Filter Transformation Equations between SDSS and DES Magnitudes

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ABSTRACT

For several years, astronomers have been using sky surveys as a way to mass-collect data on sections of the sky to dissect them later and speed up the scientific process. Different sky surveys require different filter systems to detect what that specific survey is looking for. Because of this, the astronomical scientific community has collected a plethora of data on a multitude of stars, but in different filter systems. In this paper, we explore the filter data extracted from the standard stars in the Sloan Digital Sky Survey (SDSS) and transform them to compare the filter set used with the Dark Energy Survey (DES). During both the Sloan Digital Sky Survey and the Dark Energy Survey, SDSS-Stripe-82 along the equator was imaged for data collection. We cross-examine the SDSS and DES data sets to search for stars that exist in both systems on Stripe-82 and take those matches into a coding program that will transform them from one photometric system to the other. The synthetic data is then used as a comparison with the already existing set of data, and the uncertainties and equations are determined. The results of this project will aid in the photometric calibration of the Rubin Large Synoptic Survey Telescope (LSST).

I. INTRODUCTION

In astronomy, we use filters to collect data from certain wavelengths of light, while blocking out all other wavelengths. Different surveys tend to use different filter systems that are unique to the objects or data they are collecting. Several filter systems have been invented for the specific use of the data they are looking for. This has created a surplus of data that has been collected, but cannot be analyzed using other images due to the incompatible filter systems. Transforming the data allows us to compare and combine two or more data sets to increase the sample size. These two surveys overlap at the Celestial Equator, SDSS-Stripe-82. Since we have collected individual sets of data on the equatorial stripe, we use Stripe-82 as a base, comparing the transformed data to the actual set. This area of the sky will also be used in future work as we compare data from other surveys, such as Pan-STARRS, to the SDSS and DES data sets. Calibration and accurate filter transformations will become more critical in the future to properly leverage the power contained in these and other sky surveys to study the universe.

A. The Sloan Digital Sky Survey

The Sloan Digital Sky Survey (York *et al.* 2002; SDSS) is a ground-based five-filter imaging survey that covered 10,000 deg^2 of the Northern Galactic Cap. The survey employed the use of a 2.5m telescope at Apache Point Observatory (APO) in Sunspot, New Mexico to image the sky. The five filters that SDSS utilizes for their survey are ‘u’, ‘g’, ‘r’, ‘i’, and ‘z’. SDSS’s goal was to obtain “both imaging and spectroscopic surveys over a large area of the sky” and collect the spectroscopy of around one million galaxies and 100,000 quasars. The *u’g’r’i’z’* standard star network (Smith *et al.* 2002) was developed to assist in the calibration of the SDSS. The goal of the Sloan Digital Sky Survey was to study the large-scale structure of the Universe via galaxies and quasars. As the survey progressed, additional science was recognized, especially in the areas of Galactic structure and evolution (Yanny *et al.* 2003) and stellar population studies (Ivezic *et al.* 2008).

B. The Dark Energy Survey

The Dark Energy Survey (Sevilla-Noarbe, *et al.* 2021; DES) is the descendant of SDSS. It embodies a collaborative effort that involves multiple nations and institutions, aiming to refine our understanding of Dark Energy and to constrain the Dark Energy Equation of State. According to Einstein's General Theory of Relativity, the interplay between mass and energy shapes the fabric of space-time, influencing the motion of both mass and energy. Per Einstein, all matter should experience a slowing down of its expansion as time progresses. However, a groundbreaking revelation in 1998 unveiled that the universe's expansion is, in fact, accelerating. This discovery prompted the realization that we needed to reconsider either General Relativity itself or the potential existence of an unfamiliar type of energy pervading the universe. This enigmatic energy is now called dark energy.

Physically, the DES is another ground-based five-filter imaging survey that covered 5,000 deg^2 of the Southern Galactic Cap. The survey utilized the 4m telescope at Cerro Tololo Inter-American Observatory (CTIO) in Chile and a custom-built imaging system (Flaugher *et al.* 2015). The Dark Energy Survey uses the *grizY* filter set to study the accelerating universe and dark energy.

II. PROCEDURE

The SDSS data from Stripe-82 were collected and cross-referenced with the Forward Global Calibration Module (FGCM) stars in the DES data (Rykoff, *et al.* 2023) to find matches in Stripe-82 using right ascension and declination. Once the matches were found, their data were collected and run through a set of transformation equations coded in Python. The Python code was initially created by Dr. Douglas Tucker. The heart of the fitting program is a linear, and higher-order, least-squares fitting routine. The user can select the filter to use and any combination of colors (difference between two magnitudes in the "bluer-minus-redder" sense) to add additional fitting power. Though this fitting routine currently works over the entire color range of the stars in the sample, the code does allow the user to restrict the fits to a smaller wavelength region. The user also has the option of going from one filter system to the other, or the opposite way around. While we only went from SDSS to DES during this project, we also could go from DES to SDSS.

The code would then produce a series of graphs, as well as the equation the code used in order to obtain the end results. This was done for the *g,r,i,z* filters, with the SDSS filters being transformed into synthetic DES data. The results would be compared for accuracy and uncertainties.

