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Building a Gold galaxy catalog for the DELVE DR3 data release

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ABSTRACT

With modern galaxy surveys, we are able to study the nature of dark matter and dark energy by probing the large-scale structure via weak gravitational lensing and galaxy clustering. With how sensitive these probes are, we must first ensure that we are using a pure galaxy sample. We developed tools to help create a catalog of objects marked with high confidence as galaxies within the DELVE footprint. These tools consist of methods to identify astrometric offsets, develop coverage maps, assemble a catalog of galaxies based on the Dark Energy Survey's Y6 Gold criteria, create cutouts of objects within DELVE tiles, and plot objects in multiple different forms. Over the course of the summer term, a program to specify which criteria to test was created. Additionally, 77 tiles were identified by our tools as having astrometric offsets or a bad exposure, both of which can cause disastrous errors in our attempts to probe the large-scale structure. These tools will help advance the work being done by the cosmic shear working group as they assemble their galaxy catalog and test it.

1. INTRODUCTION

We can simulate the growth of cosmic structure in the universe by using several cosmological parameters such as the energy densities of matter and dark energy, and the Hubble constant. We compare these simulations to observations gathered through sky surveys, like the DECam Local Volume Exploration (DELVE) Survey. By looking at the angular power spectra of the resulting survey, we can understand the distribution of matter within the universe. Dark matter, even though it cannot be observed directly, follows the gravitational attraction of all matter, increasing the local density of visible matter. Conversely, dark energy is thought to affect spacetime directly, causing the local density of visible matter to decrease. Angular power spectra (APS) and two-point correlation functions of galaxies have been shown to be powerful statistical tools for extracting cosmology from the distributions of galaxies (Eisenstein et al. 2005); (Ho et al. 2012). By using these tools, insight on the relative strengths of these opposite effects can be determined.

Another tool is to consider the effect of weak-lensing, which occurs when light from distant objects passes through the large-scale structure of the universe (Hoekstra & Jain 2008). When the light travels to us, the mass of the filament structures in the universe causes a shearing effect on the light, causing the object to appear slightly warped when we observe it with our technology.This shearing effect directly correlates to the mass of the filament that the light traveled through, and through the use of small calibrations of the shearing (Sheldon & Huff 2017) we can determine how mass is distributed in the cosmic structure. In addition, we can also look at how galaxies are distributed to measure the distribution of matter in the universe. These probes can be combined in different ways to generate a powerful and accurate measure of the large-scale structure in using angular power spectra and three two(3x2)-point correlation functions (DES Collaboration et al. 2022). However, none of this can happen until we define a quality sample of galaxies that minimizes errors in the image processing pipeline and eliminates noisy objects within our survey data.

The DELVE Survey uses DECam observations from the 4-meter Blanco telescope at the Cerro Tololo Inter-American Observatory in Chile. DELVE currently covers 17,000 $\deg^2$ of the southern night sky simultaneously in the g, r, i, and z bands, providing a wide field of coverage that is perfect for large-scale structure probes. With even more coverage within the southern galactic cap, we expect to improve upon the 3x2 pt analysis done in Y3 of the Dark Energy Survey (DES) as well as generate higher fidelity angular power spectra of the galactic distributions.

To generate these high-precision measurements, we must insure that all image processing errors have been removed. Astrometric offsets for objects across the spectral bands can cause duplication and magnitude errors in our galaxy samples, both of which interfere with our cosmological results. Other failures, such as problems in the SoureExtractor software or hot CCD pixels, introduce additional pathologies that need to be captured and removed. Developing tools to track down these issues not only helps remedy these errors, but also gives tools for the future of surveys, like Rubin LSST, which will have extraordinary amounts of data which will be near impossible for visual inspection by scientists. This summer, we developed tools to identify these problems, and continued to work towards defining a magnitude-limited galaxy sample.

2. ANALYZING THE IMPACT OF DES GOLD FLAGS

The DES Y6 Gold flags (Sevilla-Noarbe et al. 2021) were used to assemble a quality sample of galaxies which eliminated contamination from background noise and imaging artifacts, such as over-saturated CCDs and diffraction spikes around bright stars. In order to understand the impact of each of the flags in the Gold flag suite, a program was developed that applied the flag cuts to the objects in a single tile, a group of tiles, or across the DELVE catalog. This program looks at any combination of flags, up to and including the complete gold flag suite to measure the impact. Using standard Boolean logic artifacts of *and*, *or*, and *not*, complex flag descriptions can be tested on DELVE observations. Additional cuts, such as requiring objects to have a magnitude less that 22.2 in the i-band, not being masked by known stars or foreground objects, and being contained within all four of the DELVE coverage regions, can be toggled on or off at the user's discretion. The final list of objects can then be passed to a built-in extension classifier and magnitude checker to identify galaxies. These are collected as a tile-wide or survey-wide galaxy catalog available for additional study.

