Draft version June 9, 2017
Typeset using LaTeX **twocolumn** style in AASTeX61

NGC 5427 INTENSITY PROFILE

Justin Collins[1] and David Staker[1]

[1] *University of Washington, Astronomy Department*

(Accepted June 9, 2017)
Submitted to Astr480

ABSTRACT

We present the magnitude values of NGC 5427 in the SDSS g, r, and i filters using cylindrical integration on intensity profiles derived from PYRAF's ELLIPSE task. The process of reduction and potential errors are also discussed. We find that the SDSS g filter image has a seemingly reasonable intensity profile whereas the r and i filtered images are likely a bad fit. The results of each magnitude calculation are compared against SIMBAD's magnitude values for Johnson filters of a similar wavelength. We find that the SDSS g filtered image of NGC 5427 was about 1 magnitude off from the similar Johnson B filter value acquired from SIMBAD. The r and i SDSS filtered images had very different magnitudes from their similar Johnson filter counterparts.

[1] An awe inspiring colored picture is also constructed for the sake of musing about humanity's existence (See Figure 5... see deeply into it...)

1. INTRODUCTION AND BACKGROUND

ARP 271 is a pair of interacting spiral galaxies also known as NGC 5426 (bottom of images) and 5427 (top). A great deal of analysis has already taken place on the galaxy interaction pair with regards to their kinematics and dynamic interactions. From this analysis the mass to luminosity ratios have been estimated. SIMBAD hosts data regarding the pair's magnitudes using various Johnson filters (Table 7), but there has been no magnitude estimates using SDSS filters which center about different wavelengths. The aim of this paper is to assist in increasing the precision to which the mass to luminosity ratio can be determined by estimating the magnitude of NGC 5427 in the SDSS g, r, and i filters. Fuentes-Carrera et al. (2004)

This paper will first discuss the relevant observing conditions and instrument information. To determine an accurate magnitude from the image it will also be necessary to explain in detail the reduction process for the image as well as how the isophote data was gathered. This paper will then address how the isophote data was organized into an intensity profile and how this was used to calculate the resulting magnitude. These results will be compared to SIMBAD's results along with difference and error analysis. Finally, the paper concludes with a discussion on how to improve the observation and analysis for future observations.

2. OBSERVATIONS

5 science images of ARP 271 (NGC 5426 and 5427) were taken by ARCSAT on April 20th of 2017 from about 5 to 6pm UTC. ARCSAT is the Apache Point Observatory's 0.5 meter classical cassegrain telescope with an f/8.0 focal length and 51"/mm plate scale ARCSAT (NA). It is located in the Sacramento Mountains in Sunspot, New Mexico. Each image was taken with the same controllable conditions except for a different filter was used in each case. Notably the RA and DEC of the field of view always remained at RA: '14 03 25.50' and DEC: '-06 02 59.0'. During the observations the sky was mostly clear, and the airmass was acceptable but not optimal. The Table 1 below shows the filter, airmass, and time respectively for each of the 5 science images. The CCD used for observations was the University of Washington's FlareCam. Specifications for the FlareCam are noted in Table 2 ARCSAT (NA).

Table 1. Seeing Conditions

Filter	Airmass	Time (UTC)
SDSS r	1.44833348634	'05:22:38'
SDSS g	1.40992168198	'05:34:25'
SDSS i	1.38446177250	'05:44:13'
halpha	1.36115933532	'05:54:13'
nmsu	1.33760470474	'06:06:16'

Table 2. CCD Characteristics

Parameter	Value
Field size	1024 x 1024 pixels (13.3 mm)
FOV	11.2' x 11.2'
CCD	APOGEE U-47UV 13 um pixel, back-illuminated, UV enhanced
Read-out time	1 sec for the whole field
Binning	1x1 binning
Pixel Scale	0.656"/pix
Gain	1.25 e-/ADU (left, right)
Read-out noise	11.8 e-
Dark Current	0.1 e-/sec at T about -30C
QE at 5000A	65%

