

Project 2: Star Clusters in Nearby Galaxies

In this project, you will use data of three nearby galaxies from the Hubble Space Telescope to identify star clusters. Like the clusters in Project 1, these star clusters have stars of a single age. However, because of their distance, we cannot get good data on the individual stars in the clusters. Nonetheless, we can still try to estimate their ages (and masses) using the integrated light from the cluster. These clusters are the easiest way to measure stellar ages in nearby galaxies.

The Galaxies: Each of you will identify clusters in one of three nearby galaxies, NGC 247, NGC 253, and NGC 300. NGC 247 and NGC 253 are at a distance of 3.5 Mpc ($m - M = 27.70$), while NGC 300 is closer at 2.0 Mpc ($m - M = 26.50$). All three are in a loose grouping of galaxies called the “Sculptor Filament” – these galaxies are located in the constellation Sculptor, which is visible from the southern hemisphere. All three are spiral galaxies; NGC 253 has a comparable mass to the Milky Way, while NGC 247 and NGC 300 are a factor of $\sim 10\times$ less massive than the Milky Way.

The Data: All the data you will be looking at were taken with the Hubble Space Telescope’s Advanced Camera for Surveys (HST/ACS), the camera which holds the record for imaging the faintest objects in the universe. The camera has an angular pixel size of 0.05” and a field-of-view of $\sim 3\times 3$ arcminutes. Each image was taken through a combination of three filters and the color images you will be looking at are the combination of these three images. The specific filters used are F475W, F606W, and F814W; these filters roughly correspond to the B , V , and I filters you’ve already encountered. On HST, filters are named using their central wavelengths in nanometers, thus F475W is centered at 4750Å. Using the EYE_FINDER IDL program you will be searching through these beautiful images and measuring the photometry for all the clusters you find. The fields you will work on are:

NGC 247: ngc0247-wide1, ngc0247-wide2, ngc0247-wide3

NGC 253: ngc0253-wide1, ngc0253-wide2, ngc0253-wide3 (optional: ngc0253-wide4, ngc0253-wide5)

NGC 300: ngc0300-wide1, ngc0300-wide2, ngc0300-wide3, (optional: ngc300-1, ngc300-4, ngc300-6, these fields have different B and V filters)

These field names are important, as they will be used to reference the fields in the IDL programs.

What do star clusters look like?

The clusters you will be finding have a wide range of ages, masses, and sizes. This makes identification challenging! In general, star clusters in these galaxies are identifiable because they look fuzzy and (at least around their outskirts) they resolve into individual stars. But the bright backgrounds of all the other stars in the galaxies make fainter clusters undetectable in some areas. Also, background galaxies are easily mistaken for clusters. I am providing you with a tool to help you determine what real star clusters look like in these galaxies. On the web page:

http://www.cfa.harvard.edu/~aseth/astro301/fake_clusters.html

you will find examples of each of your galaxy images with fake clusters of differing masses, sizes and ages added in. These clusters range in age from young-to-old as you move left-to-right. The ages are $\log_{10}(\text{age}[\text{years}]) = 6.6, 6.8, 7.0, 7.2, 7.4, 7.6, 7.8, 8.0, 8.2, 8.4, 8.6, 8.8, 9.0, 9.2, 9.4, 9.6, 9.8, 10.0,$ and 10.2 . From bottom-to-top, the clusters are varying in mass and radius. At the bottom are clusters with half light radii of 3 pc, and masses of $10^3, 10^4$ and $10^5 M_{\odot}$. Above these three rows of clusters are clusters with half-light radii of 6 pc and 12 pc with the same three masses at each radius.

Part A: Identifying Clusters

Due Thursday Oct. 21

To identify clusters, you will be using the `EYE_FINDER` IDL routine, an interactive code which allows you to page through galaxy images, identify star clusters, and measure their photometry. You will run this on each field you have been assigned and identify all the clusters you find.

1) Look at the first field on your list, and examine what the fake cluster images look like in this field.