3. IDENTIFYING ASTROMETRIC ERRORS

As mentioned in the previous section, the DES Gold flags are a significant tool for identifying image issues. One of the flags in this set was used to identify objects which had differences in the r, i, and z-band magnitudes such that:

$$|r - i| > 5$$

$$|i - z| > 5$$

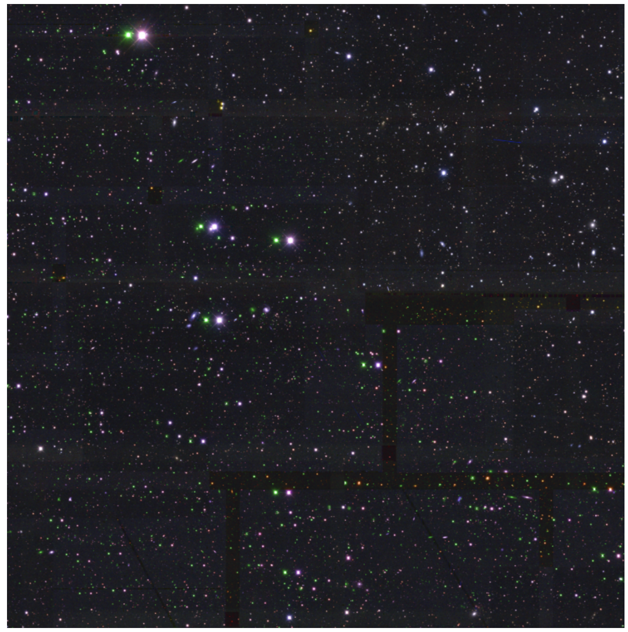

Figure 1: An example of one of the astrometric offsets we found using the DES Y6 color flags. This tile, DES1016-1749 has an offset in the r-band which corresponds to the green channel in the RGB image, which causes there to be bright green duplicate objects to the left of some objects within the tile.

This flag in particular is good for identifying astrometric offsets due to the differences in magnitudes that come from astrometry errors.

In modern astronomy, we take several exposures of a portion of the night sky and add them together to create what we call a "coadd image". On occasion, there are errors in the image coaddition process which causes one image to be offset from the others due to errors in matching sources. When this occurs, we get duplicate objects showing up in the final image with magnitudes that will only be detected properly in one band (Morganson et al. 2018). Because of this, the colors of these objects will be extremely different from other objects within the coadd image, and the number of these objects with odd colors in a tile with astrometry issues will be higher than other tiles. The color flag from the Y6 Gold flags allows us to find images with a suspiciously large amount of these errors, which we can then visually inspect in more detail to find what errors might be occurring.

To limit false detections of these astrometric offsets, we needed to add additional criteria for an object to be flagged as having an unnatural color. One of these

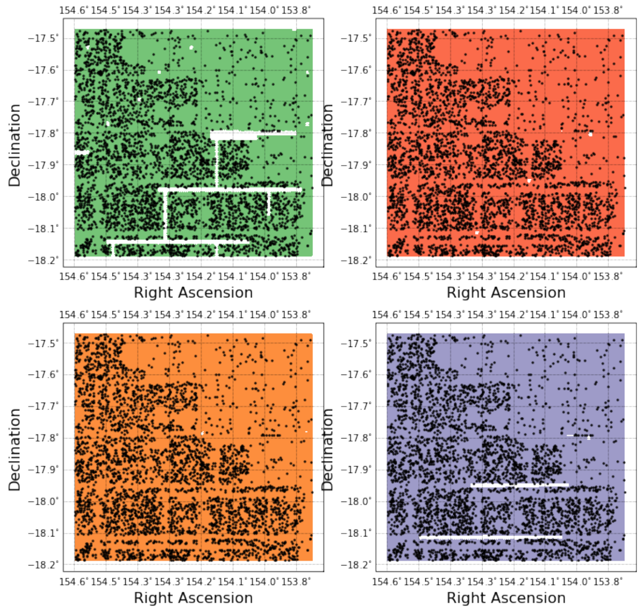

Figure 2: The plot for the tile, DES10161749, which shows where objects that failed the color flag are located. The overdense regions on the left-hand side of each band show where the offsets are located. The green ,red, orange, and purple plots correspond to the g, r, i, and z bands respectively.

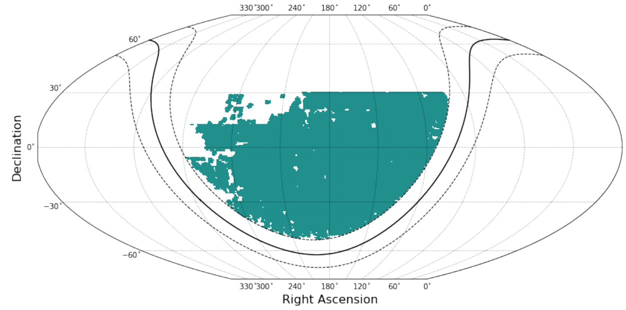

Figure 3: This is one of the coverage maps made for DELVE DR3 which shows regions of the sky which have coverage in the g-band.

false detections can be regions around bright stars which contain halo-like imaging artifacts as well as diffraction spikes. To remove such artifacts, we implemented a foreground mask which removed bright stars and galaxies that was made by one of the members of the DELVE Collaboration, Dhayaa Anbajagane.