Taken from ARCSAT website

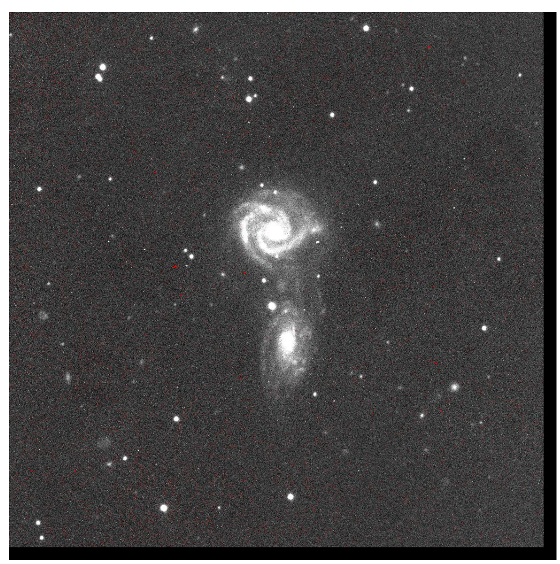

Figure 1. original science image in the g filter

3. REDUCTION PROCESS

Several steps were taken to reduce the image to a more accurate form. The Space Telescope Science Institute's PYRAF STScI (2013) program was used to accomplish the image reduction. Approximately 10 bias filters were combined and averaged using the IMCOMBINE task with the combine = "average" parameter. The output of this became the master bias. Using IMARITH with

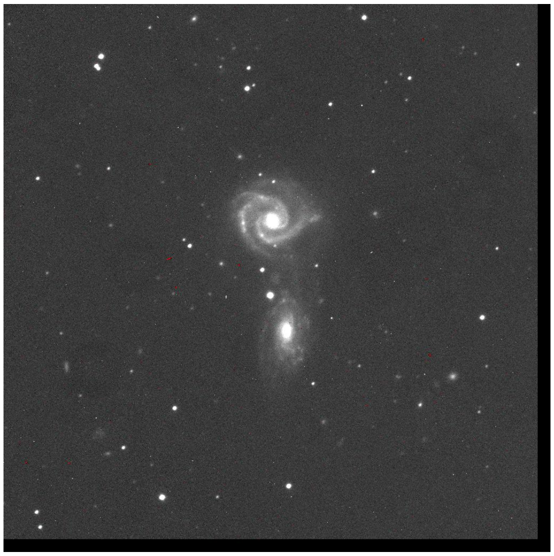

Figure 2. original science image in the r filter

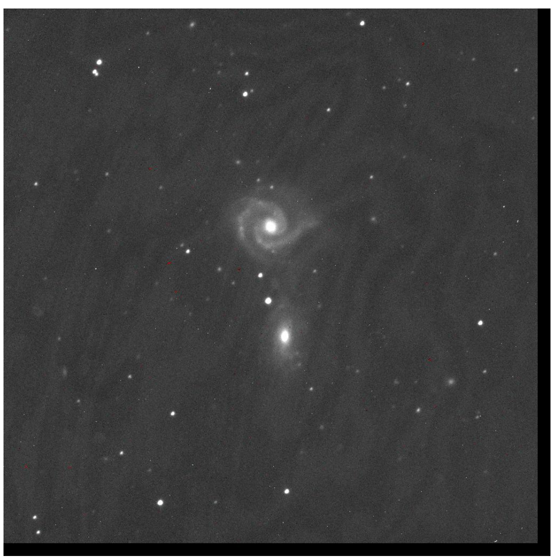

Figure 3. original science image in the i filter

the following parameter choices (Table 3), the 5 science images were each divided by the master bias.

