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Project 3: HII Star-forming Regions

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1. OBSERVATIONS

We planned to observe three galaxies: M82, M49, and M51 in the G, R and Hα bands. These galaxies were chosen because of their large apparent size, their brightness, and the depth of literature available for each galaxy. The bands were chosen to allow for the detection of HII star-forming regions which would be revealed by a comparison of the fluxes of the broadband and Hα band for each galaxy. Originally we planned on 20 minutes exposures in Hα and 10 minute exposures in R and G. However, we had some problems with streaking and saturation so we ended up modifying this plan. Also it would turn out that the Hα filter was actually the Z filter which complicated analysis and made the data less robust.

For M82 we ended up taking 7 minute exposure in Z, and 3 minute exposures in R and G. For M49 we took a 7 minute and a 12 minute exposure in Z and 3 minute exposures in R and G. Finally, for M51 we took a 7 minute exposure in Z and 3 minute exposures in R and G. I think for future observations of the type we should have taken multiples of these shorter exposure times as that would do a better job of resolving the star-forming regions.

2. RESULTS

The galaxies I chose for my own analysis were M51, M82, M101, NGC 2903, and NGC6946. As always, the first order of business was to make the master bias and master flats for each band and then apply them. The NGC6946 was from an observation in 2018 so I had to take care to use calibration frames from that time period. The NGC6946 shots were also taken using a sub-array so I had to create the appropriate sub-arrays in the calibration frames before I could apply them to the image. For M51, I decided to try and take advantage of the fact that multiple groups had imaged it by incorporating each groups images into my analysis.

After creating the calibrated images, I uploaded everything to Astrometry.net to receive the images with WCS coordinates in their headers. For each galaxy, I then reprojected each shot in a filter together so that each filter was aligned, but the different filter images for a galaxy were not aligned. I then stacked each filter by taking the mean of all the images in each filter to produce the stacked image. These stacked images were then reprojected between filters so that all the images in different filters for a given galaxy were all in alignment, creating a set of master images.

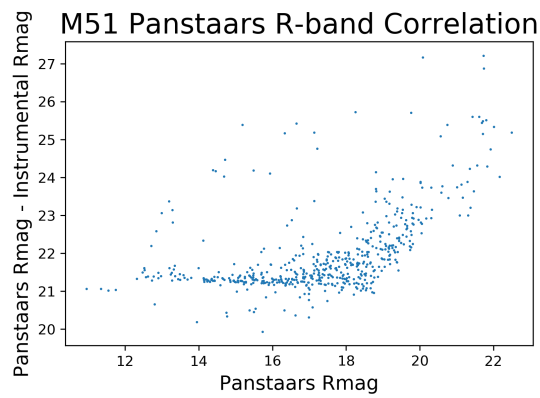

Figure 1. Panstaars Magnitude vs the difference between Panstaars and instrumental magnitudes, for each object in the catalog for M51.

From here I calculated zeropoints in each filter for each galaxy in order to find the true AB magnitudes. This was done by running Sourceextractor on each master image and then comparing the Ra, Dec, and FLUX_AUTO information from each Sourceextractor generated catalog to matches in the Panstaars catalog. To calculate the zeropoint, I then graphed the Panstaars magnitudes against the difference between the Panstaars magnitudes and the instrumental magnitudes. I made a cut-out based on what seemed reasonable from the graph and took the mean of the difference between Panstaars and the instrumental magnitudes inside of that cut-out to calculate the zeropoint for that particular filter and image. An example of this can be seen in Figure 1. For this particular image I chose to make a box from 14-19 on the x-axis and from 21 to 22 on the y-axis to calculate a zeropoint of 21.36727861465328. This process was repeated for each filter on each galaxy.

The zeropoints were then used to create calibrated images by multiplying the image data by the following quantity:

$$10^{-0.4*48.6-0.4*zeropoint} * 10^{29}$$

Band	Err
M101 Z-Band	28.018936562500002
M101 R-Band	13.286936454545454
NGC6946 Hα-Band	56.58662574074074
NGC6946 R-Band	64.50496485294117

Table 1. Errors in flux measurements as given by Source Extractor, for each image.

48.6 is the AB magnitude system zeropoint and 10^{29} is the conversion from $erg/s/cm^2/Hz$ to μJy. I converted to μJy so that later flux differences would be due to physical differences in the image and not related to differences in zeropoint values.

After applying the zeropoint correction I cropped the images to just contain the galaxies in question and then convolved the images to a 2d gaussian with a standard deviation in x and y of 5. I did this to make the difference images more reliable, as cropping cuts down on sources picked up from outside the galaxy and convolving makes subtracting out field stars work more smoothly. I then took difference images of R-Z for all the galaxies except for NGC6946 where I took an Hα-R difference image. I ran these difference images through source extractor, using the difference images as the detection images and using the cropped but not convolved images for each filter as the measurement images. Unfortunately after this stage I only got a meaningful amount of detections for NGC6946 and M101.

