Data Analysis Review:
Morphology and SEDs of Galaxies

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1 Introduction

The main goal of studying galactic evolution is to understand how galaxies produce their stars over time. The easiest way to study this is to measure star formation rates and stellar masses as a function of redshift for a sample of the galaxies. To study the properties of the galaxies spectral energy distribution fitting will be utilised. The morphology of the galaxies will be studied by constructing isophotes and radial profiles from the photometric data collected. In this data analysis review, I will outline the pipeline which my collected data will be processed through in order to achieve the above goal. This will involve reducing images, measuring absolute photometry, plotting radial profiles and isophotes, and constructing a model to infer the stellar population properties of a galaxy from photometric data. The data used in this report is from the Sloan Digital Sky Survey (SDSS), but in the final project, the data will be a mix of images taken from Calar Alto Observatory, and UV and IR data from the SDSS.

2 Data Reduction

The first step after taking images from the observatory is to reduce them. To reduce the images the master bias is subtracted from the object and then it is divided it by a normalised master flat field. The master bias is calculated for each filter by combining all the biases on a pixel-by-pixel basis and then getting the average value of each pixel. The master flat is obtained by subtracting the master bias from all the flats, combining them and then taking the average value of each pixel. This master flat is then normalised by dividing it by the average pixel count in the centre of the master flat.

Image reduction is done by subtracting the master bias from the object and then dividing by a normalised master flat field for each filter used.

The pixel values of the image are then converted to right ascension and declination. This is achieved using Nova Astronomy.net. This identifies the background stars to provide a new FITS file containing the astrometric data. Then using the *WCS* module from *astropy* the image is then with declination versus right ascension[1].

Next, using the *photutils.background* package[2], the background of the image was measured and then subtracted from the data.

Archival images will also be used from the SDSS to provide ultraviolet and infrared data. These images can be retrieved using the *astroquery.sdss* module[5]. These images are already reduced and contain the WCS data in their FITS file, so do not have to go through the process outlined above.

3 Absolute Photometry of Galaxies

Next the absolute magnitude of the galaxy in the image is calculated. This is achieved using the *astropy* and *photutils* packages. The first step is to label all the connected pixels with the positive integer for the same source. All background pixels are attributed the value of zero. This process results in the image shown in Figure 1.

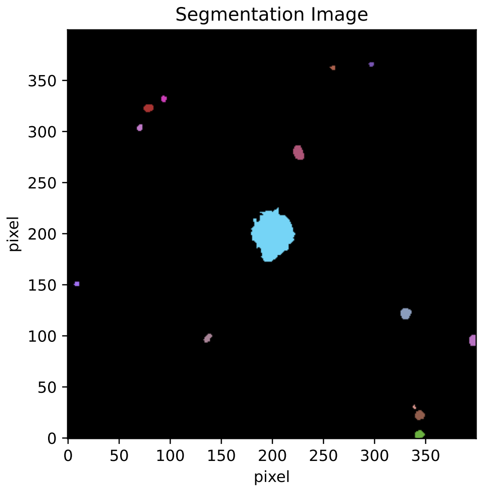

Figure 1: Segmentation of the Light Sources.

This process labels all overlapping sources as one object. This means some sources close to each other are labelled as the same source, to correct for this the data is then deblended using the *deblend_sources* command from the *photutils.segmentation* package.

Now the sources have been segmented, their properties are measured using *photutils.segmentation*'s *SourceCatalogue* function. This function identifies all the labelled objects in the images' centres, shapes, and fluxes. The flux is given in both the segment flux and the Kron flux. The Kron flux is calculated from the light inside the Kron aperture which is constructed from the shape data of the source. Figure 2 shows the Kron aperture plotted over the galaxy, which was used to calculate the Kron flux.

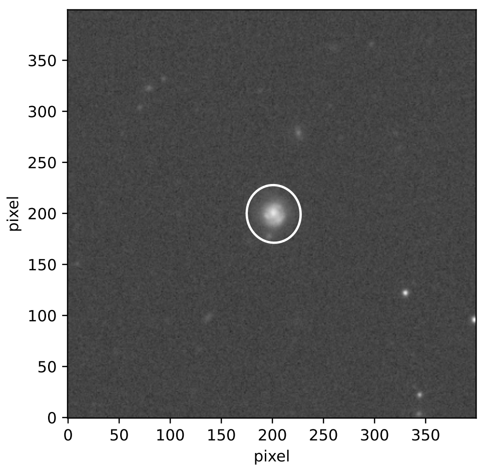

Figure 2: Kron Aperture Plotted Over the Galaxy.

