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Galaxy Colors in the MUSYC 1030+05 Field

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ABSTRACT

The primary goal of this project was to analyze data generated from source catalogs of images from the MUSYC SDSS1030+05 fields. Our data was obtained from the MUSYC Public Data release, where we sourced images with the filters U B V R I z. The software SExtractor, a program that reduces large-scale galaxy survey data, was used to generate catalogues of objects from the MUSYC images. Specific parameters were chosen to filter the output data into what was necessary to produce histograms and color diagrams. The parameters selected in SExtractor corresponded to the magnitude of objects in an image and the stellarity index, which indicates the probability that an object is a point-source or extended object. The SExtractor data was extracted, filtered, and subsequently processed through MATLAB via a sorting program that generated color-magnitude diagrams. We present our color-color and color-magnitude diagrams with descriptions of the detection images used for each. From our analysis of the diagrams produced, we concluded that galaxies outnumber stars in the images, and different photometries present different insights into information about object detection.

1. INTRODUCTION

We are a group of enthusiastic undergraduate students. Our research was driven by our nature to explore new findings in the Universe. One of our main goals was to find out the ratio of stars to galaxies in one of the MUSYC fields, a 30' x 30' [arc-minutes] field of space. In this research we will find out that some it is very challenging to deal with image noise that related to very bright stars. Our data was taken from the MUSYC Public Data Release at physics Rutgers developed by Eric Gawiser (Rutgers), Pieter van Dokkum (Yale), Paulina Lira (U. Chile) et al., 2007-2011, led by Carolin N. Cardamone. Her team report is available at Cardamone et al. 2010, ApJS 189, 270. The software SExtractor, available at SExtraction, was utilized to reduce the images and generate a catalogue of object sources. This catalogue of data was filtered by varying the parameters in the output, allowing us to produce histograms and color diagrams. Section 2 of this paper describes our data and how it was obtained. Section 3 explains our methodology, and Section 4 describes our interpretation of the data. Section 5 introduces our results with different photometry bands, the discussion of which is provided in Section 6. Section 7 details the conclusions we drew.

2. THE DATA

The images used for our data were taken by the Multiwavelength Survey by Yale-Chile (MUSYC) in the early 2000s, using the MOSAIC imager on the CTIO 4m telescope. Four 30'x30' fields of the sky over the Extended Chandra Deep Field-South (ECDF-S) were observed in the filters *U B V R I z*. The data was downloaded from astro.yale.edu/MUSYC/sdss1030/optical in the form of FITS files. The titles of the files were kept the same in order to easily identify which optical filter was used on a particular image.

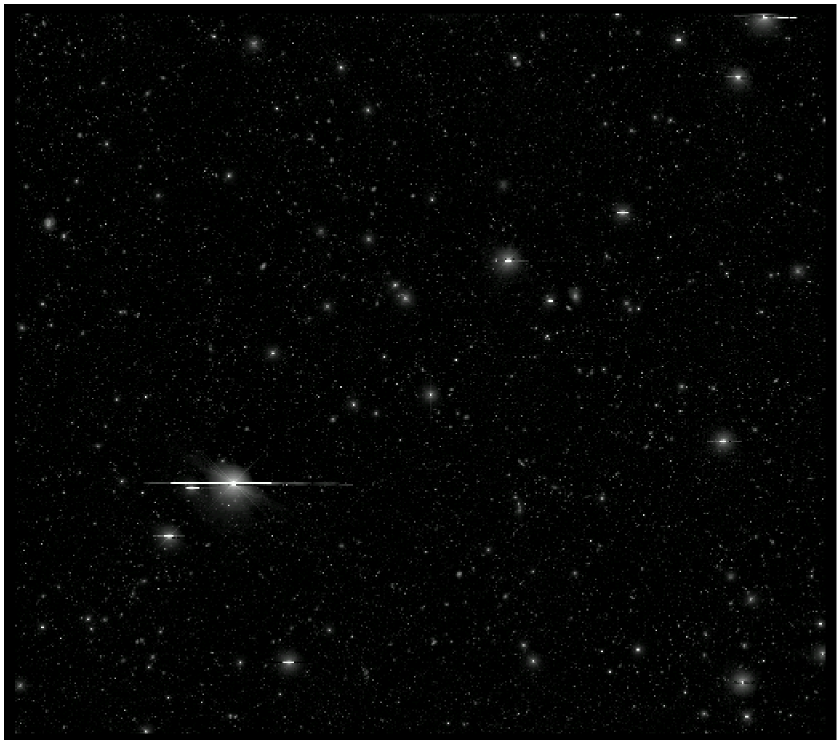

Figure 1. Image of the MUSYC SDSS1030+05 field with the B-band, V-band, and R-band superimposed.

