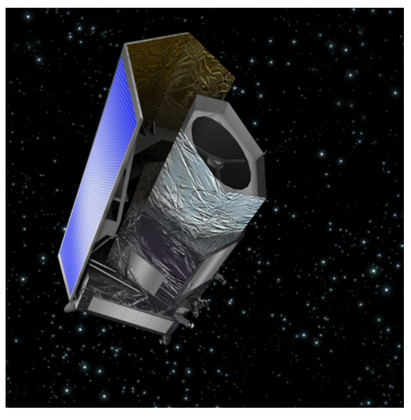

Calibration of ground based survey data using Gaia

Application to DES

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The calibration of ground based optical imaging data to photometric accuracy of 10 mmag over the full survey and to color uniformity better than 5 mmag on the scale of the VIS focal plane is a key science requirement for the Euclid mission. These accuracies enable stable photometric redshifts of galaxies and modeling of the color dependent VIS PSF for weak lensing studies. We use the Gaia photometry to calibrate the g/r/i/z magnitudes of Dark Energy Survey (DES) data to meet the stringent requirements from Euclid. The Gaia G band magnitude along with the BP-RP color information of stars observed in the DES single epoch (SE) exposures are used to derive the transformation from Gaia to DES photometry for individual CCDs and to characterize persistent photometric errors across the DES focal plane. We also use Gaia photometry to study the bandpass variations across the DECam focal plane in the g/r/i/z bandpasses.

GAIA transformed to DES

We created a transformation function between broad band GAIA G band filter and relatively narrow band DES (g/r/i/z) filter system using GAIA G, BP, RP and DES photometry of stars covering the Euclid Deep Field South (EDFS). EDFS covers RA range 55.1^0 to 67.4^0 and DEC range -51.9^0 to -45.1^0, chosen for EUCLID science surveys. We used the DES DR1 data from EDFS field with 11500 stars overlapping in GAIA DR2 data to construct the transformation function. A polynomial function (trans_func) of order 10 is found to be a good fit for the GAIA to DES g/r/i/z filter transformation as shown in equation below and in Figure 1.

$$DESmag(g/r/i/z) = GAIA\ Gmag + trans\_func(BP\text{-}RP)$$

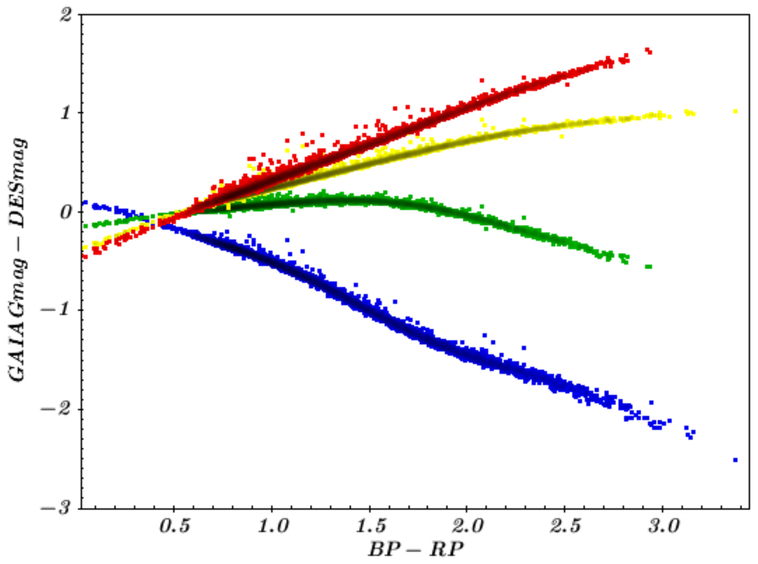

Figure 1: The transformation between GAIA G to DES g/r/i/z magnitudes as a function of GAIA BP-RP color can be fitted with a polynomial function of order 10. Points are color coded with DES g (blue), r (green), i (yellow) and z (red) with corresponding NMAD scatter about the transformation function of 1.3, 0.9, 0.9 and 1.4 % respectively.