From the information on the objects' centre, the objects of interest can be identified on the image. The objects of interest include the galaxy being studied and background stars. The background stars are used as reference stars, allowing for absolute photometry to be performed. A histogram of the known real magnitude of the reference stars minus the instrumental magnitude ($m_{inst} = -2.5log(Flux)$) is plotted. From this histogram the zero point (ZP) and its uncertainty are obtained from the mean and full width at half maximum, respectively. Then using this ZP, the absolute magnitude of the galaxy can be calculated using the equation:

$$m_{abs} = -2.5log(Flux) + ZP \quad (1)$$

This process is repeated for each filter in order to find their absolute magnitude. For the SDSS data, the absolute magnitude is already calculated so this process does not need to be used for the UV and IR data.

4 Radial Profile & Isophotes

The radial profile of a galaxy can be found using the *RadialProfile* function from the *photutils.profiles* package. This function requires the pixel coordinates of the centre, which were found when performing the photometry, of the galaxy and the edge radii. The radial profile generated for the sample galaxy can be seen in Figure 3.

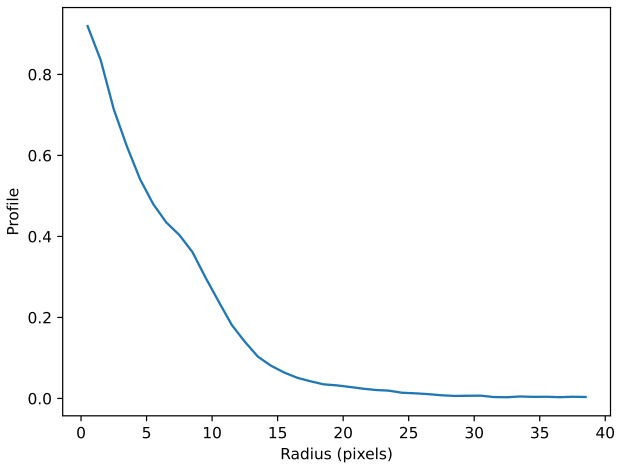

Figure 3: Radial Profile of the Galaxy.

Next, using the *photutils.isophote* module an ellipse model was fitted to the galaxy using its centre, semi-major axis length, and ellipticity data previously obtained. Then using this model isophotes were fitted to the galaxy, this can be seen in Figure 4.

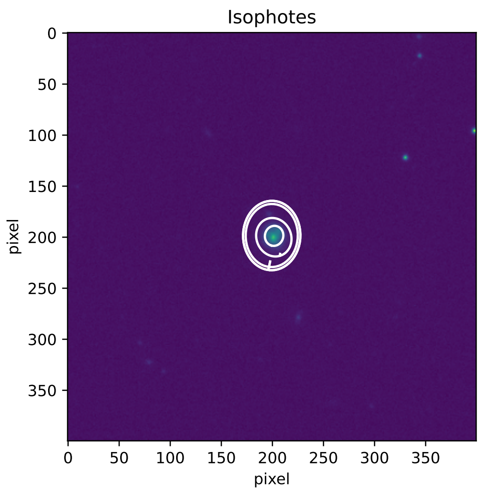

Figure 4: Galaxy Plotted with Isophotes.

5 Prospector

The final step is SED fitting. SED fitting is achieved using a Python package, *prospector*[6]. Using the absolute magnitudes of the galaxies calculated in different filters from the photometry process outlined previously, along with the UV and IR data from the SDSS, an SED if fitted and stellar population properties of the galaxy are inferred.

The *prospector-α* model will be used as described in the literature[6]. This model includes 11 free parameters such as metalicity, mass, and dust. I have yet to be able to get this model to run, but I am confident I can with more time, so in this report, the *parametric_sfh* model will be used as it contains only 5 free parameters. Once the model is selected, and the redshift of the galaxy is fixed, prior for the free parameters are set. Then, using the *fsps* package predictions are made for the parameters[3]. Next, the *emcee* package is used to run a fit[4]. The number of walkers and iterations are set. A corner plot of the results is then plotted, giving a mean value and standard deviation for each free parameter. An example corner plot of the results obtained from running the *prospector-α* model on the sample galaxy can be seen in Figure 5.