To find the error for flux in each image I created histograms from the FLUX_ERR columns in the relevant Source Extractor column, defined a cut to remove outliers, and then took the mean of these values. The histograms can be seen in Figure 2. The values are presented in Table 1

To find the distribution of luminosities of the HII regions, I first converted from the flux in frequency given by the catalog to the flux in wavelength, and then to erg/sec from uJy, using Equation 1, where λ is the central wavelength of the filter.

$$F_\lambda = F_\nu \frac{c}{\lambda^2} * 10^{29} \tag{1}$$

I then solved for the $Flux_{H\alpha}$ for NGC6946 using Equation 2 and for M101 using equation 3, where $\Delta\lambda$ is the width of the filter.

$$F_{H\alpha} = \frac{F_{\lambda,R} - F_{\lambda,H\alpha}}{\frac{1}{\Delta\lambda_R} - \frac{1}{\Delta\lambda_{H\alpha}}} \tag{2}$$

$$F_{H\alpha} = \left(F_{\lambda,R} - F_{\lambda,Z} \frac{\lambda_R^\beta}{\lambda_Z^\beta} \right) \Delta\lambda_R \tag{3}$$

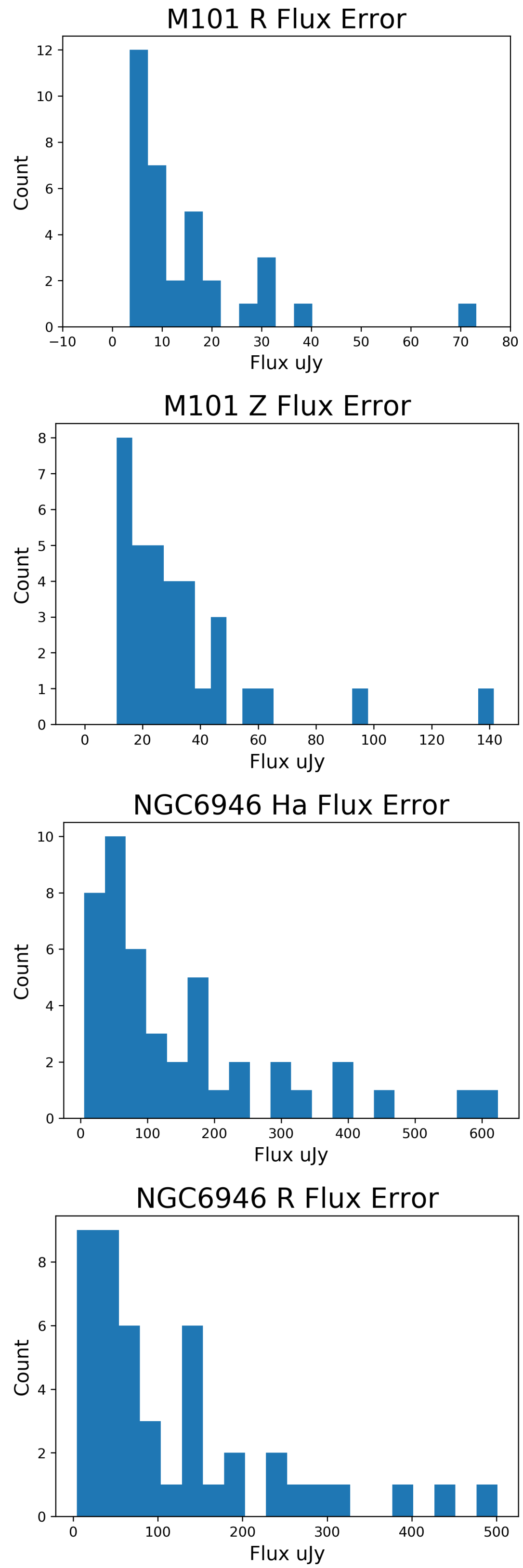

Figure 2. Distribution of flux errors for each object measured in each image.

