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Netting Space Jellies

by

Elliot Arthur Codd

An Honors Capstone

**submitted in partial fulfillment of the requirements
for the Honors Diploma
to**

The Honors College

of

The University of Alabama in Huntsville

April 30th, 2017

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Table of Contents

Abstract	3
Introduction	4
Method	6
Results	9
Conclusions	11
Tables and Figures	14
Reference List	19
Appendix	20

Abstract

Presented in this paper are the details concerning the creation of a computer program to search Hubble Space Telescope archive images for jellyfish galaxies. These jellyfish are a class of galaxies that feature streams of stars and gases, stripped from the galaxy by the shock of entering a massive galactic cluster and interacting with the medium therein. Jellyfish galaxies are therefore important to the studies of galaxy morphology, galaxy evolution, and massive galactic clusters. This project hopes to aid astronomers in their search for these objects by creating a tool to automatically and efficiently search FITS images for jellyfish galaxy candidates.

Using the imaging program SAOImage DS9 and the cataloging package Source Extractor, I learned to measure galaxy morphology quantitatively by searching for significant groupings of star-clusters that could indicate a jellyfish galaxy's tail feature. Presented below are the ideas behind the approach, as well as the actual methodology and the eventual results. Also, known and possible sources of error are discussed, and suggestions for future improvement are proposed. Included are the images retrieved from the three targeted clusters, tables summarizing the findings, and the full MATLAB code that I produced.

Introduction: The Morphology of a Jellyfish

The goal of this research project was to study so-called “jellyfish galaxies” – a type of galaxy featuring a peculiar morphology reminiscent of the aquatic animal. These objects are not yet fully understood, but their appearance in massive galactic clusters has drawn them to the attention of astronomers. However, few jellyfish galaxies have yet been identified and confirmed. If we could find a way to extract efficiently the locations of jellyfish galaxies from cluster images, our own research as well as that of others would benefit greatly. Thus, this project was born, with the goal of creating a computer program in MATLAB to search archive images of galaxy clusters for potential jellyfish galaxies.

Before I begin the description of the project itself, some background is required as to the nature of these objects. “Jellyfish” is a morphological term for a galaxy that features long “tentacles” or a “tail” of gas and bright, young stars clusters. These tails can be found streaming out from the object opposite the object's direction of movement. Tail features are commonly many parsecs long.

The leading theory for the formation of these objects is that they are formed due to the ram pressure induced when a galaxy falls into a massive galactic cluster (Ebeling et. al. 2014). The gaseous medium within such clusters is extremely dense and hot. When this medium slams into the comparatively much less dense gas within the incoming galaxy, the galaxy's gas is stripped and pushed away, trailing out behind for a great distance and creating the tail formations that make jellyfish galaxies unique. The shock of the medium interaction induces great pressure in the out-flowing gas, triggering the formation of bright, new star clusters (Owers et. al. 2012). These features can be seen in Figure #1 as the blue tendrils streaming away from jellyfish galaxy ESO137-001 (HST, PI: Sun).

Why They Matter To Us

Jellyfish galaxies represent an important resource in understanding how galaxies evolve in extreme environments. The interaction between an incoming galaxy and a massive galactic cluster is

important to understanding how such a cluster forms, and the types of objects found within one. It has been theorized that galaxies are altered from spiral to elliptical morphology by their interaction with a dense cluster (Quilis et. al. 2000), and jellyfish galaxies could be the intermediate step – the stripping process destroys the galaxy’s previous shape, leaving a mass of stars to merge inside the cluster into a new form.

Despite all this, there are rather few examples of jellyfish galaxies known today. The ram-pressure-stripping process discussed above has been predicted to proceed quite rapidly, making it unlikely that any particular galaxy will be caught in the act by our telescopes. Additionally, this class of object is a relatively new topic of research, which means that there are likely many jellyfish galaxies hidden in already-existing telescope images, unidentified as such because nobody was looking for them at the time of observation.

The CLASH Survey

To pursue my goal of developing a program that could identify jellyfish galaxies, I needed to create a training set of images to test it on. For this purpose I turned to the Hubble Space Telescope’s Cluster Lensing And Supernova survey (CLASH). This survey consisted of dozens of images at many different wavelengths of 25 massive galactic clusters. Using the imaging software known as SAOImage DS9, I sorted through these archive images by hand to create my training set. I focused specifically on images taken with HST’s high-sensitivity Advanced Camera for Surveys, and on composite images containing as many filters as possible. As I was not trying to exclude any particular wavelengths, I wanted images with as many light sources as possible to give my program enough data to work with. This method would also subject my program to a significant amount of background noise, which it would have to be capable of dealing with. When my visual analysis was complete, I was left with one image each from three different clusters that I believed had the potential to contain jellyfish galaxies.