Figure 1 displays an image of the MUSYC SDSS1030+05 field as shown through the B, V, and R filters. The bright streaks shown on some of the objects is due to CCD readout bleeding from the heavily saturated stars.

3. METHODOLOGY

The core software used for analysis in this project was SExtractor. SExtractor is a program that typically takes astronomical images of large scale galaxy survey data and generates a catalogue of sources from these images. All of the imaging data and images used for this project were taken as described in Section 2 above. In order to run the software to fit our needs, we prepared a configuration file which gave SExtractor details on how to run on the images. In conjunction with this, we prepared a parameter file that gave SExtractor instructions on which parameters to select as needed for our project. These extraction parameters included stellarity index and magnitude (CLASS_STAR and MAG_AUTO).

The stellarity index was used to determine whether the object in the catalogue was a star or a galaxy. The "class_star" parameter in SExtractor estimates the stellarity index of an image, with 0 indicating an extended object like a galaxy, and 1 indicating a point source like a star. We used cutoffs of < 0.3 to mean the object was a galaxy, while > 0.8 was a star. All values in between were designated as ambiguous (in the range $0.3 \leq SI \leq 0.8$). An important point to note is that the closer a galaxy's stellarity index was to 0, the more confident SExtractor is in its determination of galaxy; likewise, the closer a star's stellarity index was to 1, the more confident SExtractor's classification of a star. We generated Python scripts in order to analyze these confidence intervals for both stars and galaxies. A full explanation of SExtractor's methodology for SI calculations is beyond the scope of this paper, but an overview can be found at: https://sextractor.readthedocs.io/en/latest/ClassStar.html.

Next, we found the R-band photometry on the image using SExtractor's dual-image mode. SExtractor dual-image mode operates by utilizing two images as inputs, one used for detections and another used for executing measurements. Object characteristics are then measured at the same positions and apertures using different photometric channels. The output catalog is photometry data in the specified measurement image band; for example, using the BVR band image as a detection image and the R-band image as a measurement image generates R-band photometry. Dual-image mode is useful in this aspect for operations such as retrieving more precise color magnitudes. A more in-depth overview on dual-image mode can be found at: https://sextractor.readthedocs.io/en/latest/Input.html.

The B+V+R (BVR) image was chosen for detection and the R-band image as the measurement image, which produced a new catalogue that derived the precise color indices in the R-band. This process was then repeated twice, instead using the U and V-band images as the measurement images. In turn, this generated the U and V-band photometry. Finally, we generated histograms to plot the number of galaxies vs. the magnitude of the flux. This was done using both Google Sheets and MATLAB. These tools were also used to generate the color-color and color-magnitude diagrams seen below in the Results section.

4. DETAILS AND ANALYSIS

Before we take a view on our results, we should understand our data and what we are dealing with. This section represent some ideas of how we defined certain values as a galaxy, star and what lead us to those conclusions

Only based on a single image we cannot conclude that it is not a one of the brightest galaxies. So, in order to make it more clear we used RUphast to analyze a pixel's brightness and size.

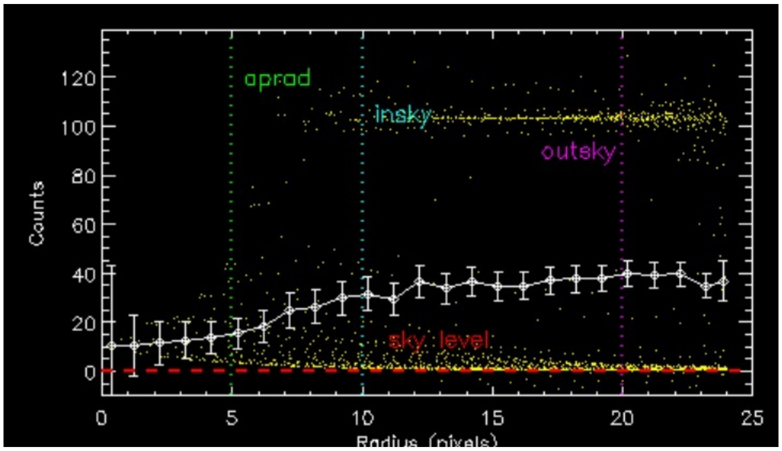

Figure 2. RUphast Sample analyses

This diagrams represent how brightness of an object increase. This sample was taken on the bottom between dark and the brightest points

As we can see on this diagram, there is a very rapid increase in brightness of pixels. As a result, we concluded that the brightest spot on the image is a star. Therefore, all data points with the highest Flux can be taken and assumed to be a star.

