Homework Assignment 1

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Abstract

This assignment has is an attempt to recreate Hubble's analysis in his 1929 paper *A Relation Between Distance and Radial Velocity Among Extra-Galactic Nebula[1]* by performing linear fits on the data set included in his paper. Hubble grouped data and and attempt is made at replicating these groupings. Using a data set of supernova redshifts and distance moduli from *Davis et al.* Hubble's constant is found and compare to his original value. An accelerating rate of expansion of the universe was then found by splitting the supernova data set into low and high redshift values and taking linear fits for each.

1 Problem 1

Hubble's data set consists of the velocities an distances of 24 nebulae relative to earth, on which a linear fit of velocity vs distance was performed. The 24 galaxies were also partitioned into nine groups on which the same linear fit was performed.

Velocity	Distance	Group
-185	0.275	1
-220	0.275	1
-70	0.263	1
920	1	1
170	0.032	2
290	0.034	2
-30	0.9	3
650	0.9	3
960	1.7	3
200	0.63	3
300	0.8	4
500	1.4	4
290	0.5	4
500	2	5
850	2	5
800	2	5
1090	2	5
150	0.9	5
450	1.1	6
270	0.5	6
200	0.45	6
500	0.9	7
-130	0.214	8
500	1.1	9

Table 1.
Hubble's data[1] and my groupings

I chose groupings by finding the error square in between right ascension and declination data from *The Interactive NGC Catalog Online[2]* for all combinations of nebulae, then matched the galaxies into groups that had low errors together. Sheet 1 of *newneb.xlsx* contains this process. After grouping I ran both the 24 nebula and 9 groups through *hubble.py* with some edits to annotate graphs and add a trendline:

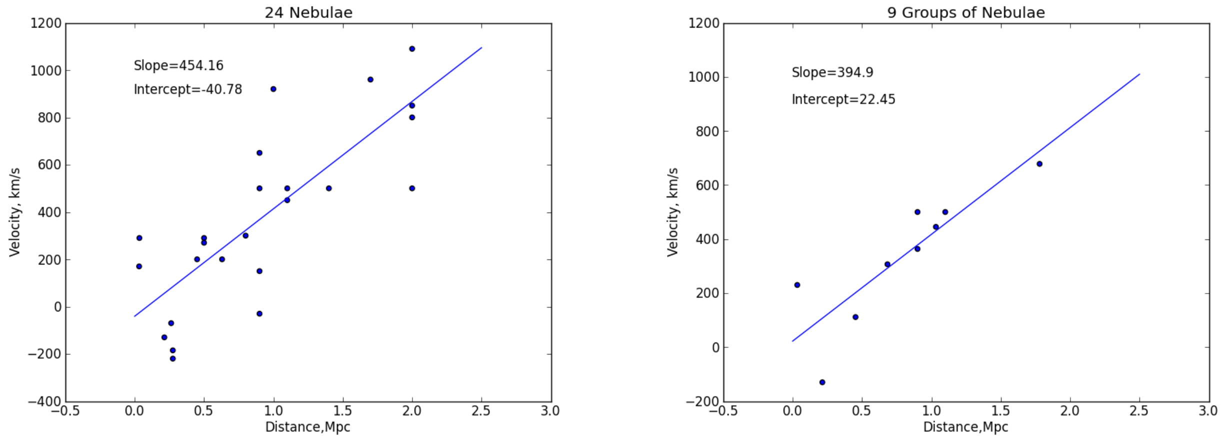

Figure 1: Graphs of all nebulae and nebulae groups

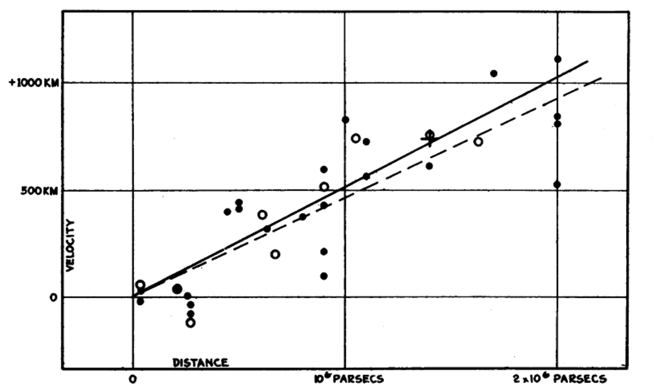

Figure 2: Hubble's graph[1]

Table 2 below lists the values from my fits and groupings alongside Hubble's for the simplified problem of $v = Kr + a$ with K in $\frac{km}{sMpc}$ and a in $\frac{km}{s}$

	K	σ_K	a	σ_a	
Hubble 24	465	± 50			
My 24	454	± 75	-40	± 83	
Hubble Groups	513	± 60			
My Groups	394	± 89	22	± 83	

The values for the slope are not consistent. Curiously even the linear fits for all 24 nebulae are different., likely because Hubble broke the intercept into three separate parameters that could account for latitude and longitude. Modern measurements of $68\frac{km}{sMpc}$[3] from the Planck spacecraft are also nowhere near those of the fit.