Question A1: Because clusters get fainter with age, at some point you can no longer detect the clusters. Using the 6 pc half-light radius clusters (the middle set), identify the oldest age for which clusters of 10^3 , 10^4 and $10^5 M_{\odot}$ are visible and make a table with these values.

Question A2: In the same image with the added fake clusters, look in the least crowded regions and identify some background galaxies with sizes similar to the clusters. Describe how these background galaxies look different from the star clusters.

Question A3: Look at the *galaxy-wide3* field fake cluster image (located closer to the center of the galaxy). When the clusters fall on top of bright regions of the galaxy, how does their appearance change?

2) Now get started identifying clusters. First make a `proj2` subdirectory in your `astro301/` directory and copy the `eye_finder.pro` program into it from `~aseth/astro301/proj2/eye_finder.pro`. Also copy over the `postage_stamps.pro` file for later use. To start identifying clusters enter IDL, and type:

```
IDL> .rnew eye_finder
IDL> eye_finder, fieldname
```

After typing this, the program should find the associated raw data file and after some work, will launch two windows, one with an overview of the entire galaxy, and another with a full-resolution image of a portion of that field. The program is operated through keystrokes. When you exit or hit 's', the data will be saved into two files, a regular textfile with a name `fieldname_objects.dat` and an IDL save file that can be read in to resume cluster IDing if you have to quit in the middle of a field.

Every time you identify a cluster you will be given information on the clusters' magnitude, color and size. For reference, a typical old globular star cluster will have an absolute F814W magnitude of ~ -8 , and a half-light radius of ~ 5 pc, note that the half-light radii are given in pixels.

Identify clusters in each field that you are assigned with your partner. In your report summarize what issues you faced in identifying clusters and how you resolved them. When you are done with all the clusters in a single field, you can make a compilation of all the clusters in the file using the `POSTAGE_STAMPS` program.

```
IDL> .rnew postage_stamps
IDL> postage_stamps, fieldname
this creates a postscript file called fieldname_stamps.ps
```

After you are done identifying clusters in each field, write an IDL program that will make the following plots:

- A color-color diagram of all the star clusters, i.e. plot F606W-F814W vs. F475W-F606W. Use `OPLOTERROR` to overplot errors on the colors. Note, to calculate the error on the color, you add the errors of each magnitude in quadrature; the error in the F475W-F606W color is $\text{SQRT}(\text{F475W_ERR}^2 + \text{F606W_ERR}^2)$.
- A histogram of magnitudes in the F814W band. You can make histograms with the `PLOT_HIST` procedure.

- A histogram of cluster sizes in parsecs. You can convert your pixel size to parsecs by calculating it yourself, or using the numbers that are given for the relative sizes in `EYE_FINDER`.

Question A4: Based on the fake cluster images, estimate the age and mass of your three brightest clusters.

Question A5: Determine the luminosity of your brightest and faintest cluster in the F814W (*I* band). The absolute magnitude of the sun in F814W is 4.08.

Question A6: Why is the color-color diagram the best way to determine the cluster ages?

Question A7: Use your color-color diagram to interpret the cluster population in your galaxy based on what you have learned about stellar populations so far. Where do the oldest and youngest clusters fall in the diagram? Which seem to be more common in your galaxy?

Part B: Measuring ages using single stellar population models

Due Oct. 28

You will now use models to estimate the ages and masses of star clusters in your galaxy. This is probably best done within a single IDL program that will perform all the steps.

