
r	16.340208	16.3432	0.0004	39	-0.0030	0.0018	0.011
i	16.257366	16.2588	0.0004	38	-0.0014	0.0018	0.011
z	16.245108	16.2432	0.0001	169	+0.0019	0.0018	0.012
Y	16.267345	16.2701	0.0005	49	-0.0028	0.0019	0.012

<sup>*a*</sup> The given passband's FGCM  $\sigma_{mag}$  added in quadrature with the estimated FGCM sample uniformity vs. Gaia (1.8 mmag).

<sup>b</sup> A rough estimate of how well DES synthetic magnitudes for C26202 are tied to the true AB system, based on uncertainties in the CalSpec system (see § 4.2.2 of Abbott et al. 2021).



**Figure 5.** (top) The g-r, r-i color-color diagram for all stars with  $N_{good} > 2$  for the g, r, i bandpasses. (bottom) Same as the top figure, but just for those FGCM calibration stars with matches to the SpecPhoto view from the Sloan Digital Sky Survey Data Release 17 (SDSS DR17; Abdurro'uf et al. 2022) database available on the SDSS CasJobs server (https://skyserver.sdss.org/CasJobs). In the SpecPhoto view, objects depicted as gray symbols were classified as stars; cyan symbols are objects that were classified as Quasi-Stellar Objects (QSOs); purple symbols were classified as galaxies; and red symbols were stars that were further subclassified as carbon stars.



**Figure 6.** (*top*) The r-i, i-z color-color diagram for all stars with  $N_{good} > 2$  for the *r*, *i*, *z* bandpasses. (*bottom*) Same as top figure, but zoomed onto the blue-blue quadrant and now color-coded by the *r*-band absolute magnitude ( $M_r$ ) of each object, making use of the Gaia EDR3 geometric distances from Bailer-Jones et al. (2021); roughly 90% of FGCM calibration stars have Gaia EDR3 geometric distances. Note the trifurcation of the stellar locus is composed of low-luminosity ( $M_r \approx 14$ ) white dwarf stars, medium-luminosity ( $M_r \approx 6$ ) main-sequence stars, and high-luminosity ( $M_r \approx 3$ ) blue horizontal branch (BHB) stars. We note that Vickers et al. (2012) have previously used SDSS *z*-band as a proxy measure for stellar surface gravity to discrimate BHB stars from white dwarfs.



**Figure 7.** The i-z, z-Y color-color diagram for all stars with  $N_{good} > 2$  for the *i*, *z*, *Y* bandpasses.



**Figure 8.**  $\sigma_g$  vs. g. Data are binned in 0.001 mag ( $\sigma_g$ ) × 0.1 mag (g) bins. (Here we do not apply any  $N_{\text{good}}$  cuts.)



**Figure 9.**  $\sigma_r$  vs. r. Data are binned in 0.001 mag ( $\sigma_r$ ) × 0.1 mag (r) bins. (Here we do not apply any  $N_{\text{good}}$  cuts.)



**Figure 10.**  $\sigma_i$  vs. *i*. Data are binned in 0.001 mag ( $\sigma_i$ ) × 0.1 mag (*i*) bins. (Here we do not apply any  $N_{\text{good}}$  cuts.)



Figure 11.  $\sigma_z$  vs. z. Data are binned in 0.001 mag ( $\sigma_z$ ) × 0.1 mag (z) bins. (Here we do not apply any  $N_{\text{good}}$  cuts.)



**Figure 12.**  $\sigma_Y$  vs. Y. Data are binned in 0.001 mag ( $\sigma_Y$ ) × 0.1 mag (y) bins. (Here we do not apply any  $N_{\text{good}}$  cuts.)



**Figure 13.** Histogram of  $\sigma_{mag}$ . Data are binned in 0.001 mag bins. Note that variable stars and QSOs are not preculled from the FGCM calibration star sample, which helps explains the long tail in the distribution of  $\sigma_{mag}$ 's. Despite the long tail, over 90% of the stars have  $\sigma_g < 0.02 \text{ mag}$ . (Here we do not apply any  $N_{good}$  cuts.)