III. RESULTS

The initial set of results was created by the transformation equation Python code. An example of the output is illustrated by the plots and equation in Figure 1. Initial coefficients were created by the code. An equation and a set of graphs were generated by the code for SDSS *griz* filters. The transformed SDSS data have yet to have been compared to the original DES data. Figure 1 displays the (*i-z*) outputs for filter '*i*' as an example of the filter transformation code. Every transformation that was input resulted in an rms value that was within the uncertainty range of 0.020 rms. Table 1 displays the best results for each of the color bands, determined based on their rms value.

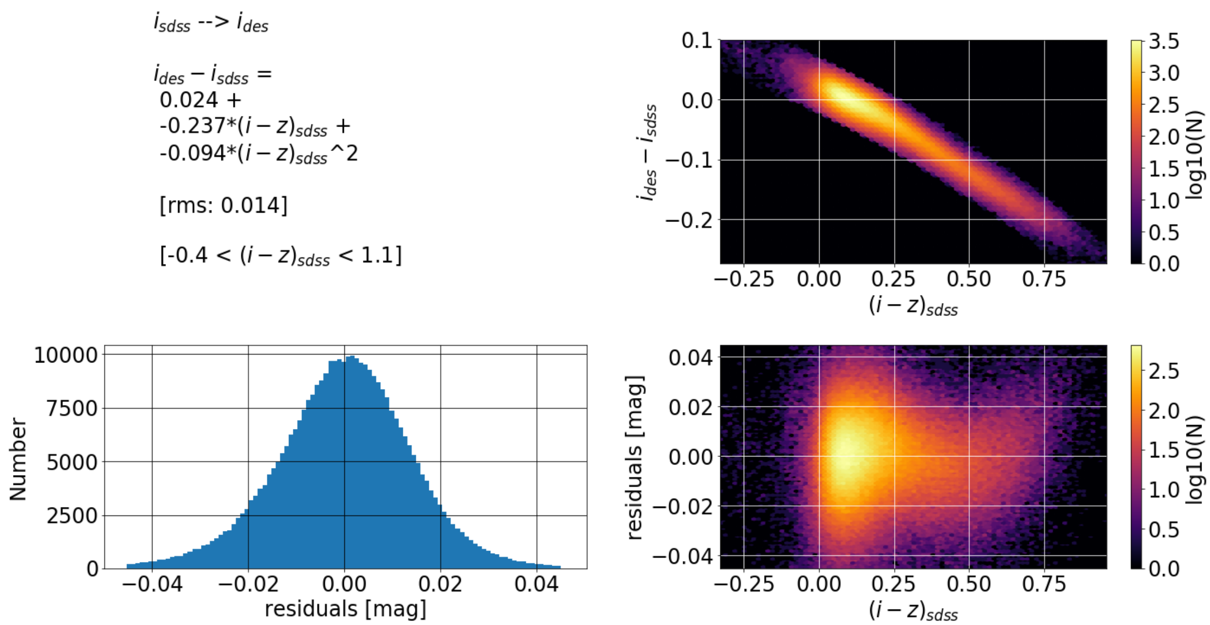

Figure 1. The results of the matched SDSS and DES data are put through the transformation equation code. The top left image is the equation generated by the code. The rms value is viewed as the uncertainty value for this set of plots. A good uncertainty value is considered to be any number smaller than 0.020. The top right graph is the color-magnitude-density diagram. The bottom left graph is a histogram of the residual magnitudes. The bottom right is the color residual-density diagram.

Filter band and color index	g, g-i	r, r-i	i, i-z	z, i-z
Equation	g_{des}-g_{sdss} = 0.006 + -0.056*$(g\text{-}i)_{sdss}$ + -0.002*$(g\text{-}i)_{sdss}^2$	r_{des}-r_{sdss} + 0.003 + -0.210*$(r\text{-}i)_{sdss}$ + 0.049*$(r\text{-}i)_{sdss}^2$	i_{des}-i_{sdss}= 0.024 + -0.237*$(i\text{-}z)_{sdss}$ + -0.094*$(i\text{-}z)_{sdss}^2$	z_{des}-z_{sdss} = 0.022 + -0.078*$(i\text{-}z)_{sdss}$ + -0.019*$(i\text{-}z)_{sdss}^2$
rms (mag)	0.017	0.014	0.014	0.019

TABLE. 1. Overview of transformation results. The equations that were chosen for this table were based on the best rms value that was produced for each filter band.

IV. CONCLUSION

We produced transformation coefficients for the SDSS-Stripe-82 and the FGCM stars, going from the SDSS filter system to the DES filter system. We obtained low uncertainties as judged by the rms of the residuals of the fits. The transformation fit values tell us that the coefficients are accurate and therefore, they could theoretically be used for transforming any SDSS data to DES with the same accuracy.

This work represents the initial output of this effort. There are additional tests to perform on these data such as exploring the color range for which these transformations are valid. We also need to expand this work to additional filter systems such as the Johnson-Cousins *UBVRI* filters which have been in use since the early 1950s (Johnson & Morgan, 1953). Part of this work will include an examination of the transformations to/from the Galaxy Evolution Explorer (GALEX) ultra-violet bands. Among the first additions will be a comprehensive look at the transformations between the SDSS standard star network and the SDSS native magnitude systems. This will include the different telescopes used to establish the SDSS standard network and its southern hemisphere extension. This work should occur over the next one to two semesters. Ultimately, this transformation work will be undertaken for photometric calibration for the Rubin LSST.

V. REFERENCES

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