NGC 7448 Galaxy Kinematics

Gavin Peterkin
(Data Collected with: Brendan Lee, James Creswell, and Humna Awan)
September 29, 2014

Experimental Astronomy 4410, Prof. Don Barry

Abstract

In this lab, we use a long-slit spectrograph (600 grooves/mm, 135mm f.l., 200μm slit, 12d) on the James R. Houck 25-inch Telescope to study the spiral galaxy NGC 7448. More specifically, I determine the redshift of the galaxy and study its rotation. From the redshift, I determine the distance to the galaxy using a value of Hubble's constant from the literature. From the tilt of the H-α line, I determine the rate of rotation and find a value for galactic mass gathered from the kinematics of the galaxy itself (kinematic mass). Using results from the literature, I also determine luminous mass. Finally, it's found that the kinematic mass is about five times greater than the luminous matter. This result and it's meaning is discussed.

Introduction

Using the long-slit spectrograph detailed above I aim to determine the redshift of the galaxy NGC 7448 at both ends of its major-axis, where its radial velocity relative to the earth is a maximum. These two extreme measures of redshift can be averaged to compute the overall redshift of the galaxy, which in turn can be used to calculate the recessional velocity and the distance to the galaxy (using a known value of Hubble's constant).

The extreme measures of redshift along the two edges of the galaxy can also be used to compute the difference in the velocities, and from that, the velocity of rotation at a fixed radius. The length of the major-axis (or diameter) in pixels can easily be converted to arcseconds. Since the distance was determined previously, it is now a simple matter to find the diameter and radius in units of length. Newton's laws can then be used to calculate the enclosed mass, which gives the kinematic mass (M_k).

Using stellar mass-to-light ratios from Bell & Jong's article, tabulated data on the sun's absolute magnitude in several bands, and published data on the galaxy's photometry, it is possible to estimate the mass contributed from luminous matter (M_{Lum}).

This will provide two different values for mass. The ratio of the two masses can then be used to form a rough estimate of the amount of dark matter present in NGC 7448.

Procedures

Observations were made on the night of September 19, 2014 on the Houck 25-inch Telescope at the HBO. A long-slit spectrograph (600 grooves/mm, 135mm f.l., 200μm slit, 12d) was used with the previously studied thermoelectrically-cooled Andor CCD Camera. The following exposures were taken:

Exposure Number	Object	Universal Time	Air Mass	Exposure Length (sec)
1	NGC 7448	1:28 AM	1.38	120
2	NGC 7448	1:34 AM	1.31	900

3	Bias	-	-	-
4	M57	2:09 AM	1.13	180
5	58 Aql	2:19 AM	1.41	60

Exposure number 2 was chosen over 1 because it had a more distinctive H-α line, as would be expected with a longer exposure. All frames were bias corrected using exposure number 3. The planetary nebula M57 was used to calibrate the spectrum generated from exposure number 2. Exposure number 4, airmass, and exposure length are included only for completeness. The listed values of universal time were used later for radial velocity corrections in IDL.

Six spectral lines were fitted on to the spectrum of M57 at a constant y-coordinate of 340 (Y_{ref}). A bright atmospheric mercury line located at an x-coordinate of ~890 was used to determine the skew of discrete spectral lines. Since it extends throughout the y length of the array, it is possible to get a reasonably accurate measure of the x-displacement as a function of the y-coordinate. The M57 calibration was applied to the galactic spectrum and skew-corrected wavelengths (also using dispersion relations) were used to determine redshifts.

Results and Discussion

Galactic Redshift

(All wavelengths are given in Angstroms and velocities in km/s.)

NGC 7448	Corrected λ_{obs} (y=323)	Corrected λ_{obs} (y=249)	λ_{source}	Z (y=323)	Z (y=249)	Vel (y=323)	Vel (y=249)
H-α	6609.4	6617.8	6562.8	0.0071	0.0080	2130	2395
Error	±0.2	±0.3	-	±0.0001	±0.0001	±30	±30

Table 1.

Errors in Angstroms were determined from the Gaussian fit and from the CCD.