**Figure 14.** Histogram of the number of good measurements that went into the magnitude estimate for each star in a given filter band. We cut this histogram off at  $N_{good} = 12$ , which is a reasonable cutoff point for stars outside the 10 DES TF's (a.k.a. the "supernova" or "deep" fields). Note that a significant number of stars have  $N_{good} = 0$  for *Y*-band. Observations made in *Y*-band were not used in the determination of nightly atmospheric parameters, but rather calibrations in *Y* were "dead-reckoned" from observations taken on the same night in other bands (primarily these were *z*-band observations). (Here we do not apply any  $N_{good}$  cuts.)



**Figure 15.** Same as previous figure, but the y-axis is now logarithmic. Note that stars in WF portion of the DES have typically <10 good measurements, but that stars in the TF's (the "deep" or "supernova" fields), which have a much more frequent cadence, have hundreds of observations in the *g*, *r*, *i*, and *z* bands. (Here we do not apply any  $N_{\text{good}}$  cuts.)

$N_Y$	0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
$\sim N^2$	1 1 2 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5 5
$N_i$	3     3     3       3     3     3       4     4     4       5     5     5       6     4     1       1     1       1
N,	0 0 4 4 4 0 4 4 4 4 4 4 4 0 4 4 4 4 4 4
$N_{g}$	4 v x x v x x x v v - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0 - 0
٥	99.00000 99.00000 99.00000 99.00000 99.00000 99.00000 99.00000 0.00169 0.00169 0.00134 99.00000 0.00351 0.00356 99.000000 99.00000 99.00000 99.00000 99.00000 99.00000 99.00000 99.00000 90.000000 90.000000 90.000000 90.00000000 90.000000 90.0000000000
ά <sup>ν</sup>	0.01089 0.000497 0.000497 0.000407 0.000398 0.000398 0.000398 0.000399 0.000399 0.00122 0.00149 0.00122 0.00149 0.00122 0.001269 0.000299 0.000299 0.000299 0.000299 0.000299 0.000299
$\sigma_i$	0.00481 0.00060 0.00346 0.00345 0.00336 0.000336 0.00336 0.003336 0.00337 0.003336 0.00337 0.00339 0.00145 0.00399 0.000145 0.00292 0.00294 0.00292 0.00292 0.00292 0.00292 0.00292 0.00256 0.002956 0.00256
a	0.00598 0.00095 0.000496 0.00602 0.00874 0.00873 0.00376 0.00373 0.00543 0.00547 0.00547 0.00547 0.00587 0.00587 0.00587 0.00587 0.00533 0.00533 0.00533 0.00533 0.00533 0.00533
d <sub>s</sub>	0.00491 0.000769 0.000769 0.00769 0.00080 0.00402 0.00404 0.00404 0.003309 0.003309 0.003309 0.00336 0.001375 0.001375 0.00137 0.000137 0.000336 0.000337 0.000336 0.000336 0.000336 0.000336 0.000336 0.000336 0.000336 0.000336 0.000336 0.000336 0.000336 0.000336 0.0000336 0.0000336 0.0000336 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.0000376 0.00000000000000000000000000000000000
Y	99.00000 16.31429 99.00000 19.94555 99.00000 99.00000 99.00000 19.79179 19.7033 19.12033 99.00000 99.00000 17.56043 19.35236 19.40551 19.35236 19.40551 19.4
N	19.68032 16.32005 20.11771 20.11771 20.04050 20.04050 19.93955 19.93955 19.7511 19.7511 19.7509 19.45509 19.48346 17.73279 19.48346 17.73279 19.4834619.48346 19.4844619.48446 19.4844619.48446 19.484
i	19.64882 16.43824 20.12734 20.24803 20.24803 20.82457 19.45145 20.824573 19.45145 20.45573 19.83071 19.83071 19.83071 19.02869 19.28752 19.02869 19.28752 19.28752 19.28752 19.28035 17.91267 19.81734 17.91267 19.81734 17.91267 19.81734 19.88035 10.35224 20.35091 19.66448 20.351051 19.66448 19.66448 19.66448 19.66448
~	20.04067 16.64793 20.38207 20.63410 21.10612 17.02529 20.0675 20.18068 20.18068 20.49983 19.99510 20.7738 20.47983 19.51669 18.42107 20.72395 19.51669 18.42107 20.72395 20.47908 19.79998 19.79998 20.33329 20.47908
00	20.33161 17.23605 20.41214 21.50839 21.50839 21.50839 21.86613 17.98238 21.27325 20.65138 20.58051 20.44195 20.44195 20.344195 22.13167 21.03943 21.00512 21.03943 21.00512 19.61247 21.94998 22.17178 19.02387 20.90443 22.33664 19.02387 20.90443 20.9044444444444444444444444444444444444
FLAG	0 0 0 0 0 0 0 0 0 0 0 0 0 0 <u>0</u> 0 0 0 0
DEC [deg]	-23.418628 -23.418628 -23.449972 -23.393623 -23.393623 -23.359857 -23.359857 -23.359857 -23.359857 -23.43826 -23.414804 -23.41804 -23.435365 -23.414804 -23.435365 -23.46149 -23.46149 -23.461688 -23.461688 -23.461688 -23.461688 -23.461698 -23.461698 -23.461698 -23.461698 -23.46127 -23.46127 -23.461292 -23.461292 -23.461292
RA [deg]	195.960488 195.960488 195.965884 195.965800 195.966800 195.966800 195.970494 195.970494 195.971329 195.971329 195.971329 195.974451 195.973695 195.974451 195.97365 195.971459 195.9724451 195.9724451 195.9724451 195.982346 195.982346 195.982346
FGCM_ID	8200396 8200420 8200420 8200380 8193725 8200536 8193724 8200554 8193724 8192697 8190407 8190407 8190412 8190407 8190412 8190407 8192599 8192799 8192799 8193740 8193739 8193740 8193740 8193740 8193740

