DETERMINING THE RELATIONSHIP BETWEEN BLACK HOLE MASS AND ITS AGE. A. Carlton[1,3] and J. Kennefick[2,3]. [1]Dept. of Physics, Wake Forest University, 1834 Wake Forest Rd, Winston-Salem, NC 27109, carlak7@wfu.edu, [2]Dept. of Physics, University of Arkansas, 825 W. Dickson St, Fayetteville, AR 72701, [3]Arkansas Center for Space and Planetary Sciences, 202 Old Museum Bld, Fayetteville, AR 72701.

Introduction: The objective of this project is to determine the relationship between black hole mass and its age in the universe. Since black holes have a gravitational field too strong to allow even light to escape (rendering them impossible to see), studying quasars allows one to see the effects of the black hole on surrounding material. The effects studied provide information about the black hole that dwells inside. Looking at high redshift quasars allows for the study of the evolution of black hole mass.

Sample. Quasar density within the universe peaked around a red shift of two to three. Therefore, the sample includes 103 quasars between a red shift of 1.85 and 4.26. This provides for the comparison between black hole mass and age. The images of the quasars were taken in December of 2005 at Kitt Peak National Observatory. The spectra used to determine the black hole masses were downloaded from the Sloan Digital Sky Survey DR7 [2]. Image reductions were made using IRAF on each CCD image to take away such imperfections as dark frame, bias, and cosmic rays.

Methods. To determine the mass of any object, one needs the radius and velocity of something orbiting the object. The same is true of finding the black hole mass. Using emission spectroscopy, or the study of the quasar spectra from gas emissions, the spectra yield the velocity and radius needed to utilize the Vestergaard [4] equation to find black hole mass. One of the most characteristic aspects of quasars is the broad emission lines. The difference is Doppler broadening: the relatively huge velocities of the gases orbiting the black hole resulting in varying Doppler shifts and broadened emission lines.

Observationally, the quasar spectrum is composed of a continuum from the black hole accretion (essentially at the center) and broad emission lines located further out (in the broad line region). These broad lines are produced by the high velocities the gases are rotating at, creating Doppler broadened lines. The technique originally employed to find the radius is called "reverberation mapping", which measures the time delay from the change in the continuum to the change in the broad line region (BLR) in a varying quasar spectrum. However, this has only been done for about twenty nearby quasars. A more efficient method of calculating the radius of the broad line region (RBLR) is by looking at the luminosity. It was found that the BLR size correlates with the continuum luminosity. Scaling relations were made from the reverberation mapping to relate luminosity to the RBLR.

First, using the redshift z, one calculates the luminosity distance D_L using equation 1. The flux S at 1350Å (particular to the CIV line) is measured. The flux in combination with the luminosity distance yields the luminosity, as seen in equation 2.

$$D_H = \frac{c}{H_0}$$

$$D_C = D_H \int_0^z \frac{dz'}{E(z)} \qquad (1)$$

$$E(z) = \sqrt{\Omega_M (1+z)^3 + \Omega_K (1+z)^2 + \Omega_\lambda}$$

$$D_L = (1+z) D_M$$

where
z = redshift
$\Omega_M = 0.3$
$\Omega_K = 0$
$\Omega_\lambda = 0.7$
$H_0 = 70\text{hkm/s}\times\text{Mpc}^{-1}$

$$L = 4\pi \times D_L S \qquad (2)$$

To find the velocity, the width of the broad line emission from the carbon IV line is measured. This is called the full width half maximum (FWHM), and is merely the change in wavelength. A Gaussian curve is fit to these broad line emissions and the FWHM recorded. Using equation 3, the velocity can be found.

$$\upsilon = \frac{\Delta\lambda}{\lambda} c \qquad (3)$$

Using the luminosity and the velocities found above, one employs the Vestergaard equation (4) for black hole mass in the units of solar masses.

$$\log(M_{BH}) = \log\left\{ \left[\frac{V}{1000 km/s}\right]^2 \times \left[\frac{(1350A)\times L}{10^{44} ergs/s}\right]^{0.53} \right\} \qquad (4)$$
$$+ (6.66 \pm 0.01)$$

Results. The quasars were grouped into three bins based on their redshift (Table 1). Average bin mass was also computed, and then graphed against the average redshift for each bin (Figure 1).