Method: How to Find a Jellyfish Galaxy

From the beginning, we wanted to develop a quantitative method for the identification of jellyfish morphology. We thought that a quantitative approach, a method that relied solely on counting and classifying objects, had the greatest potential for portability between images and clusters. Therefore, we focused on the defining feature of the jellyfish galaxy: the star-filled tail. The program would need to be able to analyze crowded images of galactic clusters and determine the distribution of sources surrounding each galaxy. From these distributions it would locate any star-tails and so provide us with a list of jellyfish galaxies, ready for whatever further research we desired. The first problem, then, was how to break down a cluster image into location data that I could use.

Source Extractor and the Candidates

That is where Source Extractor came in. Source Extractor is a free software package that can separate light sources from the background of deep-space images. The package accepts images using the Flexible Image Transport System (FITS) format and can be configured to output an enormous variety of parameters, such as source brightness, ellipse dimensions, and world coordinates. It took several runs to decide on the best combination of values to input into Source Extractor to produce the most useful data; the results of each run were visually inspected in an image-viewing program called SAOImage DS9. This allowed us to fine-tune our detection thresholds.

This data was compiled into a table that was then easily imported into MATLAB, where my program properly began. Viewing all of the Source Extractor data at once, we decided on a minimum flux and minimum Kron radius that a galaxy would need to have to be considered, which also effectively removed most of the background noise. These minimums allowed the program to create two catalogs of detected sources: one list containing only galaxies to be analyzed, and the other containing all sources that didn't make the cut – star clusters and other objects. The catalogs contained the right ascension and declination of each source, its detected flux, its estimated ellipse dimensions (semi-major

axis, semi-minor axis, and angle), as well as a reference number for identification.

Breaking Down the Catalogs

Once the two catalogs had been completely created, it was time to put our plan into action: we would seek to identify jellyfish galaxies by locating their star-filled tails of gasses. The aforementioned constraints place on the flux and Kron radius of sources classified as galaxies helped ensure that the sources within these tails would not be detected as separate galaxies themselves. Instead, they would be found within the catalog of star clusters and smaller objects.

The program focused on galaxies one at a time. Using Source Extractor's estimated elliptical semi-minor axis for a given galaxy, a circle was calculated to encompass the main body of that galaxy. Another circle was circumscribed 30 kiloparsecs out from the galactic center, creating an annulus. This distance I estimated to have the best chance of containing the galaxy's gas star tail. I tested other values such as 100 kpc and 50 kpc, which either captured too many star sources, hampering the program's ability to detect significant concentrations, or overlapped with other targeted galaxies too frequently, leading to false positives and negatives as galaxies detected each other's tails.

For the sake of the targeted galaxy's analysis, all sources not falling between the two circles were discarded from consideration. All remaining sources were then checked again to make sure that none of them fell within the innermost circle of any galaxy – this was to prevent star-clusters within the main body of any galaxies overlapping the target from being counted as part of the target galaxy's tail. This left me with a set of only those sources that could form part of the targeted galaxy's jellyfish tail. I owe UAH grad student William Waldron a debt of gratitude for his aid in outlining this section of the program and the next.

Pin the Tail on the Galaxy

The next step was to identify any significant groupings of the remaining sources. It was my advisor, Dr. Ming Sun who proposed the solution: if I could divide the sources radially into bins, I

could determine if any bin contained significantly more sources than the others. A significant bin could indicate the position of a galactic tail.

At this point, the program created 12 bins, each consisting of a 30-degree wedge of radial space surrounding the targeted galaxy. Every source was then re-centered to the targeted galaxy and assigned a bin based on the source's angle from the horizontal axis. MATLAB's built-in “atan2d” function proved immensely useful here – an inverse tangent operator that could evaluate over all four quadrants, needing only to be corrected to exclusively positive values afterward. The first bin consisted of all sources falling in the range of 0 – <30 deg from the horizontal, the next covered the range of 30 – <60 deg, and so on around the annulus. After each source was assigned to the appropriate bin, it was a simple matter of counting how many sources each bin contained and comparing that value to the average value of the other 11 bins combined, as in the formula below:

$$(V - M) / \sqrt{V} \geq \sigma$$

where V is the value of the bin being tested, M is the mean value of the other 11 bins, and “ σ ” is the chosen sigma value. If the ratio is found to be greater than or equal to the chosen sigma value, the bin's value is considered significant. Testing established that a difference of two sigmas or higher was a good threshold for significance. Finally, any targeted galaxy that possessed at least one significantly filled bin was flagged as a potential jellyfish galaxy and its coordinates were outputted to a DS9 region file for visual inspection. Also outputted were the object's annulus and the sources found within. This process of binning is depicted nicely in Figure #2.