Table 2. First 25 entries from the DES Y6 FGCM calibration star catalog (sorted by RA).

NOTE- The full machine-readable table can be found at https://des.ncsa.illinois.edu/releases/other

# 3. CONCLUSIONS

In this Technical Note, we have presented and described a catalog of roughly 17 million calibrated reference stars, calibrated in the AB magnitude system for the DES *grizY* bands. This reference catalog, generated by the Forward Calibration Method (FGCM) pipeline (Burke, Rykoff, et al., 2018), was used for the photometric calibration of the DES 6-Year data set (which itself was the basis for DES DR2; Abbott et al. 2021). Due to its large number of stars, its precision and accuracy, and it large coverage of the Southern Sky (approximately  $5000 \text{ deg}^2$ ), we believe this catalog of reference stars will be useful for the photometric calibration of other data – both DECam data and data using filter sets similar to that of the DES.

The full machine-readable table can be found at https://des.ncsa.illinois.edu/releases/other.

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# Facility: Blanco (DECam), Astro Data Lab, SciServer

*Software:* HEALPix (Górski et al. 2005),<sup>4</sup> healpy (Zonca et al. 2019),<sup>5</sup> healsparse,<sup>6</sup> matplotlib (Hunter 2007), numpy (Van Der Walt et al. 2011), scipy (Jones et al. 2001), astropy (Astropy Collaboration 2013), fitsio,<sup>7</sup> easyaccess (Carrasco Kind et al. 2019), skymap,<sup>8</sup> TOPCAT (Taylor 2005), STILTS (Taylor 2005)

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<sup>&</sup>lt;sup>4</sup> http://healpix.sourceforge.net

<sup>&</sup>lt;sup>5</sup> https://github.com/healpy/healpy

<sup>&</sup>lt;sup>7</sup> https://github.com/esheldon/fitsio

<sup>&</sup>lt;sup>8</sup> https://github.com/kadrlica/skymap

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