2 Problem 2

The *supernova.py* program plots the distance modulus vs the log of the redshift and gives a chi squared fit for the same problem using data from *Davis et al.[4]* . The linear fit should match up with the relativistic Hubble's law:$\mu = 25 + 5\log(\frac{cz}{H_o}) = 25 + 5\log(\mathrm{c}) + 5\log(\frac{1}{H_o}) + 5\log(\mathrm{z})$. There is a hidden $1Mpc$ in the denominator of the log's argument, so $c = 9.716 \times 10^{-15}\frac{1}{s}$.

Running the program gives a slope of 5.553 ± 0.026 and intercept of 44.152 ± 0.022. Hubble's constant can be found from the intercept:

$$\begin{aligned}
b &= 25 + 5\log(\tfrac{c}{H_o}) \\
\frac{b-25}{5} &= \log(\tfrac{c}{H_o}) \\
\frac{c}{H_o} &= 10^{\frac{b-25}{5}} \\
H_o &= c10^{\frac{25-b}{5}} \\
H_o &= 1.436 \times 10^{-18}\frac{1}{s} = 44.3\frac{km}{sMpc}
\end{aligned}$$

Hubble's value is about $500\frac{km}{sMpc}$, so over ten times the value from the supernova data. There is going to be a slight difference because we are using supernovae instead of nebulae, but the major problem is that Hubble used an erroneous calibration for the Cepheid variables, so his paper showed the correct trend of red shifting nebulae but a totally incorrect value. Of note, using Hubble's erroneous constant gives the an age of the universe as about 2 gy which is incongruous with the earth's age of 4.5 gy

3 Problem 3

Using a cutoff of $z = 0.1$, the low redshift supernovae have a slope of 5.25 ± 0.14 with intercept of 43.73 ± 0.21 and chi-square/d.o.f. of 0.26 . High red shift had a slope of $5.905 \pm 0.082$with intercept of 44.239 ± 0.029 and chi-square/d.o.f. of 0.80. The high redshift supernovae have a larger slope, all supernovae moving away from the earth and are accelerating as they get further away. q_o can be estimated by taking the difference in slopes and attributing the change in slope to q_o. Over the entire data set, there is a ~ 1.7 change in z and a change in slope of .65. Using the term neglected in Hubble's law in problem two to account for this change:

$$\begin{aligned}
\Delta slope &= 1.086(1-q_o)\Delta z \\
.65 &= 1.086(1-q_o)1.7 \\
q_0 &= 0.647
\end{aligned}$$

The cutoff was made by editing *supernova.py* and adding a condition checking if $z > 0.1$ before $\log z$, μ and σ_μ were added to the lists, then doing the same for $z < 0.1$.

References

[1] A Relation Between Distance and Radial Velocity Among Extra-Galactic Nebulae", Edwin Hubble, Proc. Natl. Acad. Sci. USA 15 , 168-173 (1929).

[2] The Interactive NGC Catalog Online, http://spider.seds.org/ngc/ngc.html

[3] Bucher, P. A. R.; et al. (Planck Collaboration) (2013). "Planck 2013 results. I. Overview of products and scientific Results"

[4] Davis, Mörtsell, Sollerman and ESSENCE, 2007, astro-ph/0701510

Project Code:

All project code can be found at https://github.com/darvilp/comphys1/tree/master/HW/HW1
The major edit to *hubble.py* was to add labels and annotations to the plots:

```
import numpy
ecks= numpy.linspace(0,2.5,1000)
why= ecks*b+a
plt.xlabel("Distance,Mpc")
plt.ylabel("Velocity, km/s")
plt.plot(ecks,why)
a=math.ceil(a*100)/100
b= math.ceil(b*100)/100
plt.annotate('Slope='+str(b),xy=(0,1000))
plt.annotate('Intercept='+str(a),xy=(0,900))
plt.title("9 Groups of Nebulae")
```

The change is made at the very end of *9grouphubble.py* and *24nebhubble.py*.

The edit to *supernova.py* is to add if statements at line 46-48:

```
qq=0.1
logz_data = [math.log10(float(datum[1])) for datum in data if float(datum[1])>qq ]
mu_data = [float(datum[2]) for datum in data if float(datum[1])>qq ]
mu_err_data = [float(datum[3]) for datum in data if float(datum[1])>qq]
```

Which will split the dataset at whatever value is placed in *qq*.