The full MATLAB code as it was implemented can be found in the Appendix.

Results: Analysis of Three Clusters

In this section I will lay out the results of the current program's analysis of each of the three training-set clusters mentioned earlier. I will discuss each cluster in turn, focusing on how effectively my program filtered and reduced the number of sources picked up by Source Extractor, and the jellyfish galaxy candidates produced from each image. Not all candidates proved viable, however; I will cover in more detail the various issues encountered during the analysis in the next chapter.

Cluster: MACSJ0429-02

Of the 7196 sources detected and cataloged by Source Extractor in this cluster, 40 of the objects met the established galactic Kron radius and flux thresholds. Once those objects were analyzed, the program returned 7 candidates for jellyfish galaxies. These values are arranged in Table #1.

These candidates were then subjected to individual visual inspection. Two were found to be nearly concentric, and actually a single galaxy that had been detected as multiple objects. These two objects were therefore dismissed. Two more candidates were discounted because they were located so close to the image's edge that their annuli extended beyond the boundary, meaning that their data was incomplete and unreliable. One candidate simply lacked a convincing jellyfish morphology.

This left two viable candidates, depicted individually in Figures #3.1 and #3.2 and together in Figure #3.3. Object 1 from this cluster was an exciting find, and was the first potential jellyfish detected by my program. It features identifiable tentacles of stars, and I am quite hopeful that this galaxy's classification as a jellyfish can be verified. Object 2 from this cluster is also well defined, with tail extending in a single direction. I am less inclined to champion this object, as the single tail and the thin body of the galaxy could indicate that this object is actually a spiral galaxy at an angle, or an object warped by gravitational lensing. Such a distorted view could cause the galaxy's own body to extend into the annulus and be detected as a jellyfish tail if the warping is severe enough. This being said, the object is defined enough to warrant inclusion in this section as a candidate worthy of further analysis.

Cluster: Abell 2261

Of the 7734 sources detected and cataloged by Source Extractor in this cluster, 76 of the objects met the established galactic Kron radius and flux thresholds. Once those objects were analyzed, the program returned 26 candidates for jellyfish galaxies. These values are arranged in Table #2.

These candidates were then subjected to individual visual inspection. No less than 19 of these candidates were immediately dismissed due to their proximity to the edge of the image and the resulting contamination. Two candidates were actually the same galaxy, which itself did not possess the correct morphological features. Two more candidates appeared to be nothing more than a field of small objects, which collectively caught the program's notice but were unremarkable upon inspection. This left three candidates which unfortunately lacked convincing jellyfish morphology.

Therefore, no viable jellyfish galaxy candidates were detected in cluster Abell 2261.

Cluster: MACSJ1423+24

An impressive 24,290 sources were cataloged by Source Extractor in this cluster, and 61 of the objects met the established galactic Kron radius and flux thresholds. Once those objects were analyzed, the program returned 12 candidates for jellyfish galaxies. These values are arranged in Table #3.

These candidates were then subjected to individual visual inspection. Once again, and underscoring the continuing importance of this issue, 8 candidates were immediately discounted due to their annuli exceeding the bounds of the image. The remaining four were contaminated by a source encountered only in this image so far: the contrast at the edge of a filter. It appears that the filters in their section of the image field did not line up, and the square edge of one filter can be seen giving way to the rest. For any galaxy near this area, a large amount of noise and contamination fills the detection annulus. Through careful visual inspection, I believe I can still say that none of these four galaxies appear to possess the proper jellyfish morphology.

Therefore, no viable jellyfish galaxy candidates were detected in cluster MACSJ1423-24.

Conclusions: Problems, Solutions, and Successes

This section will briefly explain the two major causes for false positive results over the course of this research project. These represent recurring issues that will need to be further investigated as the project moves forward, to improve the reliability of the program. Then, smaller improvements will be discussed, and finally the accomplishments of the program itself will be reviewed.

False Positives: Up Against the Wall

Despite my programs success in identifying viable jellyfish galaxy candidates, it can be seen in the above descriptions that the program also produced a comparatively much larger number of false positives. Interestingly, these incorrectly or inappropriately flagged galaxies often proved quite easy to catch in visual inspection after the fact. They also shared several common features.

