Lab #9: Galaxy Morphology

April 16, 2012
Due April 20, 2012

Objectives:

- To gain familiarity with the NASA/IPAC Extragalactic Database (NED).
- To apply the Hubble galaxy classification system to real-world objects.
- To create color images in MATLAB.

Equipment:

- Data from NED
- MATLAB

Part I: Hubble's Tuning Fork

There are three main types of galaxies, first classified by Hubble: spirals, ellipticals, and irregulars. Elliptical galaxies show no evidence of a dusty disk, and, without a disk, no new star formation occurs. Ellipticals are classified based on how circular they appear; An E0 elliptical is round in appearance, while an E7 is extremely elongated, almost like a cigar. An E4 is somewhere in between. The system also includes E1, E2, E3, E5, and E6, but for our purposes, deciding between E0, E4, and E7 is sufficient.

Spirals, on the other hand, show evidence of spiral arms in a dusty disk and star-formation. Spirals are classified first by whether or not the center of the galaxy is bar-shaped. Spirals with a bar are denoted as SB, while spirals without a bar are denoted simply as S. They are further classified by how tightly the arms are wound about the center and by the ratio of the bulge to the disk. Spirals with tightly wound arms and a very large bulge relative to the disk are called Sa (or SBa if the center has a bar), while spirals that are have loosely wound arms and a relatively small bulge are classified as Sc (or SBc), and spirals in between are called Sb (or SBb). Spirals can further be described as either grand design or flocculent. Grand design spirals have a few very well defined spiral arms, while flocculent galaxies have very ragged, more poorly defined spiral arms.

On Hubble's tuning fork, there also exists the S0 (or SB0) category, which is reserved for galaxies that essentially look like ellipticals, but have traces of a dusty disk with no obvious spiral arm structures. These are the lenticular galaxies, and they differ from the Sa (or SBa) galaxies because they have no clear delineation between the yellow/red bulge and blue spiral arms. The dust lanes are visible, but they are not associated with blue spiral arms.

The last category, irregulars, is essentially made up of everything that does not fit into one of the other two categories above. Irregular galaxies either show star-forming regions that do not have a clear organized structure, such as the Large Magellanic Cloud, or show a somewhat spiral structure that has been distorted into an asymmetrical shape, likely due to interactions with other galaxies. (Note that flocculent spiral galaxies differ from irregulars, because the flocculent spirals still show a central bulge and a blue disk structure.)

For the following list of galaxies you will classify each according to the Hubble type. Assign it a type from this list:
E0, E4, E7, S0, SB0, Sa, SBa, Sb, SBb, Sc, SBc, Irr
and note, for the spirals, whether they are grand design or flocculent.

(Reference: `http://www.le.ac.uk/physics/faulkes/web/galaxies/r_ga_tuningfork.html`)

Procedure

1) Open a web browser and access the Nasa/IPAC Extragalactic Database: `http://nedwww.ipac.caltech.edu/` (or by following the link from the lab's website at `http://www.astro.umd.edu/~cychen/MATLAB/ASTR121/labGal/`)

2) Click on By Name; enter the name of the first galaxy from Table 1 and press the Enter key.

3) When the information for that galaxy has finished loading, scroll down the page and click on images, this will load several thumbnail images of the galaxy that you queried in a separate web page.

4) Select an image, SKETCH the galaxy (on separate piece of paper) and classify the galaxy from the list above, remembering to note, for spirals, whether it is grand design or flocculent. Be aware of the waveband of the image you're looking at! Keep in mind that different wavebands highlight different features.

5) Repeat steps 2-4 for all of the galaxies in Table 1.

Table 1
M74
M110
NGC 1365
NGC 4414
M87
NGC 1427A
NGC 1300
M51
M59
Sextans A
M64

Part II: Creating a Color Image

The CCDs that astronomers use to take images do not store color information about the scene; They only record the intensity of light at each pixel. You may have noticed, however, that some of the galaxies in NED had color composite images available. Color information about the scene can be found by taking images using a filter to select a limited wavelength range. If you take an image, for example, through the B filter, you find out how much blue light is coming from the object. Combine it with a V filter image and an R filter image, and you have your RGB color information that your display device needs to show a color image. Personal use digital cameras work on the same principle, except that the filters are built into the camera, and so the images through different filters are all taken at the same time and combined without you knowing about it.

In astronomy, the filters are separate from the camera because there are a wide variety of wavelength ranges that we are interested in, rather than just splitting the image into 3 colors for RGB display. Often astronomers will use narrow-band filters, which are filters that span a very limited wavelength range, unlike the BVRI filter system. These narrow-band filters allow you to focus on an emission line from a specific element or ion and provide information about the relative amounts of that element or ion. The BVRI system, however, is not without its uses.

Combining the B, V, and R images of a galaxy will allow you to see the different populations of stars. The spiral arms, with their star-forming regions, appear blue, since they are home to hot, massive, blue stars, while the older stellar populations in the bulge, lacking star formation, will appear yellow or red, as they are composed of cooler, lower-mass, redder stars.

To see this, you are going to make a color composite image of one of the spiral galaxies you classified above, using MATLAB.

Procedure

1) Pick a galaxy from the following list: M74, NGC 1365, NGC 4414, M51, or M64. (NGC 1300 doesn't appear to have the necessary data for these steps).

2) Create a folder in the A121 folder on the desktop, using your and your lab partner's initials and the number 9, since this is Lab 9.

