

ASTR 323/423 HW #1

Note: running python/astropy, most of the datafiles can be easily loaded by saying:

```
from astropy.io import ascii
# load the file
data=ascii.read('http://burro.case.edu/Academics/Astr323/HW/HW1/<filename>')
# look at data column names
print(data.colnames)
# plot data
plt.scatter(data['<some_column>'],data['<some_other_column>'])
```

1. Homework tips

Please read the [Homework Tips](#) document and the [Submitting Electronic HW](#) docs and then write “Yes, I promise I read the Homework Tips and Submission documents”. Extra point if you also tell me the name of your favorite astronomical object and why its your favorite.

2. Adopt-A-Galaxy (courtesy Matt Bershad, UWisc)

You have been assigned a galaxy to adopt (see table below). For your galaxy, track down a nice *optical* image of the galaxy and classify it along the Hubble sequence. Include this image in your writeup.

Now look up the galaxy in [NED](http://ned.ipac.caltech.edu/) (<http://ned.ipac.caltech.edu/>) and give the following information:

Observed properties: Apparent V magnitude, redshift (in km/s), color (B-V, or something similar), angular diameter (in arcmin), surface brightness (V mags per square arcsecond).

Distance (in Mpc): Find a redshift-independent distance (*not a Hubble distance!*). Explain how it was derived. Compare this to the redshift distance ($d=v/H_0$), and comment on how well they match.

Physical properties: Absolute V magnitude, V band luminosity, diameter (in pc or kpc). Calculate these from observed properties and distance.

When you do this, **don't pull the numbers from the NED overview page**; get the values by using the tabs that say “Distances”, “Diameters”, etc, and then thinking about the information contained in those tabs. When there are multiple options for values, describe how you made choices for the numbers you selected.

Finally use [ADS](https://ui.adsabs.harvard.edu/) (<https://ui.adsabs.harvard.edu/>) to look up some articles in the refereed scientific journals (ApJ, AJ, MNRAS, A&A, etc – no news articles or popular websites) describing this galaxy. I have found that the most efficient way to search for papers about

specific objects is by searching for their names in the abstract of papers. Once you have looked over a few papers, write about half a page explaining why this galaxy might be of interest to astronomers. Make sure to list at least three references that you looked at for this writeup.

Galaxy Adoption List				
Astronomer	Galaxy		Astronomer	Galaxy
Barber	1 Zwicky 18		Jones	NGC 1300
Burns-Watson	NGC 4449		Li	NGC 1512
Carver	NGC 6166		Malkan	NGC 1569
Dowhan	NGC 4594		Metz	NGC 1316
Driehuys	NGC 3949		Schroeder	NGC 4486
Duey	NGC 3370		Smith	NGC 5128
Gold	NGC 3115		Steirman	NGC 2997
Iyer	NGC 7742		Zhou	NGC 2442

3. The Danger of Hubble Distances

A “Hubble Distance” is the distance of a galaxy using Hubble’s law and the galaxy’s observed redshift, often expressed as the radial velocity: $v_r = H_0 d$. But Hubble distances can be very incorrect at times, because their radial velocity is affected not only by the Hubble expansion but also by gravitational motion, which is referred to as its “peculiar velocity”. So really the measured radial velocity is given by

$$v_r = H_0 d + v_{pec}$$

Every galaxy has its own peculiar velocity, which depends on its own gravitational environment, and is typically not well known.

Use [NED](http://ned.ipac.caltech.edu/) (<http://ned.ipac.caltech.edu/>) to look up the observed radial velocity for two nearby spirals: Andromeda Galaxy (M31) and M101. Make the assumption that the peculiar velocity of these galaxies is small (so ignore the v_{pec} term), then use Hubble’s Law and their radial velocities to calculate their Hubble distances. Now do the same for two elliptical galaxies in the Virgo Cluster: M87 and M86. Do these different distances seem reasonable? Explain why or why not.