Table 1. Redshift and Mass by Bin

Quasar Bin	Avg. Red Shift	Avg. Mass
A	1.877065	8.98736
B	2.798531	8.699686
C	4.05612	8.31992

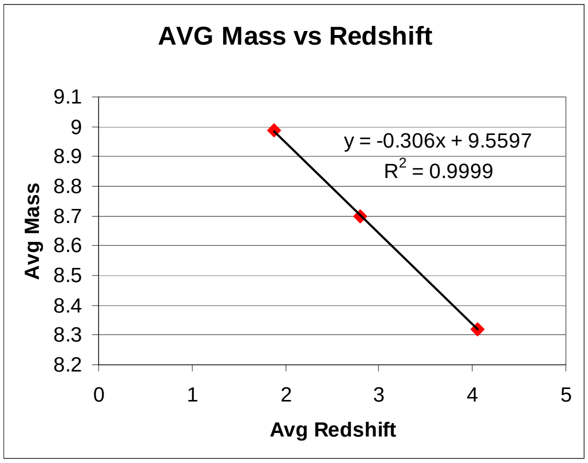

Figure 1. This is a graph of the average mass (in solar masses) of each quasar bin against the average redshift.

This figure demonstrates the increase in black hole mass over time.

Fluxes and FWHMs were measured using IRAF [3]. Also, some quasars were thrown out because the spectra had high absorption, preventing accurate measurements. Therefore, to confirm the measurements, they were compared to those from SDSS. They were relatively close, validating the original measurements taken.

To test these results, the same techniques were applied to the MgII emission line. A slightly different version of the Vestergaard equation was employed, but the RBLR and velocity were measured like the CIV line, but at a wavelength of 2799Å. However, this wavelength is only common to quasars in bin A, so the comparison is only made between quasars in the first bin. Figure 2 demonstrates that the masses calculated from the CIV line are similar to those calculated from other emission lines, further validating the results.

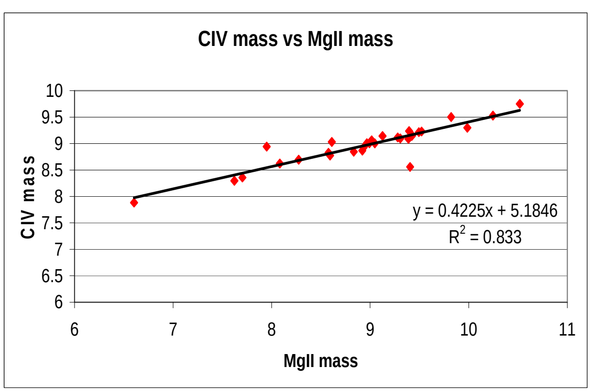

Figure 2. This is a graph of the black hole masses found using the CIV line against the masses found using the MgII line.

Conclusions. Preliminarily, the results seem to indicate a positive linear relationship between black hole mass and age. This makes sense on the most basic level: black holes continue to “eat” over time, and gain more mass over time as a result. In emission spectroscopy, further analysis should be done on different emission lines, such as those in the near infrared region, which allows for highly red shifted emission lines. However, by using the CIV line, the most quasars could be accounted for in the sample.

By using the spectra and various cosmological calculations, the velocity and radius of the broad line region were calculated for the CIV line. From this information, the Vestergaard equation was employed, indicating a relationship between black hole mass and its age in the universe complentary to modern views of galaxy formation and evolution.

Acknowledgements: I would like to thank the National Science Foundation for funding this project, along with my mentor, Julia Kennefick, at the Center for Space and Planetary Sciences at the University of Arkansas, Fayetteville, AR.

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Additional Information: If you have any questions or need additional information regarding this abstract, contact A. Carlton at carlak7@wfu.edu.