Here are the steps that are required:

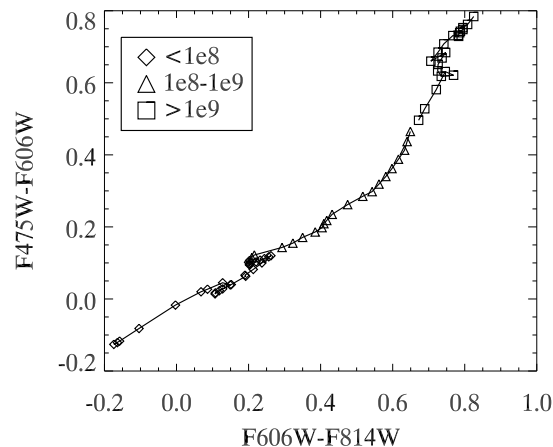
1) Correct your cluster photometry for foreground dust absorption in the Milky Way. A dust map of the Milky Way was produced from sky-wide maps in the far-infrared and published in a famous paper by Schlegel, Finkbeiner, & Davis in 1998, often referred to as the SFD map. To determine the extinction values for each galaxy I have used the NASA Extragalactic Database (NED). The extinction in V band A_V is 0.060, 0.062, and 0.042 magnitudes for NGC 247, 253 and 300 respectively. To calculate the extinction in magnitudes in each band use these relations:

$$A_{F475}/A_V = 1.192$$

$$A_{F606}/A_V = 0.923$$

$$A_{F814}/A_V = 0.606$$

Question B1: To remove the effects of the dust extinction, should these values be added or subtracted from your magnitudes?



2) Now copy over the single stellar population models I have downloaded from the Padova group

website <http://stev.oapd.inaf.it>. These are located in `~aseth/astro301/proj2/ssp_models/` and have names `ssp_*.dat`, where the wildcard is the $[Fe/H]$ value of the models. These model files have absolute magnitudes for a population of stars as a function of age for all the filters in the ACS camera. The models are given in absolute magnitudes assuming a mass of $1 M_{\odot}$, which will allow you to calculate cluster masses. However, these models are made averaging the colors of millions of stars in order to well-populate all the evolutionary phases at a given age. A color-color diagram for the $[Fe/H]=-0.5$ models is shown above.

Question B2: Compare the color-color diagram plotted above to the color-color diagram of your clusters. Do most of the clusters fall along the line of the models? Apart from measurement error, why might clusters not fall along the models, especially when they are lower mass?

3) Now find the best-fit ages for your clusters from the models. You will need to use a FOR loop to loop over each cluster. For each cluster compute the closest model point in the color-color diagram to your data to find its age. We don't know the metallicities of the clusters, but given that the clusters are in the disks of small spirals (or the outer disk of NGC 253), use the $[Fe/H]=-0.5$ models to determine your ages.

Compare the distance between the cluster and best-fit model in the color-color diagram to the errors in the colors. Cluster ages are likely to be unreliable if the the distance between cluster and model colors is much larger than the errors, or if there is a large overall offset between the cluster and models. Keep track of the clusters that may have less reliable ages. In your program, also calculate the *masses* of the clusters. Once you know the age, you can use the model absolute magnitude to calculate the mass. You could do this in any filter, but use the F814W here; as the reddest filter, it is least susceptible to dust extinction. Output a table listing the two colors (after correcting for dust), age and mass for each cluster. You don't need to turn this in, but should list where it is located on ladyhuggins so I can look at it. Also make these plots:

- A histogram of cluster ages both including and excluding the clusters with less reliable age determinations.
- A histogram of cluster masses both including and excluding the clusters with less reliable age determinations.
- A plot of mass vs. age for all the clusters in your galaxy, with different symbols for your reliable and less reliable age estimates.

Question B3: We have accounted for the dust in our Galaxy, but there could also be dust surrounding the star cluster in its own galaxy. For one bright cluster in your sample, consider the effect of dust on the estimated age assuming we are observing it behind a dust cloud with an $A_V = 0.2$. Make a figure showing the effect of correcting for this dust and describe the difference in age.

Question B4: By analogy to the Milky Way, the older globular clusters may have a lower metallicity than the rest of the clusters. Select out your two brightest clusters which you think are old (based on visual appearance or their colors), and determine their ages using the two lower metallicity isochrones. Do these isochrones provide a better fit? What happens to the derived ages when you decrease the assumed metallicity?

4) For class on Thursday, Oct. 28, you will prepare a short presentation using your plots from both Parts A and B to present your galaxies' cluster population to the rest of the class. I'm excited to see your results!