5. RESULTS

SExtractor was run using the sum of the B, V, and R band images of the MUSYC SDSS1030+05 field to generate source catalogs. As aforementioned, objects in the catalog were classified as either a star, galaxy, or as an ambiguous source based on their stellarity index (SI). Histograms of the objects detected and classified in the detection are shown in Figure 3. These histograms show that even though using a single image with SExtractor provides fairly accurate results, in that there are many more galaxies than stars, there are still many ambiguous objects that are unable to be confidently classified. When using the R-band image as the measurement image, however, SExtractor is able to more accurately classify images as either galaxies or stars, thus showing the increase in galaxies and decrease in stars and ambiguous objects.

A full review of the results will be left to the **Discussion** in section 6.

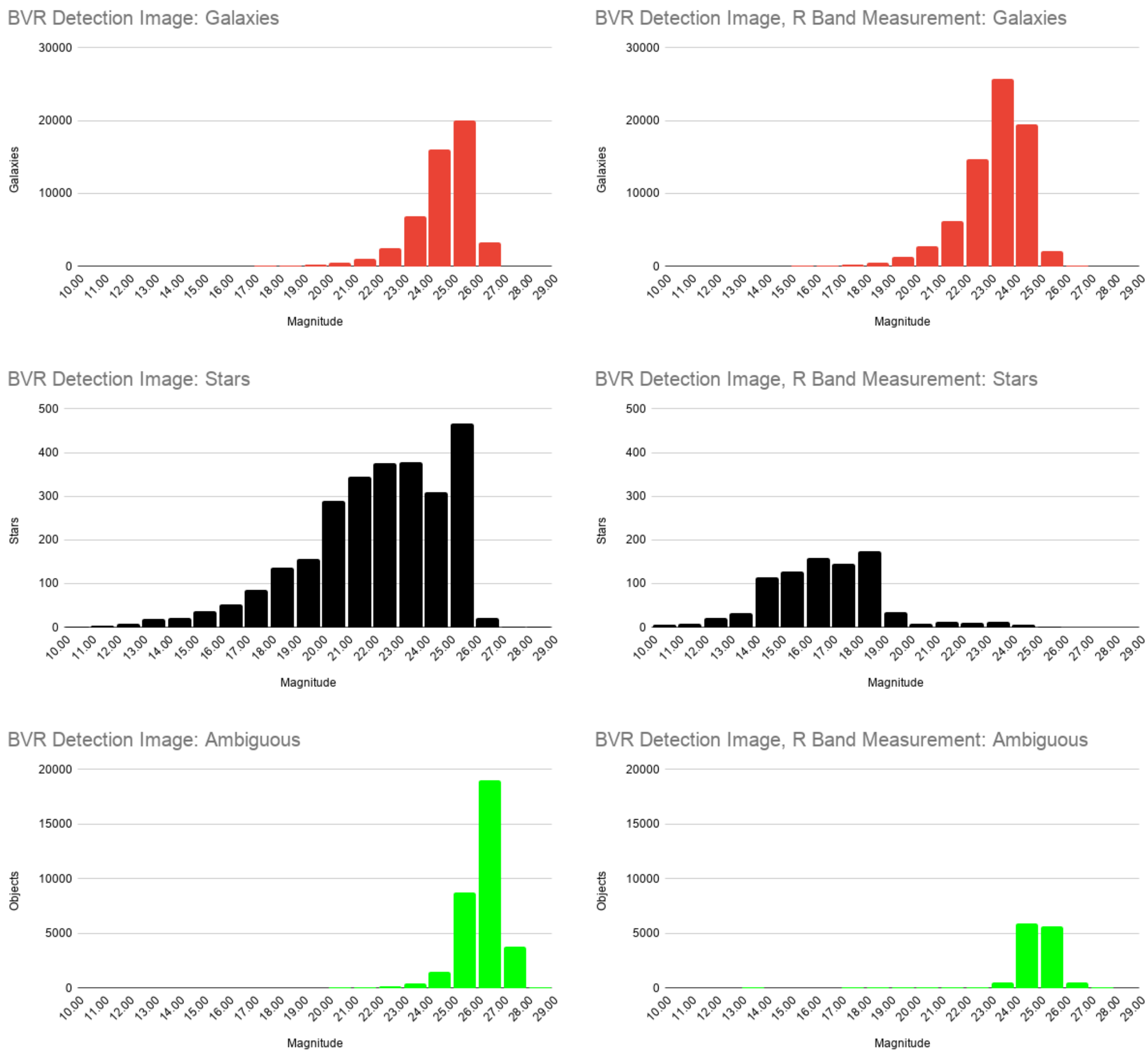

Figure 3. Histograms of objects detected in the sum of the B, V, and R band images, sorted by magnitude and object type.

Band photometry is subsequently created for the U, V, and R bands in SExtractor dual-image mode, using the sum of the B, V, and R band images as a detection image. Color magnitude and color-color diagrams are created from the magnitude data retrieved from the photometry source catalogs. The U-R vs. R color magnitude diagram is displayed in Figure 4 and the UVR color-color diagram is displayed in Figure 5.