Table 3.

operand1	operand2	op
Science Image	Master Bias	"/"

The night of observation for the science images did not include any darks. Since the science images were 300 second exposures a 300 second dark from another observing night was used. This dark was subtracted by the master bias using IMARITH, with op = "-", in a similar fashion as the above table. Afterward the dark was subtracted from the 5 science images again using IMARITH.

Flats were all taken from other observing nights than the one the science images were observed on. The g, r, and i filters had 2 flats of slightly different time exposures. The halpha and nmsu filters only had one flat. The filters with two flats were combined using IMCOMBINE with parameters; combine = median and scale = mode. To normalize the flats, IMSTAT was run on the resulting flats. This produced several pieces of data including the mode of the combined flats. Normalization was achieved by dividing the resultant flats by their mode using IMARITH. Finally, again using IMARITH, the science images were each divided by the normalized flats so as to reduce deviations in the quantum efficiency of the pixels.

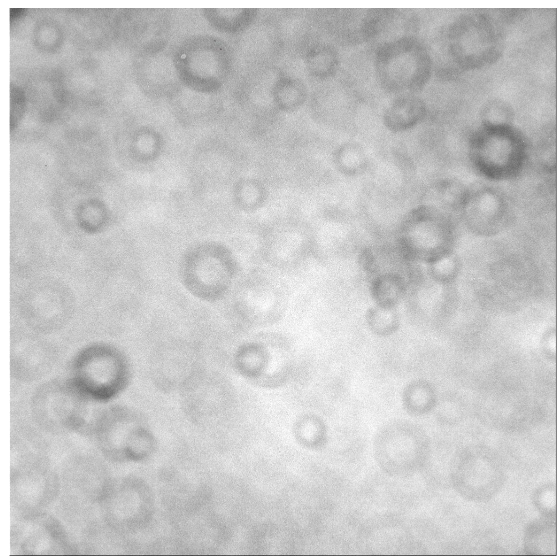

Figure 4. example: combined g flat normalized

This photo was made with python using the Python Imaging Library (PIL). The values in the fits file were very small so they were multiplied by 200 and the deviations from the normalized flat value of 1 were multiplied by 10 to make deviations more apparent.

ALIGNMENT

After the reduction process came the alignment process. From here on out the analysis was only performed on the g, r, and i filtered science images. The Halpha and NMSU filters didn't produce enough data to be significantly useful in calculating the magnitude of NGC 5427. For convenience this paper will refer to the filtered images by the filter letter (eg. "the g image").

To align the g, r, and i filtered science images the PYRAF task, IMALIGN, was used. IMALIGN requires input images as well as a coordinate reference file and a shift file. One of the images must also be the reference image, for which the g image was chosen. To create a coordinate reference file DAOFIND was utilized. DAOFIND is a task that calls other tasks such as DATAPARS in order to find stars in an image. A high degree of accuracy wasn't required here so the standard predetermined parameters were used including a 2.5 value for the FWHM parameter in DATAPARS. The goal was simply to acquire a large list of stars, most of which showed up in every image. The DAOFIND task created a coordinate file. TVMARK was applied using this coordinate file to visually identify the pixel groups, "stars", that were found by DAOFIND. A few of the stars on the top half of the image seemed questionable. To avoid errors the top half of the "stars" were removed. Plenty of fits were still remaining (more than 10).

A shift file is also required to provide initial guesses of the shift. The values are shown in Table 4. The shift values were based on when the g,r, and i images were superimposed in python. This superimposition was done by human eye with guess and check. When both the reference and shift files were complete, IMALIGN was run. The results were mediocre. the g and i images aligned quite well but not the r image; it maintained an offset. Ultimately, however the error would not have a significant effect on the analysis since each image was dealt with separately.