Another instance of false detection of an astrometric offset can be caused by gaps in coverage. DELVE uses r, i, and z-band images for detecting objects. If, for example, an r-band image is missing from the coadded g, r, i, and z-bands, then we would see an object flagged as having an odd color due to the fact that it would have a sentinel value of 99 in the r-band, since the object was detected in the g, i, and z bands. To account for these objects, we used coverage maps made using `decasu`[1] and `healsparse`[2] which allowed us to make high-resolution HEALPix maps of DELVE coverage. The code to put together these maps was made by Peter Ferguson, a member of the DELVE collaboration.

Having both of these valuable tools allowed us to assemble a new method for detecting astrometric offsets. By looking at the distributions of objects that were flagged in each tile, we were able to find outliers that had a 2σ deviation from the mean number of objects within a given tile.

In addition to finding these astrometric offsets, we also identified several exposures which had trails from airplanes/satellites, movement from the telescope, and other single-epoch errors which can be detected with color tests such as this one. Once errors in a single exposure are found, we can have the exposure removed from the tile, as well as any other tiles that it could be used in.

4. GALAXY CATALOG ASSEMBLY

Assembly of a quality galaxy catalog for our science is a crucial step towards understanding the distribution of matter within the universe. To do so, we began by assembling a catalog similar to the DES Y6 Gold catalog, and then createD a magnitude-limited sample of galaxies which would implement both the foreground masks and the coverage maps.

4.1. *Gold Catalog Assembly*

Once we finished identifying issues with image processing, we then proceeded to assemble a Gold catalog using the same cuts that went into the assembly of the DES Y6 Gold catalog. These cuts are designed to eliminate noise and provide cosmologists with a high-quality catalog of objects to use in their science. Assembly of a catalog of this caliber is not only useful for our analysis, but is necessary for future science.

The Gold flags make use of measurements from `SourceExtractor`[3] and model fits performend on multi-epoch imaging using `fitvd`[4] and `ngmix`[5] to identify noisy objects which often contaminate our results. For

[1] https://github.com/erykoff/decasu/tree/main/decasu

[2] https://github.com/LSSTDESC/healsparse

[3] https://sextractor.readthedocs.io/en/latest/Introduction.html

[4] https://github.com/esheldon/fitvd

[5] https://github.com/esheldon/ngmix

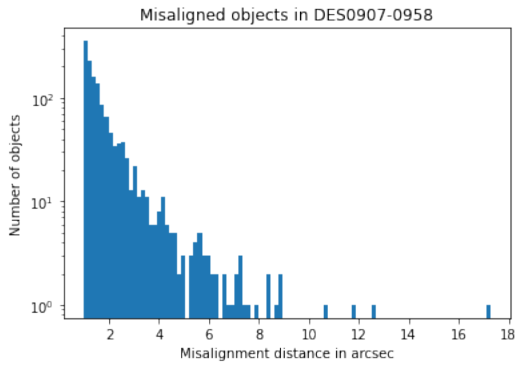

Figure 4: Distribution of misaligned objects as a function of distance in arc-seconds on the 'DES0907-0958' image tile.

example, we remove objects which have a model that is fit much larger than the actual size of the object. This occurs when `fitvd` or `ngmix` fits a model to background noise, causing the boundaries of the model to extend into the background. To implement these flags, one of the authors (Dan Suson) created a program which allows us to see not only which objects have been flagged as having issues, but also where these objects are located within the DELVE field of coverage. The program also allows us to see how many objects we lose past this step, such as when we place a magnitude cutoff on the sample or when we mask regions near bright stars. This code is not only a valuable tool for the development of our Gold catalog for DELVE, but also for future surveys.

4.2. *Misaligned Objects*

When constructing our Gold catalog, we noticed an issue with the Right Ascension (RA) and Declination (Dec) for some of the objects in the `DR3_1_1_COADD_OBJECT_SUMMARY` table and the `DR3_1_1_SOF` table, indicating a change in RA and Dec for the `SourceExtractor` measurements and the models respectively. This raised an issue, as the angular separation between the model and measured RA and Dec was fairly large, so we inspected this issue further.

Thankfully, we found from both visual inspection and implementation of various cuts that these objects were simply background noise. We applied a magnitude-limiting cut to remove these objects which also indicated that they were simply just noise.

4.3. *Magnitude-Limited Sample*

During the Spring of 2023, we spent time working with DELVE's DR2 data to assemble a magnitude-limited sample of galaxies to use for a clustering analysis. Our goal for the future is to implement the work done with that code to use in DR3. Our studies last year found that a cut at 21 mag in all 4 bands provided a quality sample of galaxies. We expect this to carry over into DR3.

5. CONCLUSIONS

In conclusion, we were able to help develop tools over the summer to aid in the production of a quality galaxy sample. These tools contribute to the construction of a high-quality catalog similar to the DES Y6 Gold catalog, as well as a magnitude-limited catalog. In addition, we also identified astrometric offsets within the DELVE data which can cause issues when trying to conduct our cosmology. In the future, we plan to generate a galaxy sample that can be used for both weak-lensing and galaxy clustering analysis.

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