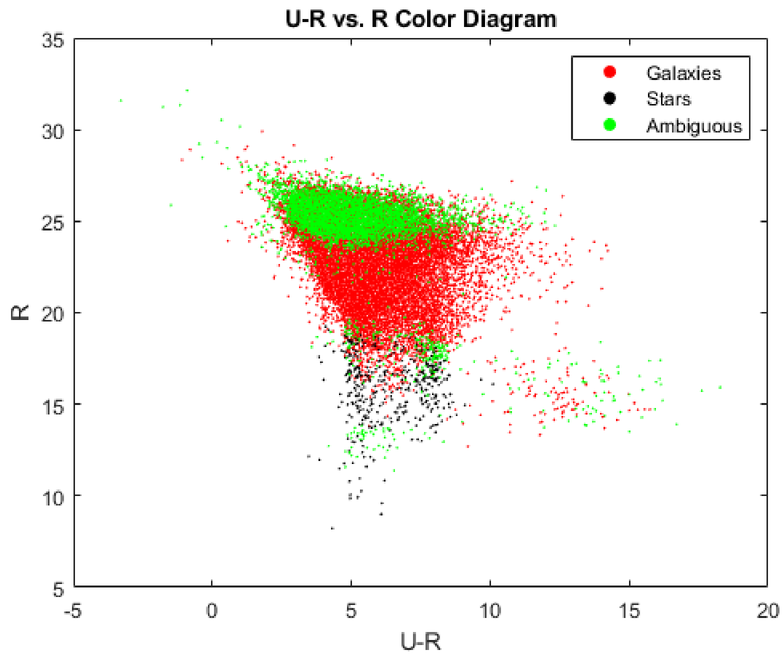

Figure 4. URR Color Magnitude Diagram for the sum of the B, V, and R band images

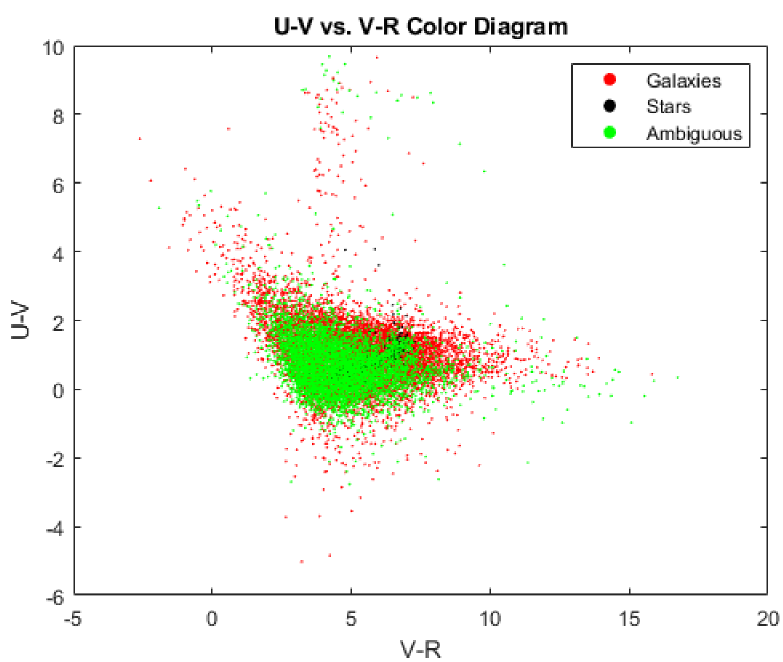

Figure 5. UVR Color-Color Diagram for the sum of the B, V, and R band images

Note that post-processing of the data was required to filter out non-detections in the band photometry; these appear as magnitude values of 99 in the source catalogs generated by SExtractor. A script was created in MATLAB (see Appendix A, section A for code) to filter out these erroneous detections and generate the colors. Objects were also classified by object type (star, galaxy, or ambiguous) based on the bounds mentioned before.

For a complete analysis, the color-color diagrams are remade using the B-band image as a detection image. U, V, and R-band photometry were generated using SExtractor dual-image mode. Color magnitude and color-color diagrams are created from the magnitude data retrieved from the photometry source catalogs. The U-R vs. R color magnitude diagram is displayed in Figure 6 and the UVR color-color diagram is displayed in Figure 7.