The largest number of false jellyfish detections came from galaxies that were found at the extreme edges of their cluster images. Some were so close the edges that their detection annuli, described in the methodology section above, extended outside the image's confines. This left the particular galaxy with a void of space surrounding it for which I had no Source Extractor data. In retrospect, these galaxies should have been omitted from the analysis entirely – if one of those border galaxies was a target, a more centered image with complete depiction of that galaxy's surroundings should have been selected. Why then did these objects register as potential jellyfish galaxies? The edges of an image represents a sudden shift in brightness, and I suspect that this is why Source Extractor detects them as hundreds of individual sources. Any object with a detection annulus that crossed the image's edge picked up a dozen or so of these false edge-sources. This large and ordered group of sources, combined with the total lack of data in the area outside the image boundaries, created a significant feature that the program believed to be a jellyfish gas tail. Cluster MACSJ1423+24 saw a similar phenomenon when one filter abruptly ended, creating a contrast-boundary that Source Extractor detected in a similar manner. These issues can be seen in Figures #4 and #5, respectively.

False Positives: Split Personalities

A far more uncommon issue was when an individual galaxy would be detected by Source Extractor to be several smaller, overlapping galaxies. This meant that when the catalog was fed into my program, the analysis process would run through each of these “mini-galaxies” separately. When this occurred, the mini-galaxies would contaminate each other’s sources and would each individually be flagged as jellyfish candidates – even if the single galaxy they represented would have been rejected by the process. This may be caused by an issue with Source Extractor’s detection, my program’s thresholds, or some combination of the two. This issue is not yet fully understood but it is clear that, moving forward, a strategy will be needed for recombining these overlapping detections into a single object before analysis begins. This issue can be seen in Figure #6.

Improvements and Adjustments

In addition to addressing the issues described above, there are two minor improvements and alterations to the program that I would suggest.

The first improvement would be replacing the circular apertures used with ellipses. This change should be fairly easy to implement, as estimations of both axes and the rotation angle are calculated by Source Extractor. This should help prevent any issues with heavily distorted galaxies being detected as their own jellyfish tail, as hypothesized in the previous section.

The other facet worth reevaluating is how objects are determined to qualify as jellyfish galaxies near the end of the analysis process. As explained above, the sources immediately surrounding a candidate galaxy are divided into 12 bins based on their radial position. In the program’s current form a single bin significantly filled with sources is the enough for an object to be flagged for review. It is possible that if a galaxy possesses a tail that is split into two adjacent bins due to its particular angular span, each affected bin might prevent the other from registering as significant, causing the galaxy to be wrongly passed over. This issue has not yet been observed in the program’s results, but is theoretically

possible. To prevent this error, we could instead sample bins two at a time, requiring two bins together to be significant over the remaining 10 bins. This idea requires further testing, but seems promising.

Final Thoughts

Now that the analysis of all three clusters has been completed I can turn at last to the program as a whole, and its accomplishments. All together, my program scoured 39,220 Source Extractor-detected sources to produce two possible jellyfish galaxies, the proverbial needles in the haystack. This is at once an exciting achievement in quantitative analysis and a reminder of the relative rarity of these objects and the work that still needs to be done.

The next and most urgent step will be to test the program's abilities on the remaining 23 clusters in the CLASH survey archive. The time constraints of the project led to the small sample size of clusters presented here. Only testing in a large variety of image scales and qualities will give us an adequate idea of the program's shortcomings to begin making improvements. It is worth noting that, though I am confident in the two jellyfish candidates produced by this study, it may be that not all jellyfish galaxies present in these clusters have been detected. After the program has been tested on a wider variety of clusters, I expect it will be worth running on multiple images of the same cluster, to account for poor image quality and other such variations.

All this being said, I count this project as a great success. Through the processes described in this paper, and with the aid of my advisor, my program has confirmed that a quantitative analysis of galaxy morphology is possible. I eagerly await the verification of the candidates produced. I greatly enjoyed the journey to this point, and I have high hopes for the project as it is improved upon and carried into the future.

Tables and Figures

This section contains tables summarizing the program results for each of the clusters analyzed, as well as individual images of the viable jellyfish galaxy candidates.

Table #1

MASCJ0429-02	$z = 0.399$
Source Extractor Detections	7196
Objects Meeting Thresholds	40
Jellyfish Candidates	7
Viable Candidates	2