Table 4. Shift File

Name	Xshift	Yshift
arp271_g_ready.fits	0	0
arp271_i_ready.fits	-3	7
arp271_r_ready.fits	-3	5

DETERMINING ISOPHOTES

To determine the magnitude of NGC 5427 it is necessary to know its intensity profile. The ELLIPSE task was used to set up accomplishing this. The ELLIPSE task fits a series of isophotes of increasing radius stemming from the center of the galaxy. Editing geompar, one of the tasks called by ELLIPSE, the center of the NGC 5427 was estimated by eye for each image. The result produced a .tab file. Using TPRINT the .tab file that contained the isophote data was converted into a .dat file which could be understood by a human. Table 5 shows all the column names outputted in the .dat file and what they mean.

CREATING A COLORED IMAGE

To construct a colored image (Figure 5) the g, r, and i images were superimposed on each other in a python program. The images used were reduced in the same aforementioned manner, but they were not aligned. The aligning for the colored image was accomplished manually. Python Imaging Library's (PIL's) Image function was imported to do this along with astropy.io.fits' fits function. Each of the 3 image fits files were read in using the fits.getdata function. This constructed an array of values which corresponded to the original pixel values. These values were far above the accepted values by PIL's RGB parameters which only reach 255. Each of the image arrays were averaged separately over all pixel values and then each pixel was divided by the average so as to normalize the array. Since the RGB must be given in integers each image post-normalization was then multiplied by 100 and the resultant value was changed into the closest integer. To get rid of background noise 40 units were subtracted thereafter. the g, r, and i images represented the blue, green, and red of the Python image values respectively. The resulting colored image was trimmed to avoid index errors since these images were aligned manually by adding or subtracting to the x and y indices of the pixel. The code below demonstrates the final step in producing the colored image.

```

plt.figure(figsize = (12 , 12))
n = 100
s = 40
new_img = Image.new( 'RGB', (1024,1024), "black")
new = new_img.load() # create the pixel map
for x in range(0 , 1000):    # testing obs pixels
    for y in range(0 , 1000):
        B = int(photog_norm[y+3][x] * n - s)
        G = int(photor_norm[y][x+7] * n - s)
        R = int(photoi_norm[y][x+5] * n - s)
        new[x , y] = (R,G,B)
new_img.show()
new_img.save('arp' + '.jpg' , 'jpeg')
new_img.close()
```

4. ANALYSIS AND DISCUSSION

With the .dat files from the ELLIPSE task the data is available to be analyzed. Specifically the key pieces of data that will be analyzed is the SMA (semi-major axis length in pixels) and INTENS (mean isophotal intensity) data. Using plotting in Python an intensity (INTENS) vs. radius (SMA) plot was made for each type of image (Figure 9). The intensity profile for the g image is expected but is mediocre for the r image and very unusual looking for the i image. It is possible the ELLIPSE task was unable to function properly since the image had

Figure 5. ARP 271 super imposed with SDSS filters g, r, and i

Table 5. Result from ELLIPSE Task

Column	Contents
SMA	semi-major axis length (pixel)
INTENS	mean isophotal intensity
INT_ERR	error in isophotal intensity (RMS / sqrt(NDATA))
PIX_VAR	estimate of pixel variance (RMS * sqrt(SAREA))
RMS	root-mean-square scatter around isophotal intensity
ELLIP	ellipticity
ELLIP_ERR	ellipticity error
PA	position angle (degrees counterclokwise from +y)
PA_ERR	position angle error
X0, Y0	ellipse center (pixel)
X0_ERR, Y0_ERR	error of ellipse center
GRAD	local radial intensity gradient
GRAD_ERR	gradient error
GRAD_R_ERR	gradient relative error
RSMA	(semi-major axis length) ** 1/4
MAG	mean isophotal magnitude
MAG_UERR	upper magnitude errors
MAG_LERR	lower magnitude errors
TFLUX_E	total flux enclosed by ellipse
TFLUX_C	total flux enclosed by circle
TMAG_E	total flux enclosed by ellipse, in magnitudes
TMAG_C	total flux enclosed by circle, in magnitudes
NPIX_E	total number of valid pixels inside ellipse
NPIX_C	total number of valid pixels inside circle
A3, B3	3rd harmonic deviations from ellipse
A4, B4	4th harmonic deviations from ellipse
A3_ERR, B3_ERR	3rd harmonic deviation errors
A4_ERR, B4_ERR	4th harmonic deviation errors
NDATA	number of valid data points on isophote
NFLAG	number of flagged data points on isophote
NITER	number of iterations
STOP	stop condition code
A_BIG	maximum (in abs. value) among 1st and 2nd harmonic amplitudes
SAREA	average sector area on isophote (pixel)
AIn, BIn	optional n-th harmonic amplitudes
AIn_ERR, BIn_ERR	optional n-th harmonic amplitude errors