Zeropoint computation for DES

Our primary goal is the calibration of SE images in DES (g/r/i/z) using the associated catalogs and the Gaia data. We can achieve this by computing the zeropoint (zp) for SE images using the transformation function and the GAIA G, BP, RP and DES (g/r/i/z) instrumental magnitude (DESim) of stars in SE catalogs as shown below.

$$zp = median(DESim(g/r/i/z) - GAIA\ Gmag - trans\_func(BP\text{-}RP))\ of\ N\ stars$$

The characteristic uncertainty in the zp is the scatter about the transformation function divided by $\sqrt{N}$, where N is the number of stars. The uncertainty distributions for zero points computed for SE images from DES (g/r/i/z) data of EDFS field are shown in Figure 2. We are effectively calibrating DES g/r/i/z data using GAIA photometry at $\sim$ 1 millimag level uncertainty.

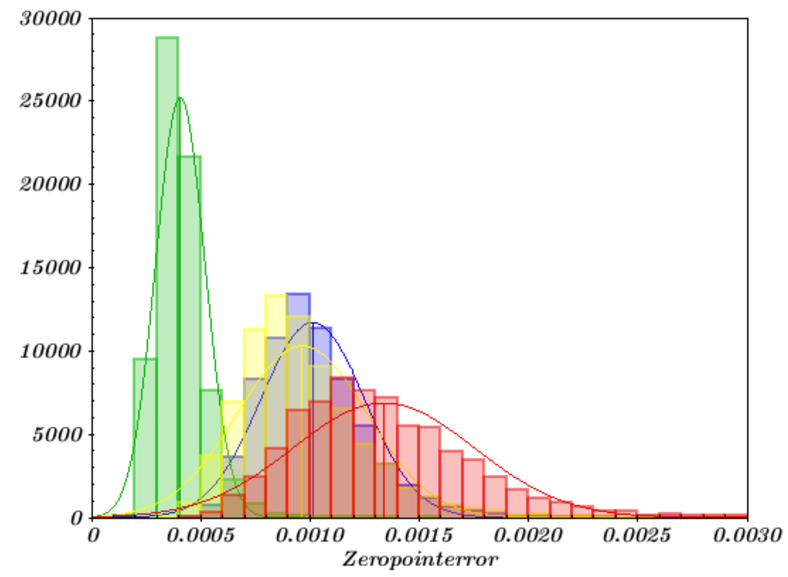

Figure 2: The distribution of GAIA calibrated zero point uncertainties (statistical using NMAD scatter presented in Figure 1) for SE catalogs. Bins are color coded for each DES band as in Figure 1

Band pass variation across DECam focal plane

The DES focal plane consists of 62 CCDs of size 2k $\times$ 4K each arranged in a hexagonal pattern. The transformation functions between GAIA and DES provide an opportunity to predict the DES (g/r/i/z) magnitude of stars lying in any region of the CCD in the DECam focal plane using the GAIA DR2 G, BP, RP magnitude information of stars. The DES (g/r/i/z) filter bandpass can show spatial variations across the focal plane which we can quantify using the transformation function. Any deviation from the predicted DES (g/r/i/z) magnitude with respect to the observed magnitude can be an indication of the change in transformation function due to band pass variation. We quantified the deviation between predicted and observed DES (g/r/i/z) magnitudes of stars in all SE catalogs for a given CCD. This deviation is found to vary with the BP-RP color of stars for each CCD. The example case of *i*-band variation in a single CCD subregion is shown in Figure 3. The best fit relation is shown in red and the slope of relation (color term) is an indication for the DES filter bandpass variation. We divided each CCD into four subregions and the focal plane map of color term variations in DES (g/r/i/z) filter are shown in Figure 4. There exist statistically significant color term variations (and therefore bandpass variations) across the focal plane for DES (g/r/i/z) filters.