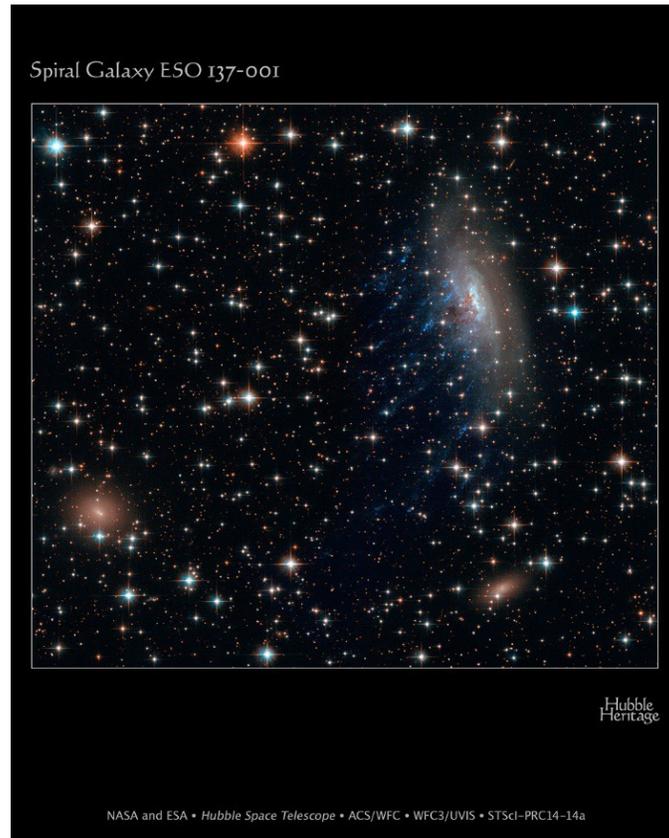
Table #2

Abell 2261	$z = 0.244$
Source Extractor Detections	7734
Objects Meeting Thresholds	76
Jellyfish Candidates	26
Viable Candidates	0

Table #3

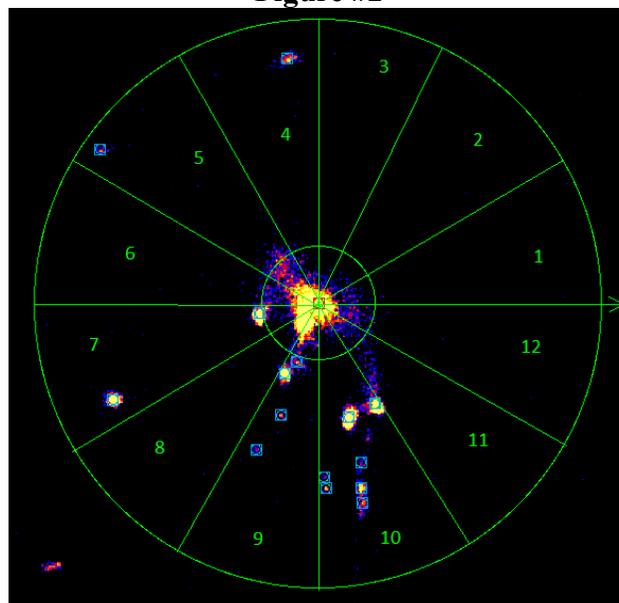
MACSJ1423+24	$z = 0.545$
Source Extractor Detections	24,290
Objects Meeting Thresholds	61
Jellyfish Candidates	12
Viable Candidates	0

Figure #1



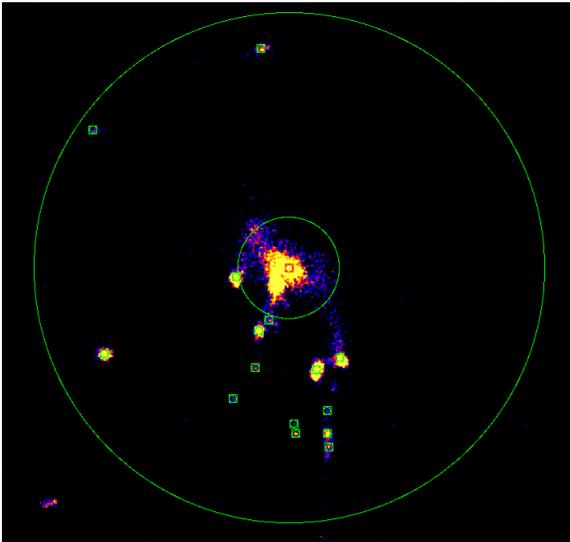
Known Jellyfish Galaxy ESO137-001
from HST, Principal Investigator: Dr. Ming Sun, UAH

Figure #2



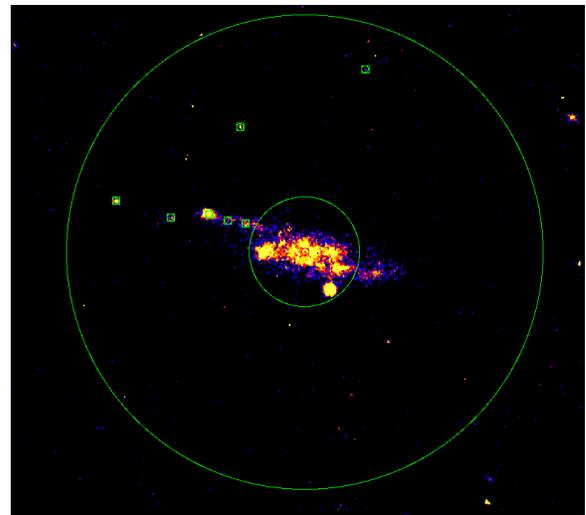
The binning process, depicting the 12 bins in green and the detected sources in light blue squares.

