Relationship between Black Hole Mass and Age

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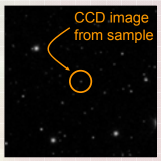
Introduction

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 (which renders them impossible to see), studying quasars allows one to see the effects of the black hole. The effects studied render information about the black hole that dwells inside. Quasar density within the universe peaks around a red shift of two to three. Therefore, the sample includes quasars between a redshift of about one to four. Looking at high redshift quasars allows for the study of the evolution of black hole mass.



Sample

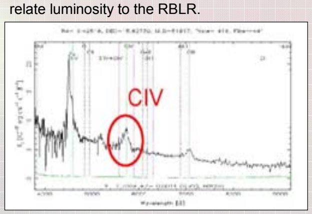
- 103 quasars
- Redshift: 1.85 < z < 4.26
- Data taken at Kitt Peak National Observatory, in December 2005

Goal: find Velocity and Radius of gases orbiting black hole, utilize Vestergaard equation to find black hole mass. Compare to Redshift.

Methods

Technique: Emission Spectroscopy

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 varying Doppler shifts.
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 BLR. However, this has only been done for about twenty nearby quasars. A more efficient method of calculating the 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.



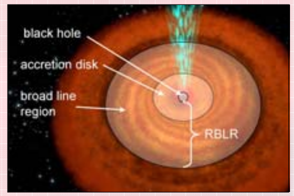
- Evaluated in IRAF, an image reduction program
- Spectra downloaded from SDSS DR7
- Look at Carbon IV (1549Å) line because it is common to all quasars in desired redshift range

Vestergaard's equation for BH mass: need velocity and luminosity

Velocity — Luminosity

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

Find Radius of the Broad Line Region (RBLR)



1. Find luminosity distance (D_L) using a particular redshift
2. Find flux (S) at certain wavelength by fitting a line to the spectrum [1350Å for CIV]
3. Use D_L and S to determine the luminosity
4. Use L to calculate the RBLR

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

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

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

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

where
z = redshift
ΩM = 0.3
ΩK = 0
Ωλ = 0.7
H0 = 70hkm/s×Mpc-1

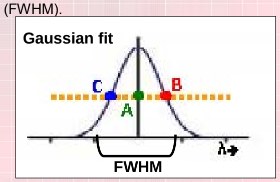
$$L = 4\pi \times D_L S$$

Find Velocity

The change in wavelength causing the broad emissions is from the varying high velocities of the orbiting material. The width of this curve at half its height is called the full width half max (FWHM).

1. Fit Gaussian curve to broad emission
2. Measure FWHM from fit
3. Use formula to calculate the velocity of the orbiting gas

$$\upsilon = \frac{FWHM}{\lambda} c$$

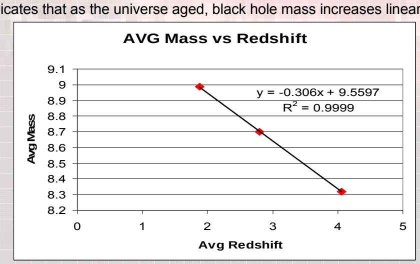


Results

The quasars were binned into three groups of redshifts and their average masses (in solar masses) were plotted.

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

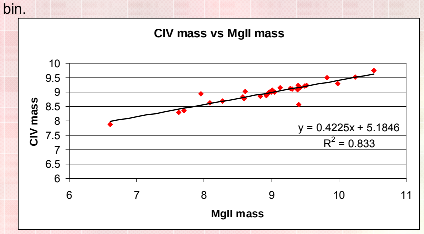
This indicates that as the universe aged, black hole mass increases linearly.



Error Analysis

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

2 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.



This figure demonstrates that the masses calculated from the CIV line are similar to those calculated from other emission lines, further validating the results.

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 complementary to modern views of galaxy formation and evolution; that of mass increase over time.

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