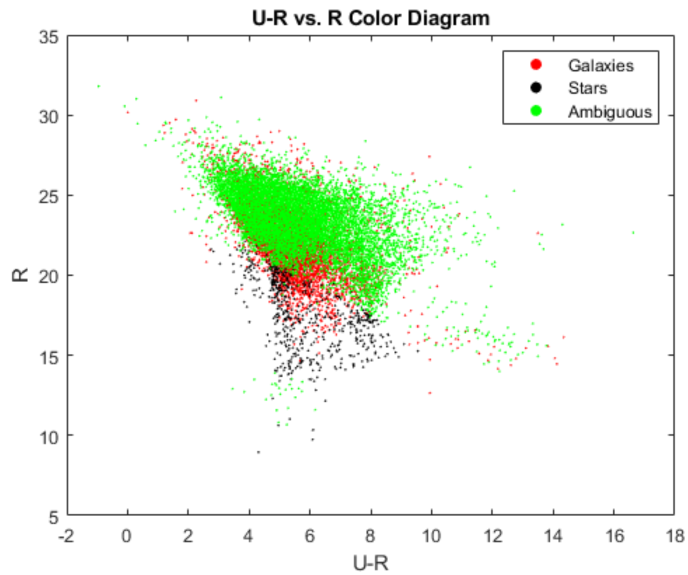

Figure 6. URR Color Magnitude Diagram for the B Band

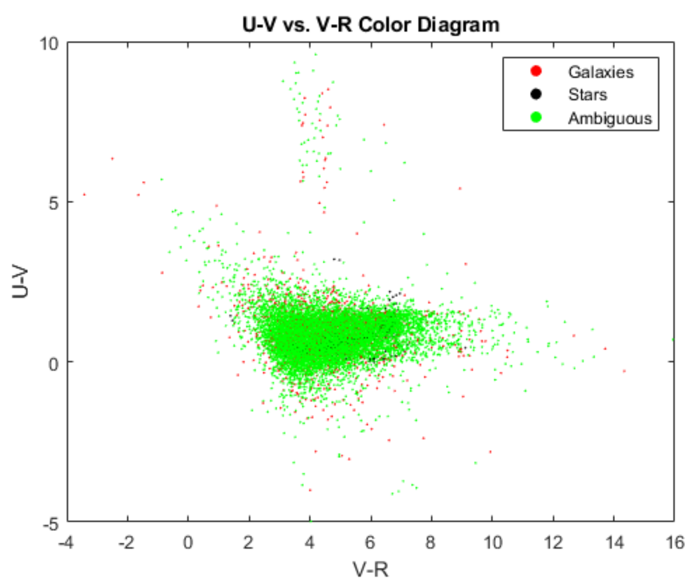

Figure 7. UVR Color-Color Diagram for the B Band

6. DISCUSSION

SExtractor has multiple options for magnitude parameters and we decided on MAG AUTO as our parameter. Shortly speaking, MAG ISO is a dirty representation of all pixels. In other words, it does not use flux through out a whole spectrum. If we were trying to detect stars then it could be a reasonable choice. Unfortunately, our main goal was to detect galaxies. So, we opted for MAG AUTO because of how SExtractor does calculations and estimate errors for MAG AUTO. With MAG AUTO, SExtractor estimates error for each magnitude individually. It is not just a standard deviation. Moreover, MAG AUTO does take Flux and finds intensity through $I = I_0 * 10^{D/\lambda}$. In addition to those, errors on magnitude are defined as Δ m=1.0857* $\sqrt{A\sigma^2 + F/g}/F$.