Figure #3.1



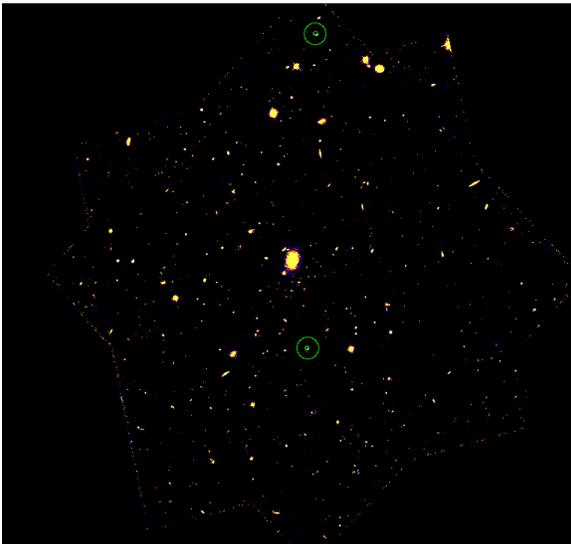
Jellyfish galaxy candidate in MACS0429-02
J200: 67.397808d, -2.897844d
(Lower center in Figure #3.3)

Figure #3.2



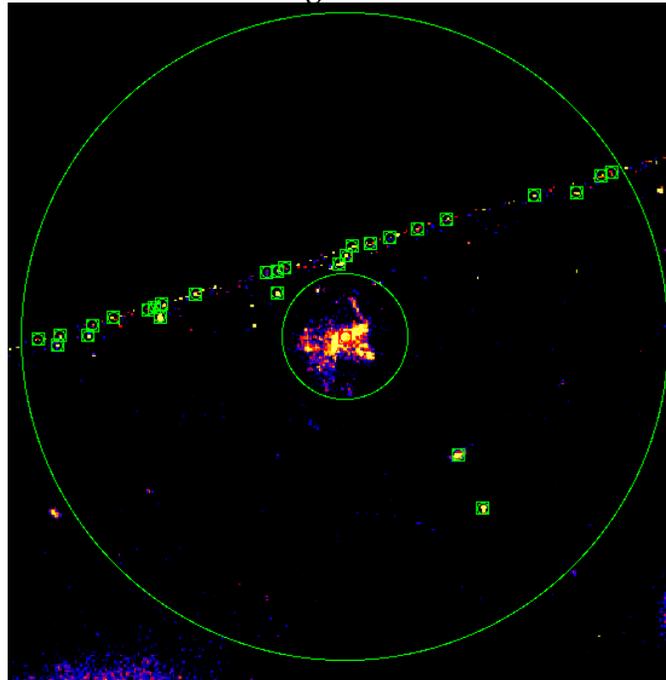
Jellyfish galaxy candidate in MACS0429-02
J200: 67.396668d, -2.852763d
(Upper center in Figure #3.3)

Figure #3.3



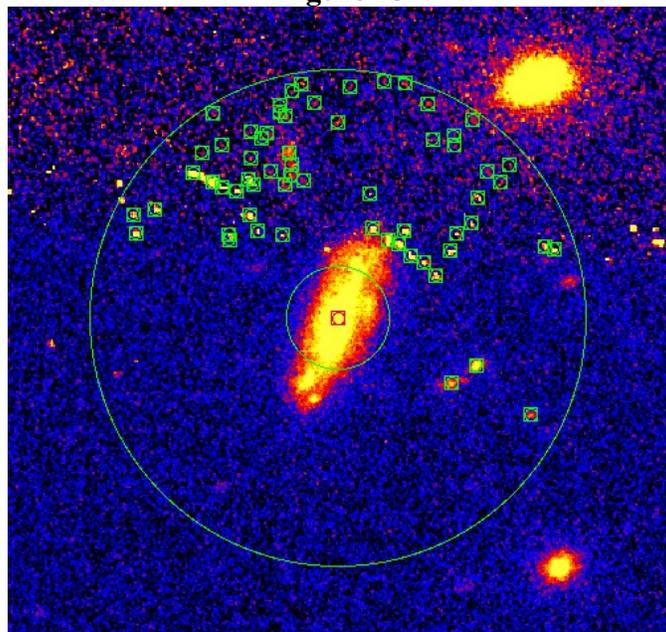
Relative positions of jellyfish galaxy
candidates in cluster MACS0429-02