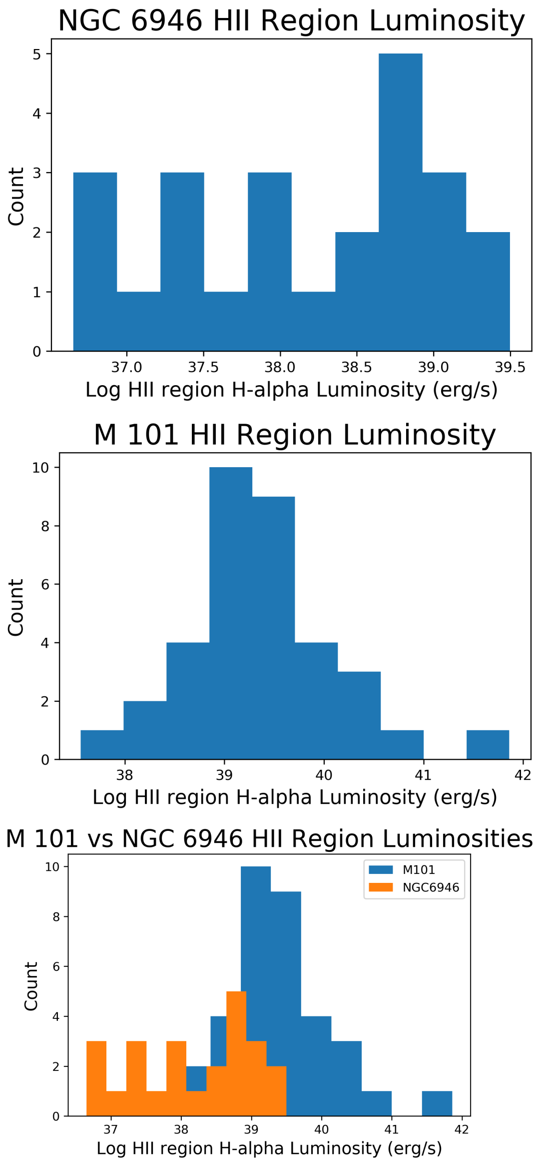

Figure 3. Distribution of luminosities for each HII region measured in each image. The bottom figure shows these two plots laid on top of each other to show that both appear to have a roughly Gaussian shape centered around 39.

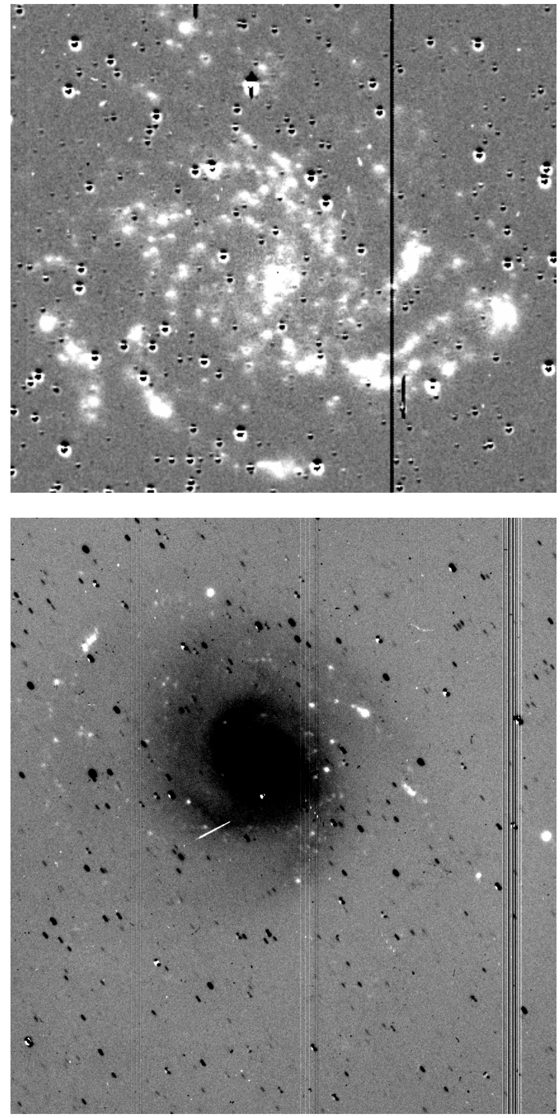

Figure 4. HII regions revealed by the Hα-R image for NGC6946(Top) and the R-Z image for M101(bottom). These reveal the strength and location of star-forming regions in a galaxy. For both these appear to be distributed along the spiral arms. Note these are not the convolved difference images used to determine the locations of star-forming regions in the analysis.

Converting to luminosities was then done using Equation 4, where d is the distance to the galaxy as found in the literature.

$$L = 4\pi d^2 F_{H\alpha} \tag{4}$$

The distributions of luminosities can be seen in Figure 3.

3. DISCUSSION

Unfortunately I was only able to get meaningful information out of M101 and NGC6946, which are both spiral galaxies with large amounts of HII regions[2][1]. The other galaxies should also show areas of high star formation but it does not seem like the imaging was good enough to resolve this with my current analysis. M101 is a much larger galaxy than NGC6946, 170,000 lightyears in diameter vs 40,000 lightyears, which helps to explain why so many more regions were detected for M101[2][1]. A larger sample size also helps to explain why its distribution appears more standard than NGC6946 which appears to have a long tail. Both galaxies appear to have HII regions following the spiral arms of the galaxies, as can be seen in Figure 4, although this is harder to make out in most of the M101 image. The difference in the appearance of HII regions for each galaxy is likely mostly due to the fact that the M101 imaging was not able to take advantage of the Hα filter.

Had I known before almost finishing this project that elliptical galaxies typically have almost no star-forming regions, I would have incorporated M49, the one elliptical galaxy observed by the class, into my analysis to demonstrate the lack of star-forming regions. However, it is questionable how convincing this conclusion would be given that 3/5 galaxies that were supposed to have star-forming regions did not show as having any star-forming regions with my current analysis. For future observations, it would also be helpful to have access to an Hα filter for these types of observations.

References

[1] *Astronomy Picture of the Day.* URL: https://apod.nasa.gov/apod/ap110101.html.

[2] *The Pinwheel Galaxy.* URL: https://www.nasa.gov/multimedia/imagegallery/image_feature_2265.html.