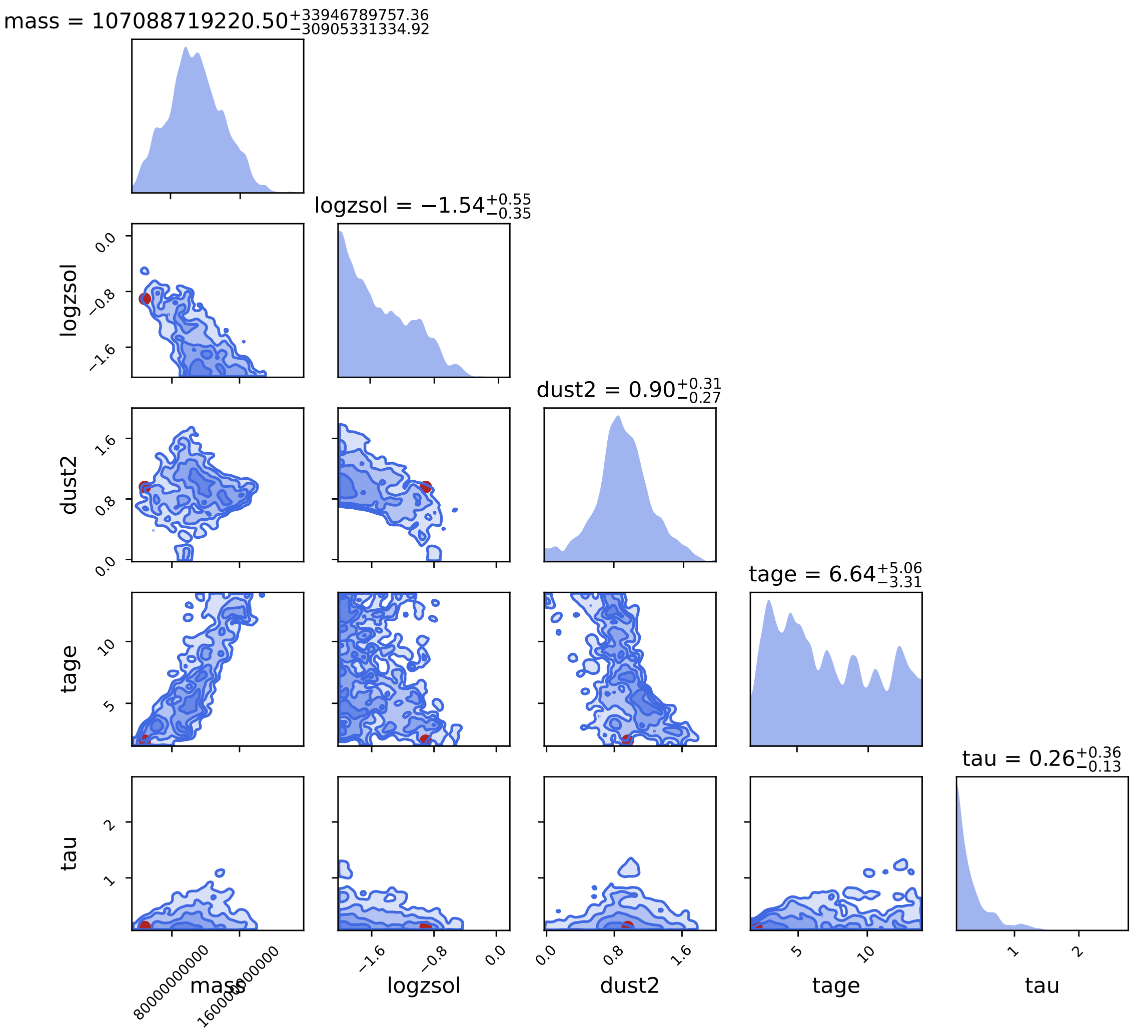

Figure 5: Corner Plot With 5 Free Parameters.

References

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[3] Charlie Conroy and James E. Gunn. *FSPS: Flexible Stellar Population Synthesis*. Astrophysics Source Code Library, record ascl:1010.043. Oct. 2010.

[4] Daniel Foreman-Mackey et al. "emcee: The MCMC Hammer". In: 125.925 (Mar. 2013), p. 306. DOI: 10.1086/670067. arXiv: 1202.3665 [astro-ph.IM].

[5] A. Ginsburg et al. "astroquery: An Astronomical Web-querying Package in Python". In: 157, 98 (Mar. 2019), p. 98. DOI: 10.3847/1538-3881/aafc33. arXiv: 1901.04520 [astro-ph.IM].

[6] Benjamin D Johnson et al. "Stellar population inference with Prospector". In: *The Astrophysical Journal Supplement Series* 254.2 (2021), p. 22.