Figure #4



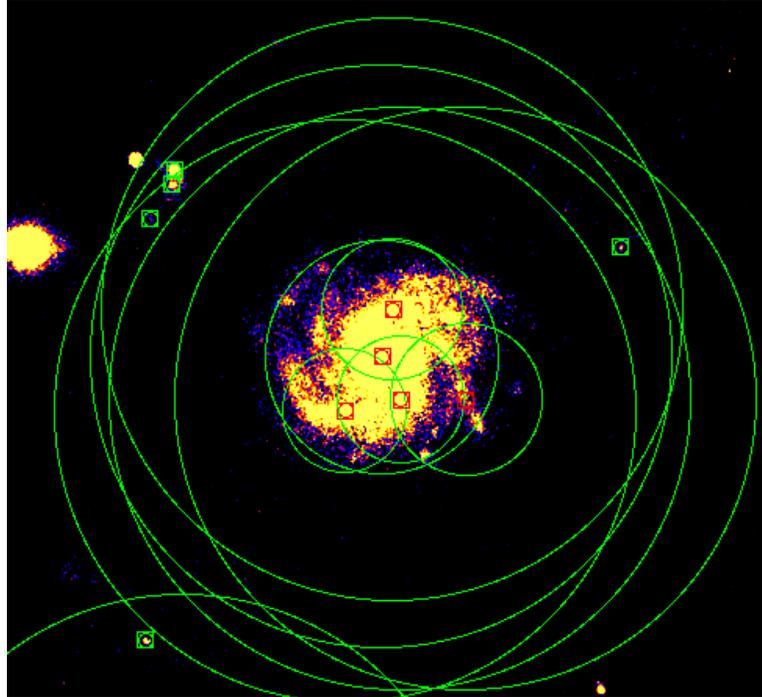
Example of a galaxy located too close to the image edge to be evaluated. False sources at image border combined with the void of data at the top of the image caused this object to be flagged as a jellyfish galaxy.

Figure #5



Example of a galaxy located where a filter abruptly ends. Possibly false sources created due to the contrast caused this object to be flagged as a jellyfish galaxy.

Figure #6



Example of a galaxy that was detected erroneously as several smaller galaxies.
Each of these false galaxies were flagged as a jellyfish galaxies,
most likely because they detected each other's sources in some way.

Reference List

Ebeling, H., Stephenson, L. N., Edge, A. C. 2014, *The Astrophysical Journal Letters*, Volume 781, L40

Owers, M. S., Couch, W. J., Nulsen, P. E. J., & Randall, S. W. 2012, *The Astrophysical Journal Letters*,
Volume 750, L23

Quilis, V., Moore, B., & Bower, R. G. 2000, *Science*, Volume 288, 1617-1620

Image of ESO137-001 used by permission of Dr. Ming Sun, University of Alabama in Huntsville

Appendix: Full Program Code

This section presents the full MATLAB code for the image analysis program. The original, in-program comments are included in *italics*. This code requires only a properly formatted Source Extractor output file to run.

PROGRAM BEGINS

```

%Elliot Codd, University of Alabama in Huntsville, 4/29/17
%with William Waldron, UAH, and Dr. Ming Sun, UAH

%Prototype for a program that will detect "jellyfish" galaxies from SExtractor output

%%%%%%%%%% IMPORT DATA %%%%%%%%%%%
close all hidden
clear
detections = readtable('sextractor.dat', 'filetype', 'text', 'HeaderLines', 9, 'delimiter', '\t');

%specify flux and Kron radius threshold values; specify kpc/arcsec scale
minflux = 5;
maxflux = Inf;
minkronA = 6e-4; %minkron * A
maxkron = Inf;

scale = 5.365; %in kpc/arcsec; different for each cluster!

%%%%%%%%%% DETECT GALAXIES %%%%%%%%%%%

%extract data from table
Flux_all = detections.ra; %best measured flux
Kron_all = detections.mag; %kron radius
X_all = detections.X_WORLD; %world x location
Y_all = detections.Y_WORLD; %world y location
A_all = detections.A_WORLD; %ellipse semi-major
B_all = detections.B_WORLD; %ellipse semi-minor

%create boolean array of which objects have Flux and Kron values within the defined bounds
galIndex = ((Flux_all > minflux) & (Flux_all < maxflux)) & (((Kron_all .* A_all) > minkronA)
& (Kron_all < maxkron));

%create galaxy arrays by extracting only those sources that tested as galaxies
Flux_gal = Flux_all(galIndex);
Kron_gal = Kron_all(galIndex);