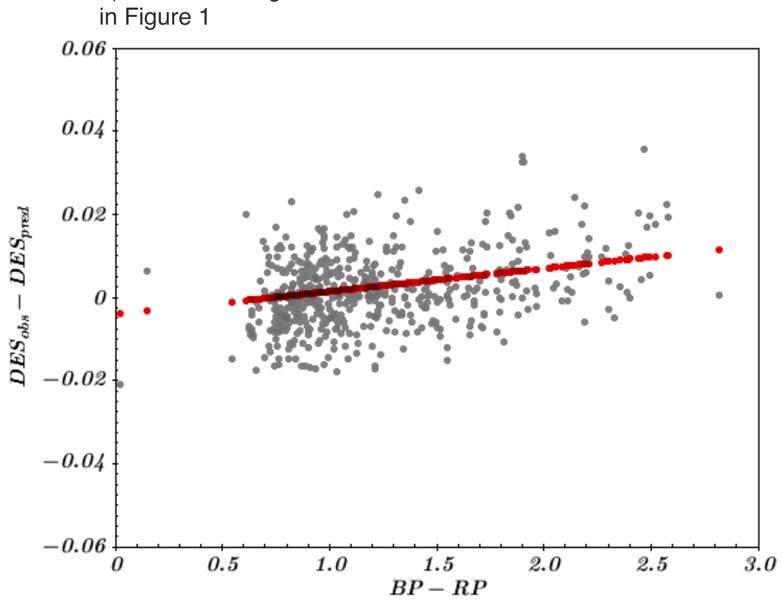

Figure 3: The deviation of DES observed and predicted magnitude of stars from SE catalogs in a subregion for a single CCD is plotted against the GAIA BP-RP color. Any color dependence in this deviation provides evidence for a bandpass difference between this CCD region and the average transformation function shown in Figure 1. The best fit relation is shown in red.

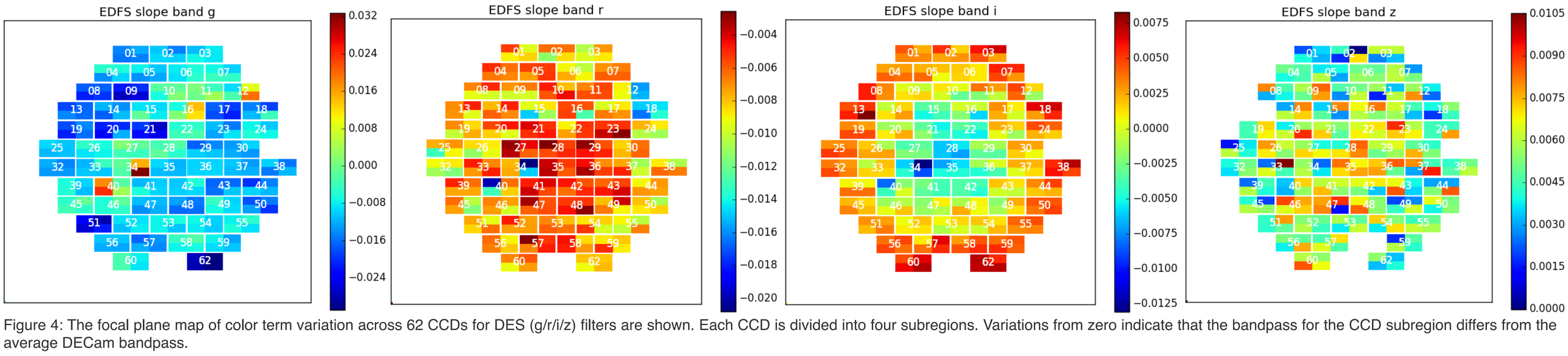

Figure 4: The focal plane map of color term variation across 62 CCDs for DES (g/r/i/z) filters are shown. Each CCD is divided into four subregions. Variations from zero indicate that the bandpass for the CCD subregion differs from the average DECam bandpass.