Research Plan

CeCe Graff and Kevin Xu

Abstract: *Gravitational lensing* is a phenomenon of bending light in space. It occurs when massive objects, such as galaxies, cause the curvature of space-time. *Gravitational lensing* is a significant discovery because it effectively proves the existence of dark matter; studies have shown that luminous (visible) matter alone cannot generate enough gravity to warp space-time, implying that a mysterious, invisible matter must exist (dark matter). To better understand the quantity and origins of dark matter in the universe, we compared the amount of dark matter in galaxies of different ages. Looking deep into space is essentially looking back in time, hence our comparison of galaxies that vary in distance from Earth.

A) Question or Problem being addressed

The Amount of Dark Matter in Galaxies of Different Ages

B) Goals/expected outcomes/hypotheses

The "Gravitational Lensing Astronomy Summer Program (GLASP)," organized by Dr. Natalia Connolly and Mr. Jeffery Rodriguez, was created in hopes of providing four Anderson High School students with a glimpse into careers in astrophysics. For a three-week session in August of 2011, we primarily focused on gaining historical knowledge of *gravitational lensing*, gathering and analyzing images of exemplary lensing galaxies, and compiling various galaxy calculations and statistics. The interns then split into two groups to delve into related subtopics, and thus our question was formulated: "How do the amounts of dark matter compare in galaxies of different ages?"

The purpose of our experiment is to become more knowledgeable about dark matter and discover how quantities of dark matter have changed over time. Perhaps a variety factors can lead to changes in the amount of dark matter, but we are only focusing on one variable: age. We hope that through our research and studies, we may be able to contemplate possible causes of the changing quantities of dark matter.

Our hypothesis for the experiment is as follows: the older the galaxy, the larger the quantity of dark matter. When one views a distant galaxy from a telescope, the image is actually a window into the past. As the galaxy's distance from the Earth increases, the image of the galaxy that one sees on Earth becomes older and older. We believe that older galaxies (which are farther away) have more dark matter because they have had more opportunities to gain mass and luminosity during their life span.

C) Description in detail of method or procedures

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Materials List

- "The SLOAN Lens ACS Survey. V. The Full ACS Strong-Lens Sample" document
- "The Double-Lensed System Analysis" document
- Summer session galaxy statistics
- Summer session galaxy calculations
- Paper
- Writing utensil
- TI-83 calculator
- Computer
- Internet access

Constants

1 pixel = .1 arcsecond = 0.0000048481368111 radian

C (speed of light) = 3x10^5km/sec

G (Newton's gravitational constant) =

.0043[pc(km/sec)^2/M○] = 2.67075377x10^{-19}km$^3/kgsec^2$

M ○ = 1.99x10^{30}kg

1 pc = 3.09x10^{13}km

Ho (Hubble constant) = 71 (km/sec)/MPC = 2.3x10^{-18}(1/sec)

1 MPC = 3.09x10^{19}km

Equations

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$d \approx \left(\frac{C}{Ho}\right) \times [\frac{(z+1)^2-1}{(z+1)^2+1}]$

$M = \frac{[(\theta^2 E)c^2(dSdL)]}{[4G(dS-dL)]}$

Mass-to-Light Ratio = M ○/L ○

<u>Procedure</u>

1. Referring to summer session galaxy statistics, convert θE from pixels to radians using dimensional analysis (1 pixel = .1 arcsecond = 0.0000048481368111 radian).

2. Convert the speed of light (3*10^8 m/s) to kilometers to match all units. With 1 km = 1000m, conversion should equal 3*10^5 km/s.

3. Use the equation d ≈ $\left(\frac{C}{Ho}\right) \times [\frac{(z+1)^2-1}{(z+1)^2+1}]$ to convert redshifts (zL and zS) to distances (dL and dS). The c value is the speed of light in kilometers, and the H0 is the Hubble constant: 2.3x10^{-18}(1/sec). To find the zL and zS values for each galaxy, refer to the data tables in "The SLOAN Lens ACS Survey. V. The Full ACS Strong-Lens Sample" document. The resulting numbers should be in km and labeled dL and dS.

4. Determine the galaxy mass in kg with the equation M = $\frac{[(\theta^2 E)c^2(dSdL)]}{[4G(dS-dL)]}$. G stands for Newton's Gravitational Constant, equaling 2.67075377x10^{-19}km$^3/kgsec^2$. The resulting answer should be in kg.