It's clear there's a significant difference in the velocity along the top and bottom edge of the galaxy, but these velocities still need to be corrected for the tilt of the galaxy along the line of sight (the observed velocity is actually less than the true radial velocity).

The NASA-Extragalactic Database (NED) provides measurements for the major and minor diameters in arcseconds.
Major Diameter: 2.7
Minor Diameter: 1.2

One can assume that the galaxy's structure is approximately a disk. That would give an angle of arccos(1.2/2.7) = 63.6° which is the angle the normal to the disk forms with the line of sight.
Sin(63.6°) = 0.896

The previous results for velocity can be used taken with the angle to obtain the following:

Vel (y=249) - V(323)	$\Delta V / 2 = V_{rot}$	Geometrically Corrected V_{rot}
265	132	147
±60	±30	±33

Table 2.

Total Recessional Velocity

The total recessional velocity can be calculated by simply averaging the corrected velocities given in table 1.

Z: 0.0075±0.0001
Recessional velocity not corrected for observer's motion: 2263±30 km/s
Heliocentric velocity: 2275±30
Local group centric velocity: 2558±30

NED provides a heliocentric velocity of 2194±1 km/s. The correction from the earth's relative motion seems to be moving the estimation in the wrong direction, so I will stick to the uncorrected figure in the following calculations.

The Hubble constant provided by the Planck Mission is: 67.8±0.77 km/s / Mpc.
Using the above result for velocity, one can then estimate the distance to NGC 7448 as: $D = Vel / H_o$ = 33.4 ± 1 Mpc
NED provides a mean distance: 27±7 Mpc, which I will use in later calculations.

The distance can be used along with the radius, which can be determined in arcseconds, to find the radius of the galaxy in meters.

D (pixels)	D (arcsecs)	D (kpc)	D (meters)	R (meters)
170	132.6	17±4	$5.2\pm1*10^{20}$	$2.6\pm0.5*10^{20}$

Table 3.

The kinematic mass can then be approximated with the radius.

$M_K = R*V^2/G = 8.4*10^{40} \pm 1.6*10^{40}$ kg.
$= \sim4*10^{10} M_{solar}$

Luminous Mass

The following formula for absolute magnitudes can be used in determining the luminosity of the galaxy in terms of the solar luminosity.
$M_{gal} – M_{sun} = -2.5* \log_{10}(L_{gal} / L_{sun})$
NED provides M_{gal} = -21.71 in the visible region I band.
M_{sun} = 4.10 in the same region and band.

$L_{gal} / L_{sun} = 2.11*10^{10}$

Again using results from NED, one finds that B-V≈ 0.4, which coupled with the models developed by Bell and de Jong, suggests a stellar mass to light ratio of ~0.4 M/L.

⇨ $M_{lum} = (2.11*10^{10}) * (0.4\ M_{sun}) = \underline{1.67*10^{40}\ kg}$

$M_k / M_{lum} = \sim 5$

Conclusion

The result suggests that only about one fifth of the galaxy's mass is comprised of luminous matter. A total of 4/5 of the galaxy is therefore dark matter.

The inaccuracy in the recessional velocity is significant and the increasing inaccuracy using a heliocentric correction suggests an unknown source of error in applying the correction. Perhaps an intragalactic correction to the M57 spectral lines is necessary to get a more accurate overall calibration.

References

"Absolute Magnitude of the Sun in Several Bands." 27 Sept. 2014. Web. <http://www.ucolick.org/~cnaw/sun.html>.

Barry, Don. "Notes on Radial Velocities." Astro 4410 Course Wiki. 27 Sept. 2014. Web. <http://coursewiki.astro.cornell.edu/Astro4410/Radialvelocities>.

Barry, Don. "Spectrophotometry." Astro 4410 Course Wiki. 27 Sept. 2014. Web. <http://coursewiki.astro.cornell.edu/Astro4410/SpectroPhotometry>.

Bell, E.F., & de Jong, R.S. 20 March 2001, ApJ, 550:212-229. Web. <http://iopscience.iop.org/0004-637X/550/1/212/fulltext/>.

NASA/IPAC Extragalactic Database (NED). NGC 7448. 27 Sept. 2014. Web. <http://ned.ipac.caltech.edu>.