If peculiar velocities are typically 200-300 km/s or so, what is the best accuracy with which Hubble distances can be measured? In other words, what are the uncertainties in the Hubble distance?

As you look at galaxies further and further away, the pure “Hubble flow” velocity ($= H_0 d$) will start to dominate over the peculiar velocity, and your Hubble distance estimate will be relatively more accurate. So if you were using Hubble distances, but wanted to make sure they were accurate to 10% or better, how far out in distance would you need to be looking?

Looking at galaxies in the Coma Galaxy Cluster, the galaxies have an average radial velocity of about $\langle v_r \rangle = 7,000$ km/s or so, but individual galaxies span the velocity range 5,500 – 9,500 km/s. Use Hubble’s Law to estimate the distance to Coma, but then also use it to estimate the “depth” of the cluster (in other words, its front to back distance). Which of these estimates seems reasonable? Which does not? Explain your reasoning.

Finally, raise your right hand and say “From now on I swear never to use Hubble distances as accurate measures for very nearby galaxies.”

4. Galaxy Populations

Download data for galaxies from the Sloan Digital Sky Survey. Go here: <http://cas.sdss.org/dr18/>, click “SQL Search”, and run the following search:

```
SELECT top 100000
ra, dec, z, zErr, dered_u, dered_g, dered_r, dered_i, dered_z, modelMagErr_u,
modelMagErr_g, modelMagErr_r, modelMagErr_i, modelMagErr_z
FROM SpecPhoto
WHERE
    class = 'Galaxy'
AND
    z>0 AND z<0.025
AND
    zErr<0.0001
AND
    modelMagErr_g < 0.1
```

Download the data in CSV format, then you can read the file by saying

```
data=ascii.read('<filename>',format='csv')
```

(Note: the data gives you apparent magnitudes (“dered_g”, “dered_r”, etc); you will need to convert these to absolute magnitudes to do the rest of the problem. Make sure you describe how to do this.)

For these galaxies, make the following plots:

1. Color – absolute magnitude plot:

- x-axis: absolute g-band magnitude. Do not autoscale your axes; use an astrophysically reasonable scale of $M_g \sim -16$ to -23 .
- y-axis: $g-r$ color. Again, do not autoscale your axes; use an astrophysically reasonable scale of -0.2 to $+1.2$.

Note that the axes are flipped from what a stellar CMD looks like. In this plot, bright galaxies should be to the left, red galaxies towards the top.

2. Color-color plot:

- x-axis: $g-r$ color, use a scale of -0.2 to $+1.2$.
- y-axis: $r-i$ color, use a scale of -0.5 to $+0.8$.

In this plot, make sure you have set your axes so that blue galaxies are on the lower left, and red galaxies on the upper right

Tip: you will have thousands of points, so dont use the default pointsize for plotting. For this, use an $s=1$ pointsize: `plt.scatter(<xdata>,<ydata>,s=1)`

Discuss what you see: how do galaxies separate in color-mag or color-color space? Do you see trends? Discuss why those trends might be there. What about the scatter or tightness of the relationships? Where do you think different morphological types of galaxies (spirals, irregulars, ellipticals, etc) would land on these plots? Explain your reasoning.

Grad students: Now make the same plots but let python autoscale your axes. You'll see there is craziness -- objects with absolute g magnitudes as faint as $M_g \sim 0$ and/or wildly negative nutty blue colors. So, pick 5 of those objects (a few of each type of craziness), and use SDSS Navigator to look at them, both their images and their spectra. In your writeup, give the coordinates for each one you looked at and tell me why you think its properties are messed up.