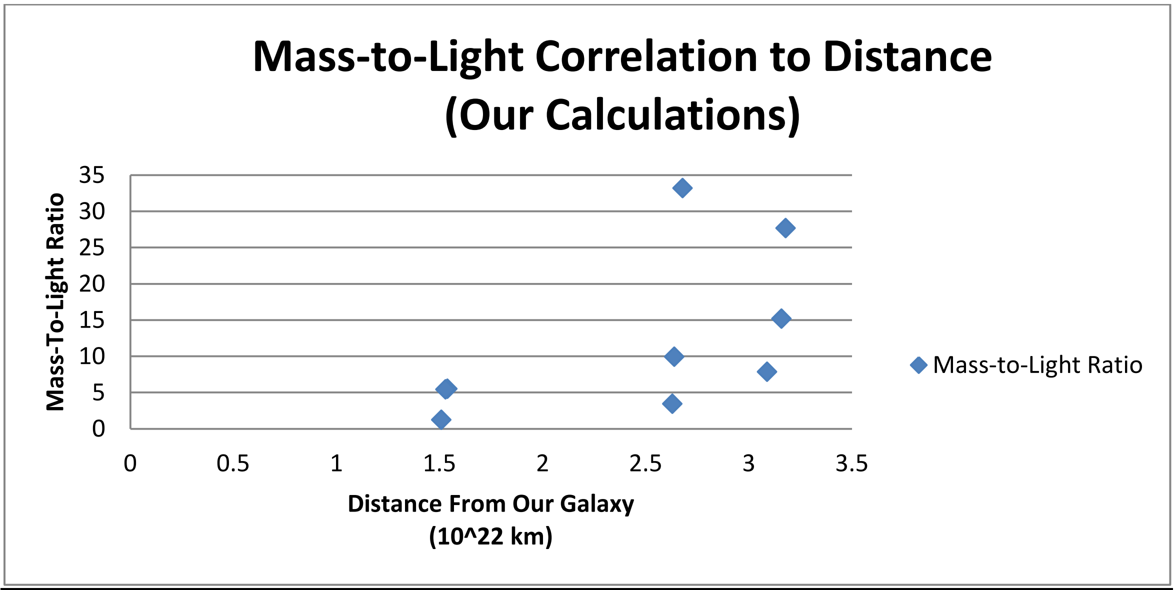
5. Convert kg to solar masses using dimensional analysis (1 solar mass = 1.99 * 10^30 kg).

5. Divide the solar mass by the luminosity mass to determine the mass-to-light ratio (M○ /L○). Refer to "The SLOAN Lens ACS Survey. V. The Full ACS Strong-Lens Sample" document to find the luminosity mass. If the ratio is greater than one, dark matter exists in the galaxy (more total mass than luminous, or visible, mass).