The majority of this analysis was done in optical wavelengths, with the primary image being the B+V+R image. Optical wavelengths show us how these stellar objects would appear to our common eye, and can be used to analyze stars and clouds of gas. There were also non-optical wavelengths such as the U-band (ultraviolet) and the R-band which is mostly in the near-infrared wavelengths. Ultraviolet bands typically tell us that the source is a very hot star or very hot gas clouds in supernova remnants. Near-infrared and infrared wavelengths tell us that the source will typically be cool stars. Overall, these wavelengths can give us information as to the composition of these celestial bodies. In all of the color diagrams, we find that galaxies typically cluster around certain values.

But optical, ultraviolet, and near-infrared wavelengths are very narrow views of these celestial bodies, so it would be prudent to observe them in other wavelengths as well, if we want to obtain as much data as possible. An additional band of wavelengths to study could be X-rays. X-rays can tell us much about both stars and galaxies. Typical sources for X-rays include clouds of gas in clusters of galaxies, gas clouds in supernova remnants, and stellar coronae. They are generally used to detect very high-energy events such as jets of super-heated materials streaming away from black holes, and supernovas. This can provide information as to the age of galaxies as well as their formation and evolution through time. With analysis of stellar coronae and supernova events, we can glean information on the age of stars and the clusters they may belong to, as well as the type of star they are. While X-rays can be used to obtain data on high-energy events happening in the universe, they are absorbed by Earth's atmosphere, raising the need for observations through space-based telescopes (like the Chandra Observatory) or high altitude balloons, all of which incur a high cost.

7. CONCLUSIONS

One of our findings is that it is important to test multiple data sets. Initially we've used MAG ISO; however, after multiple test we concluded the the most appropriate and easiest would be to use MAG AUTO since it does not require any additional steps and room for error. There are many answered questions and ideally we need to attempt more methods in order to improve our data. According to multiple independent and similar projects, our UVR color-color diagrams are off by a magnitude of about 5 on the V-R axis. One way to explain this is lack of precision with our approximations or the data set not being optimal. It would be reasonable to say that if we did use some additional programs or different computers our results could be better. Someone may try and use FLUX AUTO, but due to the nature of how SExtractor build gives us standard deviation error σ^2(FLUX AUTO) unreasonably high. From Figure 3, we concluded that there was a greater amount of galaxies than stars in the BVR image, with a large amount of ambiguous objects. When using the R-band photometry as the measurement image, however, there was a decrease in the number of ambiguous objects and increase in the number of galaxies. These findings support our prediction made prior to generating catalogues of objects from the images. Other conclusions we drew include:

1. Using the R-band photometry as a measurement image detects more galaxies and reduces the amount of ambiguous objects than just using the BVR photometry. (See Figure 3)

2. Galaxy magnitudes cluster around 25 and star magnitudes cluster around 22 or 16 depending on if the R photometry was used as a measurement image.

8. ACKNOWLEDGEMENTS

Paul Wang developed **MATLAB Code**(Appendix A.1) to generate the color diagrams, wrote the **Results** section of the paper, and prepared a part of the presentation slides. Nihar Prabhala wrote a **Python Script** to sort the stellarity indices, wrote the **Discussion** section of the paper, wrote the **Methodology** section of the paper with Paul Wang, and prepared a portion of the presentation slides. **Introduction**, **Details and Analysis**, **Conclusion**, in Discussion section added quantitative arguments about MAG AUTO, established communication with group 5 in order to acquire needed knowledge in orderto move forward with project done by L.Viktor. Srikar Vakkalagadda created the histograms in **Results**, contributed to **Conclusion**, and prepared a part of the presentation slides. Grishma Adenkar wrote the **Abstract** section of the paper, wrote the **The Data** section of the paper, contributed to the **Introduction** and **Conclusion**, and created histograms for the presentation.