Table taken form stsdas on their page about the ELLIPSE task two galaxies instead of one. A look at the final reduced, aligned images (Figures 6, 7, 8) demonstrates that NGC 5427 is most apparent in the g image. The i image also has a wavy pattern that may have interfered with the ELLIPSE task being able to analyze the galaxy. As a result the focus of the analysis will be on the g image.

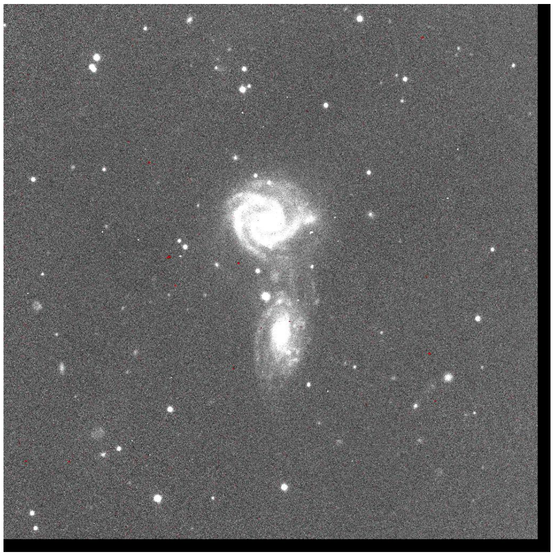

Figure 6. reduced g image

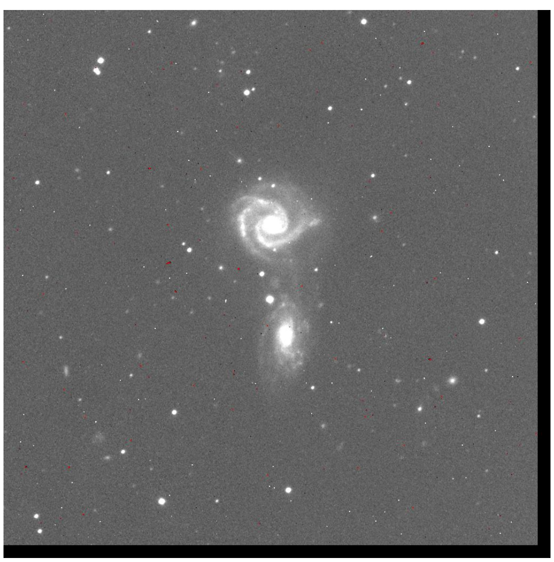

Figure 7. reduced r image

The goal is to find the magnitude of NGC 5427. The following Python code uses the SMA and INTENS data aformentioned to calculate the magnitude. The SMA data list is placed in app_mag function as the radius and the INTENS data list is the intensity. The main part of the code takes place within the for-loop. This