3) Find the galaxy you chose in NED and look at the list of available images. Look for a set of B, V, and R images (or B, V, and I images will do just as well) that are taken with the same telescope, with the same resolution, and the same field of view. They must have the .fits file extension (.fts or .fit are also acceptable). FITS files contain not only the data, but also a header portion that gives details about the observations, such as exposure time, date of observation, filter, and any other information the observatory deems important enough to include. Download these images to the folder you created, and unzip them (since they're probably actually .fits.gz files). Double-clicking on them in your folder (not in MATLAB) should unzip them. If not, try right-clicking on the files and see if there's an option to unzip them. If you right-click and the option to Extract is not there, ask for my flash drive, and I can unzip them for you.

4) You need a couple MATLAB scripts, which are available at the lab's website: `http://www.astro.umd.edu/~cychen/MATLAB/ASTR121/labGal/` Download imshift.m, rfits.m, and imscale.m to your folder.

5) Open MATLAB and change the directory to your folder.

6) Use rfits.m to read the .fits data files into variables. For example, if you had a B filter image named MESSIER_081_B.fits:

```
>> m81b = rfits('MESSIER_081_B.fits')
```

The information listed is that contained in the header file. Take note of the sky coordinates that the image was centered on, as you'll want to double check that the images are aligned (i.e. same centered coordinates). If they're not aligned, use the information obtained with

```
>> help imshift
```

in order to shift the images to align them with each other. It is simpler to just make sure you use data in this lab which is pre-aligned. This is likely the case for data taken with the same telescope in multiple filters.

7) Extract the image data from the imported data structure:

```
>> bdata = m81b.data;
```

Note the use of the semi-colon: without the semi-colon, the above command will print all the values of bfits.data to the screen, which is unnecessary.

8) Next, go ahead and view this image using imagesc:

```
>> imagesc(bdata)
```

NOTE: If you chose NGC 1365, there are some bad pixels that mess up the scaling. Proceed to step 9) and use [0 500] as your initial [min max] so that you can see the galaxy (and figure out where the background is).

You may want to follow this command with an:

```
>> axis equal
```

This will make all the pixels in your image square.

9) Try adjusting the image by using different scalings of the data. Imagesc scales the data automatically, but including bounds allows you, the user, to adjust the scaling boundary values. One uses this by adding max and min values:

```
>> imagesc(bdata, [bmin bmax])
```

where bmin and bmax are the values you choose as min and max.

You can get a good idea of what values to use for min and max by looking at your initial plot of the data in step (8) and using the Data Cursor tool in the Figure window. Select this tool and then click on the image to read off the value of the matrix (the Index value) in regions offset from the galaxy (i.e. the background) and regions on top of the bulge of the galaxy (i.e. the brightest part of the image). Also see what happens if you use the background regions as your minimum and a value from the spiral arms as the maximum, rather than the (likely) brighter bulge. It should bring out more detail in the spiral arms. Note that the values you use might be different for each filter!

11) Since the difference in brightness can be quite large between the center of the bulge and the delicate spiral arms, try displaying the log of your data in imagesc:

```
>> imagesc(log10(bdata), [log10(bmin) log10(bmax)])
```

Now the spiral arms should be quite a bit more apparent!

NOTE: If you use NGC 1365, there are some bad pixels that log10 won't appreciate. To fix this, do

>> bdata(bdata¡0)=0;

and likewise for vdata and rdata.

10) The easiest way to create a false-color image is to use the RGB colormap. You will use

>> imagesc(rgb)

to plot the final image, where rgb is a NxMx3 matrix (for 3 images which are NxM pixels in size) and each of the 3 ‘planes’ of this matrix correspond to the image from one filter. For instance, if rdata, vdata, and bdata are the names of the data matrices for images taken with a red, visual, and blue filters, you first create and initialize the rgb matrix:

>> rgb = zeros([size(vdata), 3]);

then you fill rgb with the image data:

>> rgb(:,:,1) = imscale(rdata,rmax,rmin);
>> rgb(:,:,2) = imscale(vdata,vmax,vmin);
>> rgb(:,:,3) = imscale(bdata,bmax,bmin);

In the above lines, imscale scales the image from each filter so that each pixel has a value between 0 and 1. (Look at the code for imscale to see exactly how it does this.) **You should also try giving imscale the log of your data, max values, and min values, as you did for imagesc in step 10, to bring out the spiral arms.**

Be sure to get the order of max and min correct, as it is opposite of the command above for imagesc! Setting the max and min using imscale takes the place of the [min max] array in imagesc above, and allows you to control the scale of each of the 3 colors independently.

Then plot the image with:

>> imagesc(rgb)

Note that, even with the log scaling, your spiral arms might be washed out if you use the maximum pixel value as your imscale max value. If you have trouble seeing your spiral arms, trying lowering the max in imscale for all 3 filters. If the image looks tinted a certain color, try changing the maximum (and maybe the minimum) for just that filter.

It’s probably a good idea to write the code for this in an m-file and then run the m-file (by saving it and then clicking the green arrow button in the editor window) each time you change the scalings. Play with the scaling (and whether or not you use the log of your data and max/min values) until you are happy with your result. Once you have a plot which looks the best, you can use the command **print** to print it to a jpg file.

>> print -djpeg prettyfig.jpg

but instead of calling it prettyfig.jpg, name it using the initials of both lab partners and the number of this lab, 9.

What should you turn in?

You should turn in your color .jpg file by emailing it to me at `hsheets@umd.edu`

Note that, if you are working in pairs, you only need to create one .jpg file, and only one of you needs to email it to me (but include in the email your partner's name). Make sure that you name the .jpg just as you have named your folder: using the initials of both lab partners and the number 6. That way I know which file is yours when I save them to my computer!

You should also, on paper, turn in the following:

a) Sketches of the 11 galaxies in Part I, with the classifications (including grand design or flocculent for spirals) either on the sketches or listed clearly on a separate sheet of paper. Make sure you label your sketches with the galaxy names!

b) Either on the sketches or on a separate sheet of paper, give your REASONS for classifying each galaxy as you did.