REFERENCE

[1] Cardamone et al. *2010, ApJS 189, 270 The Multiwavelength Survey by Yale-Chile (MUSYC)*

[2] E. Bertin *Institut d'Astrophysique Observatoire de Paris, SExtractor, v2.13*

[3] The MUSYC Collaboration *Multi-wavelength Survey by Yale-Chile*, Index of /MUSYC/sdss1030/optical.

APPENDIX

A. APPENDIX

A.1. *Appendix A: MATLAB code used for post-processing*


```
% Color diagram generator. Import data from 'letter_band'

j=0;
% Filter out bad detections (i.e. w/ MAG = 99)
for i=1:length(Uband)
    if Uband(i,1)~=99 && Vband(i,1)~=99 && Rband(i,1)~=99
        j=j+1;
        Uband_cor(j,1)=Uband(i,1);
        Vband_cor(j,1)=Vband(i,1);
        Rband_cor(j,1)=Rband(i,1);

        % Filtering stellarity indices (SI)
        SI_cor(j,1)=Uband(i,2);
        SI_cor(j,2)=Vband(i,2);
        SI_cor(j,3)=Rband(i,2);
    end
end

% Sorting objects by SI
% Stars (SI > 0.8)
% Galaxies (SI < 0.3)
% Ambiguous (everything else)

% Finding minimum elements of each row in SI_cor. This value will serve as
% the stellarity index of the color.
minValues=min(SI_cor,[],2);
a=0;
b=0;
c=0;

% Finding indices of stars and galaxies in colors.
for j=1:length(minValues)
    if minValues(j,1) > 0.8
        a=a+1;
        indexStars(a,1)=j;
    elseif minValues(j,1) < 0.3
        b=b+1;
        indexGalaxies(b,1)=j;
    else
        c=c+1;
        indexAmbig(c,1)=j;
    end
end

% Generating colors
for k=1:length(Uband_cor)
    UR_color(k,1)=Uband_cor(k,1)-Rband_cor(k,1);
    UV_color(k,1)=Uband_cor(k,1)-Vband_cor(k,1);
    VR_color(k,1)=Vband_cor(k,1)-Rband_cor(k,1);
end
```

```
% Sorting colors by object type
for m=1:length(indexAmbig)
    UR_color_ambig(m,1)=UR_color(indexAmbig(m));
    UV_color_ambig(m,1)=UV_color(indexAmbig(m));
    VR_color_ambig(m,1)=VR_color(indexAmbig(m));
    Rband_cor_ambig(m,1)=Rband_cor(indexAmbig(m));
end
for m=1:length(indexStars)
    UR_color_stars(m,1)=UR_color(indexStars(m));
    UV_color_stars(m,1)=UV_color(indexStars(m));
    VR_color_stars(m,1)=VR_color(indexStars(m));
    Rband_cor_stars(m,1)=Rband_cor(indexStars(m));
end
for m=1:length(indexGalaxies)
    UR_color_galaxies(m,1)=UR_color(indexGalaxies(m));
    UV_color_galaxies(m,1)=UV_color(indexGalaxies(m));
    VR_color_galaxies(m,1)=VR_color(indexGalaxies(m));
    Rband_cor_galaxies(m,1)=Rband_cor(indexGalaxies(m));
end

% Plotting U-R vs. R color magnitude diagram
figure
hold on
sz=2;

c='red';
scatter(Rband_cor_galaxies,UR_color_galaxies,sz,c,'filled');
c='black';
scatter(Rband_cor_stars,UR_color_stars,sz,c,'filled');
c='green';
scatter(Rband_cor_ambig,UR_color_ambig,sz,c,'filled');

box on
legend('Galaxies','Stars','Ambiguous');
xlabel('U-R');
ylabel('R');
title('U-R vs. R Color Diagram');

% Plotting UVR color-color diagram
figure
hold on
sz=2;

c='red';
scatter(UV_color_galaxies,VR_color_galaxies,sz,c,'filled');
c='black';
scatter(UV_color_stars,VR_color_stars,sz,c,'filled');
c='green';
scatter(UV_color_ambig,VR_color_ambig,sz,c,'filled');

box on
```

```
legend('Galaxies','Stars','Ambiguous');
xlabel('V-R');
ylabel('U-V');
title('U-V vs. V-R Color Diagram');
```