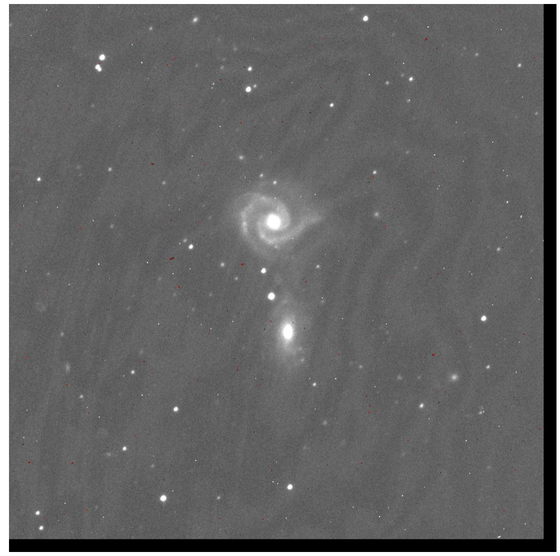

Figure 8. reduced i image

for-loop behaves as a midpoint Riemann sum where each rectangle is rotated about the y (INTENS) axis. That is, the cylindrical method of integration is used since the isophotes are rings and intensity represents the height of the cylinder. delx represents the width of the rectangle. Radius, which is averaged with the subsequent radius, represents the distance from the center to the rectangle (or cylinder). Using 2pi*r*h*delta_r for the volume of each cylinder we can integrate to find the total intensity in terms of counts. See example of the cylindrical integration below in figure 10.

Given that the gain for ARCSAT's CCD is 1.25 and the exposure times were 300 seconds and that ARCSAT lens has a quarter meter radius the flux density can be found. The integrated count value is multiplied by the gain (1.25) resulting in the amount of photons entering the CCD. Then the amount of photons is divided by the ARCSAT lens area and exposure time to find the flux. This flux is then transformed into a flux density in terms of Janskys. This is compared against the flux density of Vega in the apparent magnitude formula to determine the final apparent magnitude.

