EVOLUTION OF BLACK HOLE MASSES IN QUASARS WITH TIME.

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Introduction: Quasars are extremely distant, extremely luminous active galactic nuclei (AGN). We know that they are extremely distant from large redshifts of their spectra; however, they are bright enough to be imaged by moderately sized telescopes. In order to achieve such brightness, they need to be powered by a very strong source, which is believed to be a supermassive black hole in the center of a host galaxy. Quasars were a lot more numerous in the distant past, which leads us to believe that they are a stage of galactic evolution. This fact makes it possible to use information about quasars and their different redshifts to study the evolution of black holes and galaxies with time.

Regions of a quasar. In the center of a quasar there is a supermassive black hole. Around it is the accretion disc, where the rotating gas and dust are heated up and behave like a black body radiator, producing continuous spectra. Further out is the Broad Emission Line Region (BLR), which is named so, because the emission lines from gas orbiting at high velocities in that region are wide, due to Doppler broadening. Further out is the volume called the Narrow line region, where the low density gas orbits at lower velocities and therefore the lines are not broadened.

Objective: Using a sample of 103 quasars with redshifts $1.85 < z < 4.26$ we calculate the mass of the black hole at the center of the quasar and plot versus the redshift. We use imaging data taken at the Kitt Peak National Observatory in December 2005 and spectra downloaded from Sloan Digital Sky Survey [1]. We want to study the evolution of the black holes with time, prompting us to choose quasars along a range of redshifts. We use IRAF to process our data. [2]

Methods: Assuming the gas in the BLR is in a Keplerian orbit around the central black hole we can use the following formula:

$$M_{bh} = \frac{f \Delta v^2 R}{G} \qquad (1)$$

Where *f* is the scaling factor, *v* is the velocity of the gas, orbiting at the BLR, *R* is the radius of the BLR and *G* is the gravitational constant. This formula is the simplified version of the actual formula from the paper [3]: we are using in our calculations which is the following:

$$\log M_{BH}(C_{IV}) = \log\left\{\left[\frac{FWHM(C_{IV})}{1000\ \mathrm{km\ s^{-1}}}\right]^2 \left[\frac{\lambda L_\lambda(1350A)}{10^{44}\ \mathrm{ergs\ s^{-1}}}\right]^{0.53}\right\} + (6.66 \pm 0.01) \quad (2)$$

In this formula FWHM(CIV) stands for Full Width Half Maximum of Carbon IV line ($\lambda = 1549$ Å) and is used to calculate the velocity of the orbiting gas. It is found by fitting a Gaussian over the C_{IV} emission "line", which is not a line, because it is broadened. When we find the FWHM, we find how much the line is broadened and therefore the velocity of the orbiting gas using the following formula:

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

Here λ is the wavelength of the center of the emission line, $\Delta\lambda$ is the amount of broadening of the emission line, and *c* is the speed of light. Our speeds are well below the speed of light, so relativistic formulas are not necessary.

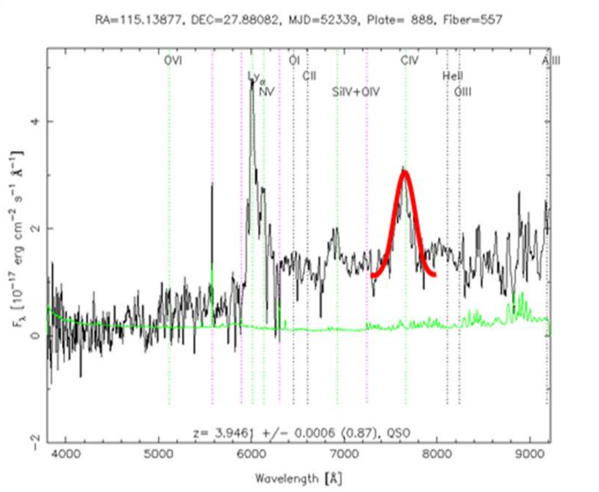

Figure 1: Spectrum of a quasar with a Gaussian fit over C_{IV} line

In order to find the radius of the BLR a technique called reverberation mapping may be used. The idea behind it is that if one observes a quasar for some period of time, he will notice that the luminosity of the quasar is not constant. The reason for that is the black hole is consuming matter at a non-constant rate. Whenever a black hole consumes some large object (a star for example), the luminosity of the accretion disc increases, so there is a change in the continuum of the spectra; after some delay, the emission lines in the BLR change as well. That delay is the amount of time it takes for electromagnetic radiation to propagate outward to the BLR. That delay, along with a speed of light can be used to calculate the radius of the BLR using the simple formula:

$$R_{BLR} = Delay \times c \qquad (4)$$

This approach is pretty accurate, though very time consuming. Kaspi et al.(2000) [4] established an empirical relationship between BLR radius and the luminosity of the continuum of the quasar. We are using similar relationship between the BLR size and luminosity at 1350 Å in the rest frame of the quasar, which can be seen in equation (2). We measure luminosity by fitting a line to the quasar continuum spectrum around 1350 Å in the rest frame of the quasar.