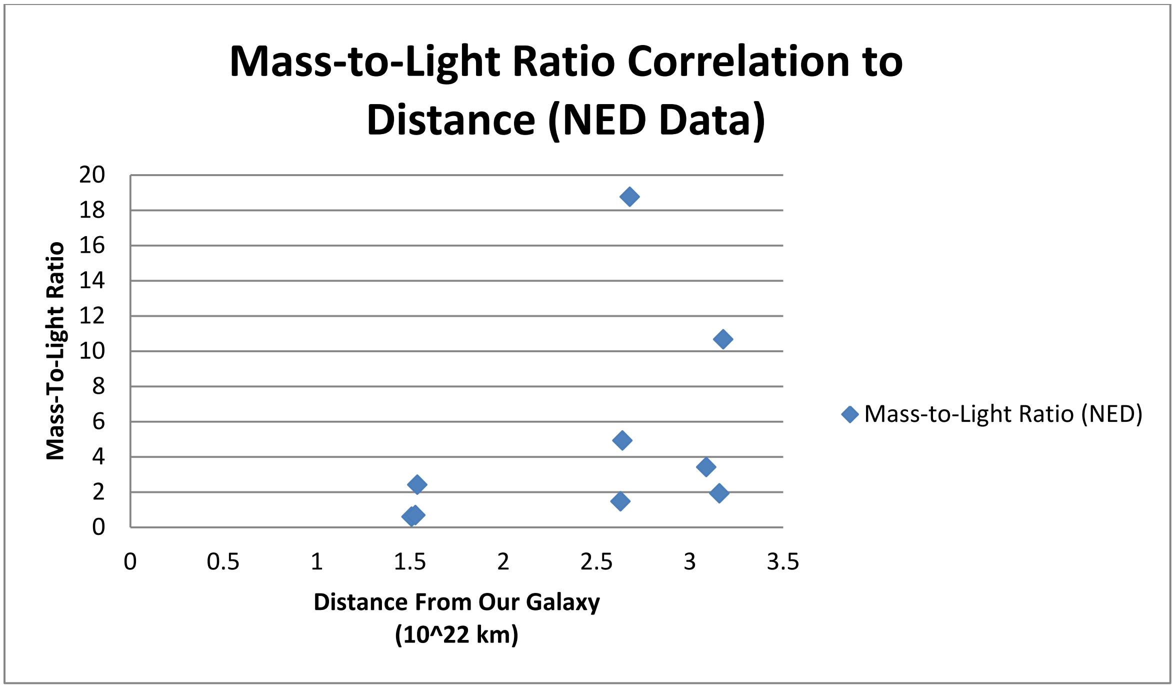
<u>Data Analysis</u>

In total, 57 galaxies were candidates for the calculation above. We began by selecting nine galaxies (sets of three that were near in range), calculating their distances and mass to light ratios by hand, and comparing our results to those of the NASA/IPAC Extragalactic Database (NED).

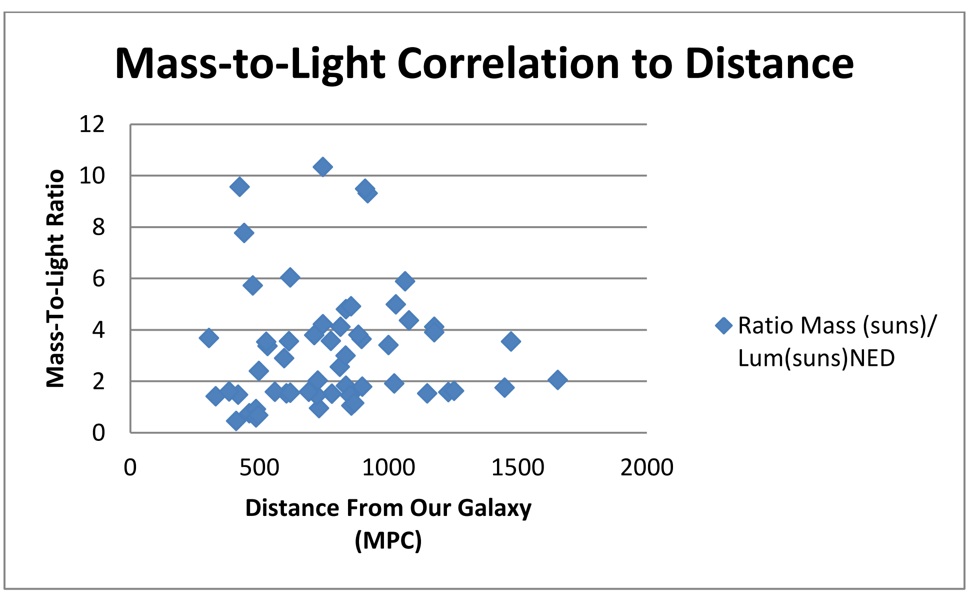
The graph below displays the relationship between our calculated distances and mass-to-light ratios. It seems to show that as distance (age) increases, the mass-to-light ratio (amount of dark matter) increases as well (direct relationship).



The graph below uses data from the NASA/IPAC Extragalactic Database (NED). We desired to check the accuracy of our calculations. It shows a potential direct relationship like the graph above and confirms the accuracy of our calculations.



To complete the complicated calculation process outlined in our procedure for all 57 galaxies, Mr. Rodriquez assisted us in writing a Microsoft Excel program. Using the calculated values from the program, we created a mass-to-light ratio versus distance graph and observed the correlations (shown below).



Referring to the slight deviation of our calculated values from the NED data, we could have miscopied numbers, incorrectly calculated some values, or suffered programming errors. The initial data we collected during the summer session could also be out of date if NED has recently been updated with new information. Referring to the graph created with our program, outliers abound and some of the values are inconsistent with our hypothesis. Therefore, a direct relationship between galaxy age and the amount of dark matter could exist, but our data is plagued with numerous outliers and our hypothesis requires further experimentation to be confirmed correct.

To improve the accuracy of our data, we could do a second collection to make sure that our summer data is not out of date. We could also locate more galaxies to use for calculations; a wider range of data would provide more accurate results.

D) Bibliography

Thank you to Dr. Natalia Connolly from Hamilton College and our physics teacher, Jeffery Rodriguez, for the opportunity to conduct extensive scientific research and gain valuable insight into careers in astrophysics.

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