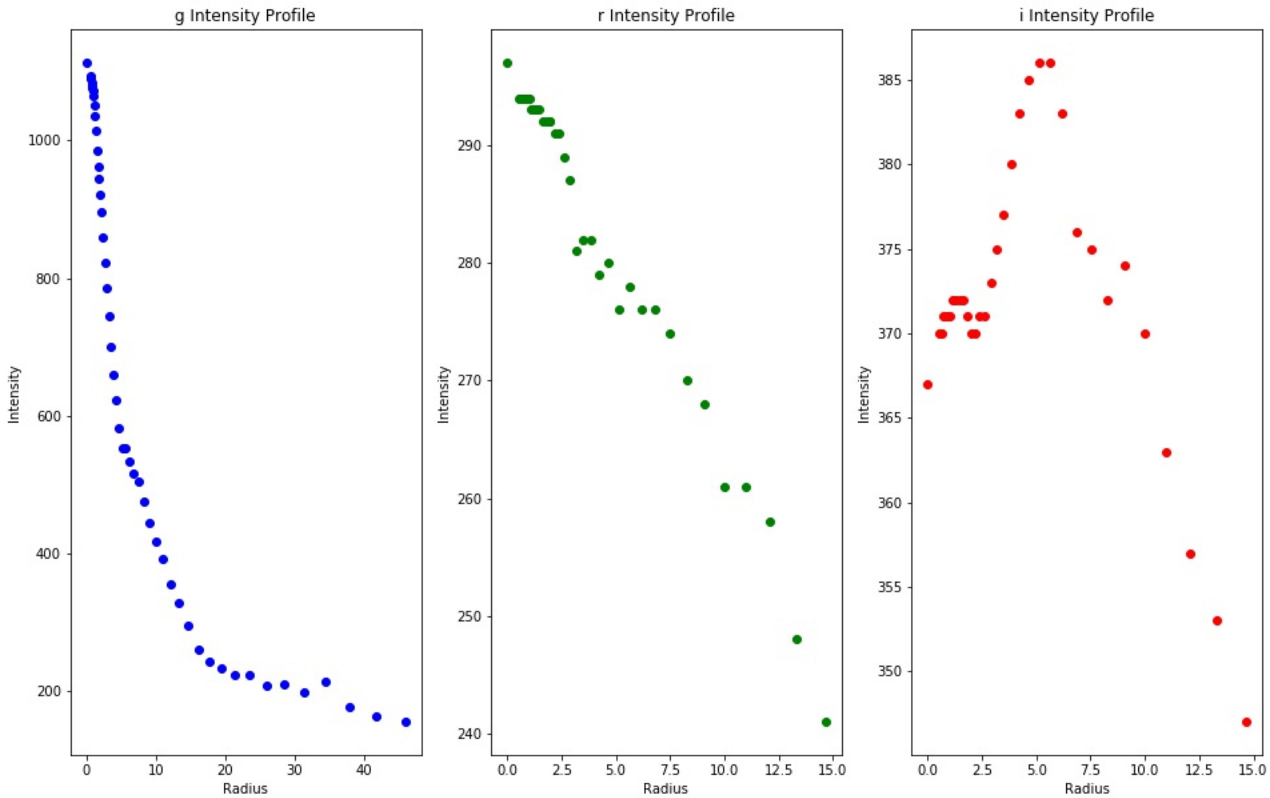

Figure 9. Intensity Profiles

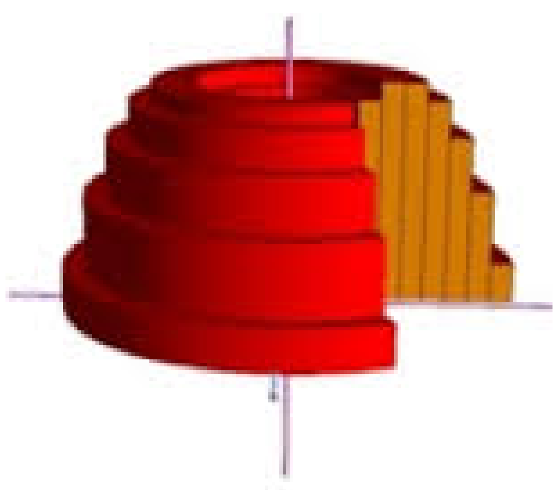

Figure 10. cylindrical integration example

```
def app_mag(radius , intensity , wavelength_A):   # wavelength_A changes values during the calculation but doesn't change the final result. Cannot be 0
    gain = 1.25   # e/ADU; for ARCSAT CCD
    time = 300   # in seconds; this is the exposure time
    area = (0.25 ** 2) * 3.1415   # in m^2; for ARCSAT lens
    c = 2.998 * 10 ** 8   # speed of light m/s
    h = 6.626 * 10 ** -34   # Planc's constant SI units
    wavelength_m = wavelength_A * 10 ** -10   # assumes wavelength in Angstroms, converts into meters
    frequency = c/wavelength_m   # frequency in Hz
    E_photon = h * frequency * 10 ** 7   # in ergs; 10 ** 7 converts joules into ergs


    amt_photons = 0
    for i in range(0, len(radius) - 1):
        delx = np.abs(radius[i] - radius[i + 1])
         mp = 2 * 3.14 * ((radius[i] + radius[i + 1])/2) * ((intensity[i] +intensity[i + 1])/2)
```

```
            amt_photons = delx * mp + amt_photons


        convert_to_jansky = 10 ** 19 # converts erg/(m^2 * s * Hz) into Jansky
        spec_flux_density = (E_photon * amt_photons * gain * convert_to_jansky) / (time * area * frequency)
        flux_vega = 3631  # in Janskys
        mag = -2.5 * np.log10(spec_flux_density/flux_vega)
        return mag
```

The results of the findings for the magnitude of NGC 5427 are listed in Table 6. These are compared against the SIMBAD's results for NGC 5427 in Table 7. However, note that SIMBAD uses Johnson filters whereas this paper uses SDSS filters. The difference in wavelengths are also shown. Finally in Table 8 the errors in intensity given by INT_ERR data provided by the ELLIPSE task are calculated and turned into upper and lower bounds for the magnitude estimates. Note that upper refers to a higher intensity and thus a lower magnitude.