Results: We have a sample of 103 quasars; however we had to eliminate 15 of them due to the problems with finding the full width half maximum of the C_{IV} line. We plotted the mass of the black holes versus redshift:

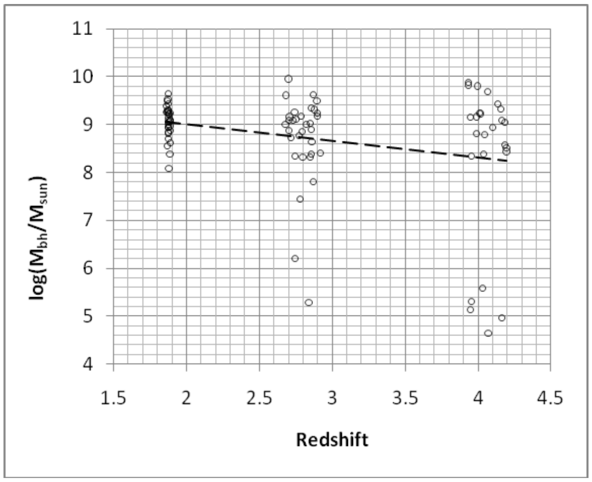

Figure 2: The plot of mass versus redshift

From the graph we can see that the black holes that power older quasars are heavier which is what we would expect, as they have consumed more material. We see that our data points are quite scattered, which we believe is due to relatively small sample size.

We split the quasars into 3 groups:

$1.861 < z < 1.890$ (age ≈ 3.3 billion ly) - 31 quasar
$2.679 < z < 2.921$ (age ≈ 2.3 billion ly) - 32 quasars
$3.934 < z < 4.194$ (age ≈ 1.5 billion ly) - 25 quasars

For those three groups we plotted the averages of mass of black holes versus the age of the quasars:

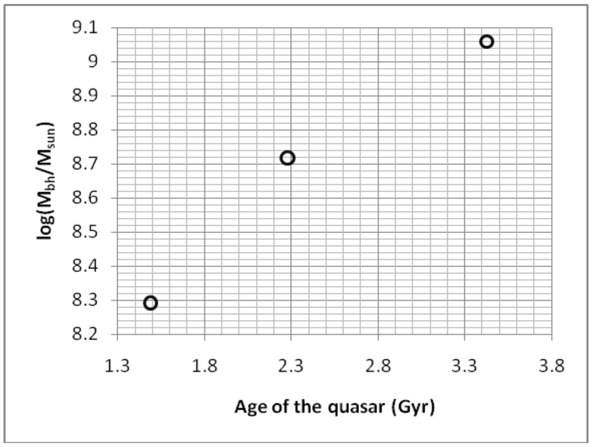

Figure 3: The plot of mass versus age of quasars

For the quasars with the redshifts below two, we repeated calculations of mass, but instead of C_{IV} line we used Mg II emission line (λ = 2799Å). We then plotted the masses calculated using both approaches:

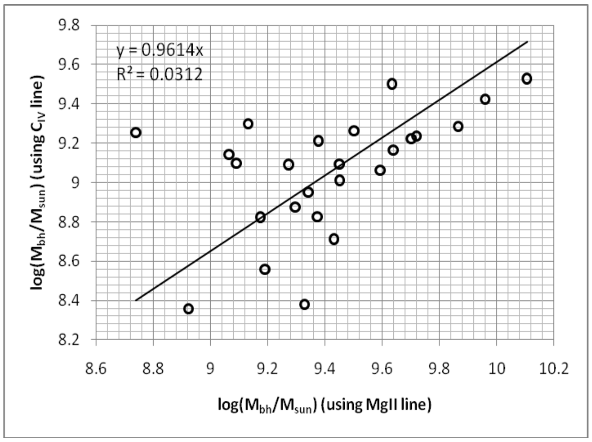

Figure 4: The plot of masses calculated using C_{IV} emission line versus the masses calculated using Mg_{II} emission line.

From this plot we can see that there is a clear correlation. Scattering of masses may be due to the uncertainties in the method.

Conclusions: Despite the small sample size there is a clear trend, showing that older black holes are heavier. In future we would like to repeat the same project using a greater sample size to see if there is a clearer trend. We would also like to look at a way to deal with self absorption at C_{IV} line.

References: **[1]** Abazajian K., Sloan Digital Sky Survey f. t., 2008 **[2]** Tody, D. "IRAF in the Nineties", A.S.P. 1993 **[3]** Vestergaard, M. “Determining Central Black Hole Masses in Distant Active Galaxies.” ApJ, 571:733-752, 2002 **[4]** Kaspi, S. “Reverberation Measurements for 17 Quasars and the Size-Mass-LuminosityRelations in AGN.” ApJ, 533, 631, 2000