```

```

X_gal = X_all(galIndex);
Y_gal = Y_all(galIndex);
A_gal = A_all(galIndex);
B_gal = B_all(galIndex);

%remove galaxies from main arrays, leaving arrays of independent stars
X_not = X_all(~galIndex);
Y_not = Y_all(~galIndex);
A_not = A_all(~galIndex);
B_not = B_all(~galIndex);

%output detected sources
fid = fopen('sources.reg', 'w');
fprintf(fid, 'j2000; point %fd %fd\n', [X_not, Y_not]);
fclose(fid);

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% REMOVE STARS IN GALAXIES %%%%%%%%%

%create meshgrids of data
[X_gal2, X_not2] = meshgrid(X_gal, X_not);
[Y_gal2, Y_not2] = meshgrid(Y_gal, Y_not);
[A_gal2, ~] = meshgrid(A_gal, A_not);
[B_gal2, ~] = meshgrid((B_gal .* Kron_gal), B_not);

%find which sources lie within galaxies themselves
%by calculating an circle, with radius of semi-minor axis (B)
starsInGal = (((X_gal2 - X_not2).^2) + ((Y_gal2 - Y_not2).^2) <= (B_gal2).^2);

%"dimension 2" means columns direction
%each row (star) is checked to see if it appears in any column (galaxy)
starsInGal = any(starsInGal, 2);

%remove stars that fell into galaxies
X_not = X_not(~starsInGal);
Y_not = Y_not(~starsInGal);
A_not = A_not(~starsInGal);
B_not = B_not(~starsInGal);

```

```
%%%%%%%%%% SCAN FOR OVER-DENSITY %%%%%%%%%%
```

```
%create annulus around every galaxy
```

```
outerRad = 30 / scale / 3600; %in arcseconds
```

```
%disable plots
```

```
figure, set(gcf, 'Visible', 'off')
```

```
%loop preparation
```

```
isJellyfish = false(length(X_gal), 1);
```

```
fid = fopen('annulus.reg', 'w');
```

```
fclose(fid);
```

```
%loop through all galaxies
```

```
for i = 1:length(X_gal)
```

```
    %seperate stars outside of the galaxy but within 100kpc radius
```

```
    starsAnnulus = (((((X_gal(i) - X_not).^2) + ((Y_gal(i) - Y_not).^2) <= (outerRad).^2)) &  
    (((X_gal(i) - X_not).^2) + ((Y_gal(i) - Y_not).^2) >= (B_gal(i) .* Kron_gal(i)).^2)));
```

```
    %seperate out target stars; re-center stars to circle
```

```
    X_annulus = X_not(starsAnnulus);
```

```
    Y_annulus = Y_not(starsAnnulus);
```

```
    X_shifted = X_annulus - X_gal(i);
```

```
    Y_shifted = Y_annulus - Y_gal(i);
```

```
    %find angle in degrees to each star, and ensure that they are positive
```

```
    angles = atan2d(Y_shifted, X_shifted) + 0.0; %final value rotates where wedges begin
```

```
    %angles above 360 are wrapped around
```

```
    angles = mod(angles, 360);
```

```
    %define bins to sort stars
```

```
    bins = 0:30:360;
```

```
    histData = histogram(angles, bins);
```

```
    %test for bins that are significantly full
```

```
    sigma = 2.0;
```

```
    %loop through each wedge
```

```
    for j = 1:length(histData.Values)
```

```
        %remove target wedge; average other 11
```

```
        test_Bins = histData.Values;
```

```
        target = test_Bins(j);
```

```
        test_Bins(j) = [];
```

```
        avg11 = mean(test_Bins);
```

```
%like finding a z-score
if ((target - avg11) / sqrt(target)) >= sigma
    %congrats, you may have found a jellyfish galaxy!
    isJellyfish(i) = true;
end
end
```

```
%output to a DS9 region file
if isJellyfish(i)
    fid = fopen('annulus.reg', 'a');
    fprintf(fid, 'j2000; annulus %fd %fd %fd %fd\n', [X_gal(i), Y_gal(i), B_gal(i) *
Kron_gal(i), outerRad]);
    fprintf(fid, 'j2000; point %fd %fd\n', [X_annulus, Y_annulus]);
    fprintf(fid, 'j2000; point %fd %fd #color=red\n', [X_gal(i), Y_gal(i)]);
    fclose(fid);
end

end
```

PROGRAM ENDS