Table 6. This Paper's Magnitude Results

Filter	Wavelength (Angstroms)	Magnitude
SDSS g	4770	15.61
SDSS r	6231	17.91
SDSS i	7625	17.55

Table 7. SIMBAD Magnitude Results

Filter	Wavelength (Angstroms)	Magnitude
Johnson B	4353	14.67
Johnson V	5477	13.96
Johnson R	6349	11.54

SIMBAD (NA)

Table 8. Error Bounds

Error Name	Magnitude Bounds	Error
g upper	15.6037439118	-0.00954788100126
g lower	15.6229243826	+0.00954788100126
r upper	17.9041107062	-0.00530395795689
r lower	17.9147446599	+0.00530395795689
i upper	17.5470133337	-0.00466619366805
i lower	17.5563658617	+0.00466619366805

this is error analysis from this paper

The results shown in this table reveal a few key issues. The SDSS g filter result and the Johnson B (which is close in wavelength) have the most similar magnitudes with a delta mag of 0.94. Some difference is to be expected due to the different wavelengths, but the delta is still quite large. The delta is much larger when we compare SDSS r and i to the similar wavelength Johnson R filter. Also concerning is the fact that from the SIMBAD data the magnitude decreases with increasing wavelength whereas this paper got a nearly opposite gradient. Based on the intensity profiles' graph the r graph and especially the i graph appear to have unusual behavior. The r graph's intensity is nearly flat which is unexpected for a spiral galaxy. The i graph's intensity increases then later decreases with radius which is very unexpected. One possible error was that the ELLIPSE task was confused by having two galaxies and this caused the task to be unsure where the galaxy ended. Indeed both r and i graphs truncate significantly earlier in SMA then the g graph. Another possible source of distinction between this paper's results and SIMBAD's data is the seeing. The airmass was not unacceptably high but still high enough that it would likely have a noticeable affect on the amount of photons that passed through the atmosphere. Clouds and external brightness might have also played a roll in dimming the image or causing a very large bias to be subtracted thus making the image appear dimmer. The gain was determined based off the ARCSAT website reference but it could have been different, though likely not to a very significant degree.

5. CONCLUSION

This paper looked at constructing an intensity profile of NGC 5427 and deriving the magnitude from there. None of the results appeared satisfactory. The g intensity profile might be a reasonable result after accounting for differences in seeing. The r and i intensity profiles, however, are very unusual and likely due to some error in the image analysis itself rather than external factors. Ideally, in the future a more powerful telescope could zoom in on NGC 5427 and the isophote fitting could be done manually to ensure greater accuracy. Perhaps also, NGC 5426 could removed either with cropping or utilizing in depth analysis of the light distribution between the galaxies. Also if the airmass during the observation could be reduced to less than 1.1 that would also improve the brightness of the image and would reveal a potentially more accurate result. Finally a larger set of darks and flats from the same observing night would improve the accuracy. This could also be used for an accurate calculation of the gain of the CCD.

google, stackoverflow, my future wife Matilda [1]

REFERENCES

ARCSAT. NA, Astrophysical Research Consortium Small Aperture Telescope, http://www.apo.nmsu.edu/Telescopes/ARCSAT/index.html, , , accessed: 6/8/2017

Fuentes-Carrera, I., Rosado, M., Amram, P., et al. 2004, A&A, 415, 451

SIMBAD. NA, NGC5427, http://simbad.u-strasbg.fr/simbad/sim-id?Ident=NGC5427&NbIdent=1&Radius=2&Radius.unit=arcmin&submit=submit+id, , , accessed: 6/8/2017

STScI. 2013, PYRAF, http://www.stsci.edu/institute/software_hardware/pyraf, , , accessed: 6/8/2017

[1] Im new to Latex so some of the formatting is a little weird.The reference on the right is all one reference