5. Modeling Colors

Now grab some population synthesis models. These are "single burst" population models (where the stars are all formed at once and then allowed to evolve over time) and give the following information: $\log(\text{time})$ in years, $g-r$ color, $r-i$ color. There are models for different metallicities:

Filename	Metallicity
colors0.dat	$Z=0.0001$
colors1.dat	$Z=0.0004$
colors2.dat	$Z=0.004$
colors3.dat	$Z=0.008$
colors4.dat	$Z=0.02$ (roughly solar)
colors5.dat	$Z=0.05$

On one plot, plot the time evolution of the $g-r$ color of all the models (x-axis: $\log(t)$, y-axis: $g-r$ color, and use different line colors to show the different models). Describe physically what is going on: why the populations are changing color with time, and why the different models have different colors at late times). Then make another plot, just like the first, but showing the evolution of the $r-i$ colors with time.

Use those models to interpret the colors of the red galaxies in the plots you made in Problem 3, in particular to explain the trends between color and luminosity seen in the red galaxies. Take two approaches:

- First, assume all galaxies have solar metallicity, and that the trend you see is due to age differences. Using the solar metallicity $g-r$ colors in your model plots, how would age be changing as a function of absolute magnitude for the red galaxies? Does that make sense as a way to explain the colors of red sequence galaxies?
- Second, assume all galaxies are 10 Gyr old, and that the age you see is due to metallicity differences. Again, use the 10 Gyr $g-r$ colors as a function of metallicity in the model plots to describe how metallicity is changing as a function of absolute magnitude for the red galaxies. Does that make sense as a way to explain the colors of red sequence galaxies?

Please be quantitative! Look at the color values for the galaxies and try to match them up to specific ages or metallicities using the model plots.

Describe observations you might make to figure out which of these scenarios is a better description of what's going on.

6. Stellar populations

Assume the following relationships hold universally for stars in a galaxy:

- the Salpeter initial mass function: $N(M)dM = CM^{-2.35}dM$
- a rough mass and luminosity relationship: $L \sim M^{3.5}$

Write down an expression that shows how the lifetime of stars depends on their mass. Describe in words what this means, and explain what it means for interpreting the color magnitude diagram for stellar populations.

If the Salpeter IMF holds for masses from M_{lower} to M_{upper} , write down and solve the integrals that give the number of stars, their total mass, and the total luminosity of the stellar population. Show that the number and mass of stars depends mostly on the lower mass limit, while the luminosity depends more strongly on the upper mass limit.

If $M_{lower} = 0.3M_{\odot}$ and $M_{upper} = 100M_{\odot}$, what fraction of the stars have $M > 5M_{\odot}$? What fraction of total mass do these stars account for? What fraction of the total light?

7. (Grad students): M101 Stellar Populations

Start by reading [McQuinn+11](#) to gain an understanding of the red and blue helium burning sequences.

Here is [HST photometry](#) of stars in the extreme outer disk of the spiral galaxy M101. Plot a color-magnitude diagram for those stars: x-axis: F606W–F814W, y-axis: F814W. Choose your axis ranges smartly, so that you can see the different features in the CMD. Clearly label all the different stages of stellar evolution that you see in the stellar populations.

Next here are stellar isochrones for different ages as a function of metallicity.

[M/H]	Young (50-500 Myr)	Old (10 Gyr)
0.0	young_0.dat	old_0.dat
–0.3	young_1.dat	old_1.dat
–0.7	young_2.dat	old_2.dat
–1.0	young_3.dat	old_3.dat
–1.3	young_4.dat	old_4.dat
–1.5	young_5.dat	old_5.dat
–1.7	young_6.dat	old_6.dat

Use them to work out your best estimate of the metallicity of a) the old red giant branch stars and b) the young stellar populations. Describe how you came to your best estimate, and give a (qualitative) uncertainty on your estimate. Include a plot of the CMD with the best match isochrones overlaid. Compare the metallicities of the populations to one another and also to that of the Sun, and interpret the differences in the context of galaxy evolution.

Note: The data is in apparent magnitude; the models are in absolute magnitude. To overlay/compare them, use a distance of 6.9 Mpc.