Project Report: Confirming Pairs of Colliding Galaxies

Overview:

In our project we aimed to create our own process to confirm pairs of colliding galaxies. For this process, we wanted to calculate the angular separation and distance between galaxies in order to determine the plausibility of the galaxies being gravitationally bound. We used a subset of the NGC Catalog and ran the data through several equations to generate these values and compare it to parameters that we set. After filtering out pairs that fit the parameters, we checked by hand using Stellarium if they were a known pair of gravitationally bound galaxies.

Methods:

In order to test our process of finding the angular separation and distance between two galaxies, we had to choose two "test" galaxies to make sure we were able to properly compute the values before applying it to a large dataset.

1) Angular Separation (1a)

Spherical Trigonometry

Right ascension, declination, and distance for two galaxies was used for computing the angular separation between galaxies. NGC 3690 and another galaxy was identified using Stellarium. To better gauge whether the angular separation was reliable, a galaxy that was close to NGC 3690 was chosen. The best candidate was NGC 3619, which was within the same right ascension hours of NGC 3690.

Galactic data used in spherical trigonometry:

	Right Ascension	**Declination**	**Distance (light years)**
NGC 3690	11h 29m55.8s	+58°25'37.3"	142,000,000
NGC 3619	11h 20m47.8s	+57°37'27.1"	92,856,720

The distance to NGC 3619 was found by averaging three distance measurements from Simbad.

Before utilizing the spherical trigonometric equation, right ascension and declination was converted to degrees and formatted as:

$$a = (\alpha_a, \delta_a)$$

$$b = (\alpha_b, \delta_b)$$

Galaxy 1/NGC 3690 (a): $\alpha_a \rightarrow$ right ascension

$\delta_a \rightarrow$ declination

Galaxy 2/NGC 3619 (b): $\alpha_b \rightarrow$ right ascension

$\delta_b \rightarrow$ declination

The spherical law of cosines equation produces the value of gamma (γ), the angular separation between galaxies, using the above values:

$$\cos(\gamma) = \cos(90^\circ - \delta_a)\cos(90^\circ - \delta_b) + \sin(90^\circ - \delta_a)\sin(90^\circ - \delta_b)\cos(\alpha_a - \alpha_b)$$

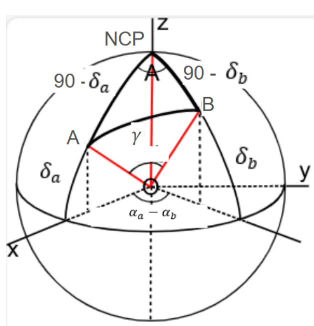
After substituting the variables, the cosine of gamma was approximately 0.99968 radians. In order to obtain just gamma, the inverse of cosine was taken.

$$\gamma = \arccos(0.99968)$$
$$=0.02528 \text{ radians}$$

This step is just an example of how the inverse is taken for preceding steps in the data pipeline. In the equation for calculating physical distance (below), the cosine of gamma can be used directly since it's already a variable in the equation.

Phase 2b: Measuring the Distance Between Galaxies

The spherical law of cosines accounts for the curvature of space, thus the angle obtained from the equation is based on the 3D model shown below.



Since curvature has been accounted for, the standard planar law of cosines can be computed using gamma:

$$c = \sqrt{a^2 + b^2 - 2ab(\cos\gamma)}$$

$c \rightarrow$ distance between two galaxies
$a \rightarrow$ distance to galaxy 1 from Earth
$b \rightarrow$ distance to galaxy 2 from Earth

Using gamma and distances from phase 2a:

$$c = \sqrt{142{,}000{,}000^2 + 92{,}856{,}720^2 - 2(142{,}000{,}000)(92{,}856{,}720)\cos(0.99968)}$$

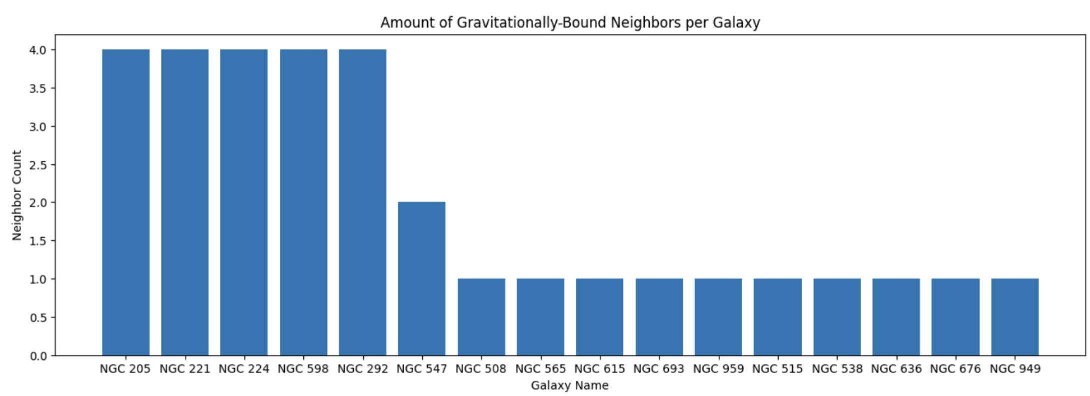
$$c = 49{,}228{,}943 \text{ light years}$$

Converting to Jupyter:

Since we were able to compute reasonable variables for our test data, we imported a csv file of 395 galaxies from the NGC Catalog. After some filtration with table methods, we were left with the distance from Earth to the given galaxy, right ascension and declination in degrees, and the name of the galaxy. We then generated resulting pairs by filtering out galaxies that were greater than 2537000 light years apart and less than 16 arcminutes. 16 arcminutes was taken from NASA's Atlas of Galaxies Book where only 1 galaxy within that frame was depicted. We chose to use galaxies with an angular separation of larger than 16 arcminutes since the galaxies would not be in the same photo, and thus, less likely to be known as gravitationally bound.

Results:

	Distance (ly)	G1	G2	Gamma
0	1.652946e+06	NGC 959	NGC 949	0.029644
1	1.432211e+06	NGC 693	NGC 676	0.009587
2	1.915582e+06	NGC 615	NGC 636	0.017550
3	2.289657e+06	NGC 205	NGC 292	1.998734
4	2.287100e+06	NGC 221	NGC 292	1.984090
5	2.288372e+06	NGC 224	NGC 292	1.991361
6	2.355140e+06	NGC 598	NGC 292	1.810007
7	1.163615e+06	NGC 547	NGC 538	0.005773
8	2.197333e+06	NGC 565	NGC 547	0.008744
9	3.509946e+04	NGC 221	NGC 205	0.015955
10	2.151365e+04	NGC 224	NGC 205	0.009779
11	6.084162e+05	NGC 598	NGC 205	0.267585
12	1.599827e+04	NGC 224	NGC 221	0.007272
13	5.764968e+05	NGC 598	NGC 221	0.253065
14	5.870424e+05	NGC 598	NGC 224	0.257863
15	1.839583e+06	NGC 508	NGC 515	0.005046



In total, we found 15 pairs of potentially gravitationally-bound galaxies. Upon further research, the galaxies are positioned similarly in the sky and are known to be in groups of galaxies, hence the prevalence of multiple neighbors per galaxy. Therefore, we were able to conclude that our method worked as intended. If we had time to expand our project to include mass and calculate the total energy of the two-galaxy system, then we would have another value to aid our distance calculation. Since negative total energy of the system would imply that the galaxies are gravitationally-bound, we would be able to confirm that they were bound with something other than assumption based on our parameters.