Evolution of Black Hole Masses in Quasars with Time

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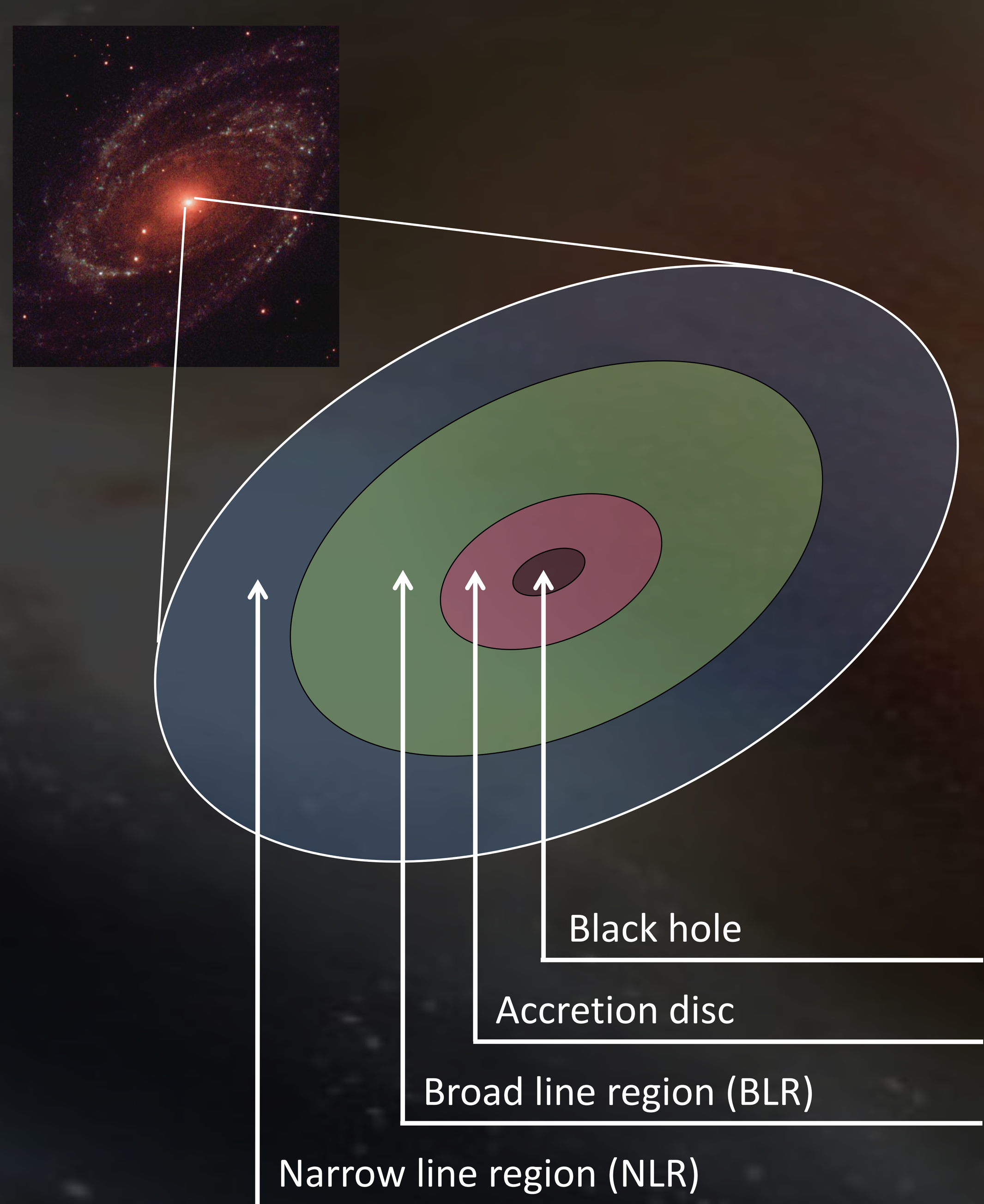
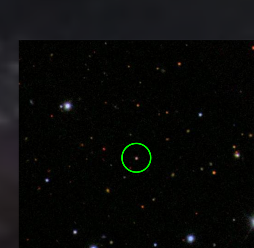
Quasars

- Discovered in early 1960s
- Extremely luminous
- Extremely distant (large redshifts)
- Complicated spectra
- Powered by a super massive black hole
- More numerous in the distant past
- Stage of galactic evolution
- Use to study evolution of black holes

Quasar regions



Our sample



- 103 quasars at redshifts $1.85 < z < 4.26$
- Imaging data from Kitt Peak National observatory
- Spectra from Sloan Digital Sky Survey, downloaded from the internet [1]
- Used IRAF to evaluate the spectra, measure the FWHM and fluxes [2]
- Used only 88 quasars, due to problems with Full Width Half Maximum of C_{IV} line

Goals

- Find the masses of the black holes in the centers of quasars, using C_{IV} emission line (1549 Å)
- Plot the masses versus redshift and age of quasars to observe the evolution of black holes
- Repeat the process using Mg_{II} emission line (1799 Å) for the quasars at low redshifts
- Compare the masses found using C_{IV} line to the masses found using Mg_{II} line

Equations

$$M_{bh} = \frac{f \Delta v^2 R}{G}$$

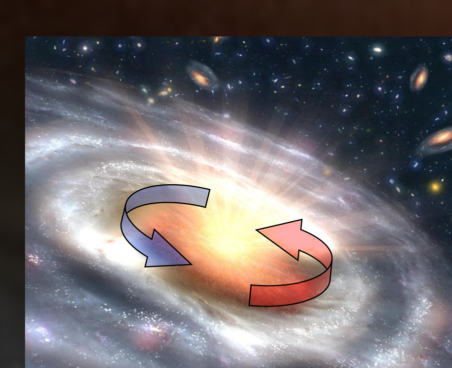
f – scale factor
R – radius of the BLR
v – velocity of orbiting gas
G – gravitational constant

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

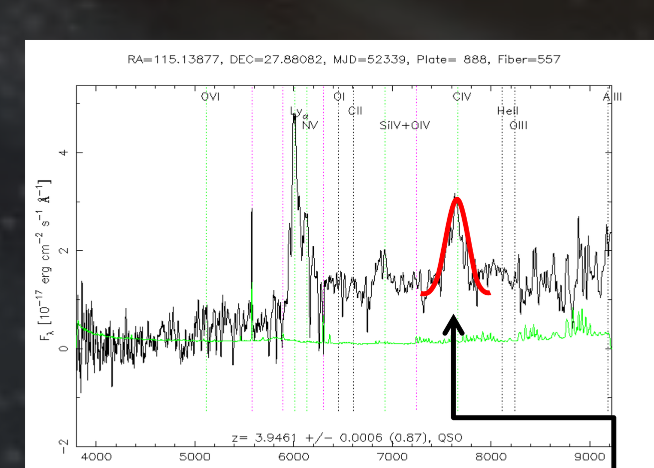
FWHM (C_{IV}) – full width at half maximum of C_{IV} line (1549 Å)
L_λ(1350 Å) – luminosity at 1350 Å

(formula is taken from Vestergaard paper [3])

Velocity of gas at BLR



Doppler shift of the spectral lines



Fit Gaussian over C_{IV} line

$$v = \frac{\Delta\lambda}{\lambda} c$$

Use formula to find velocity

Radius of the BLR

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 fact that black hole is consuming matter at a non-constant rate.

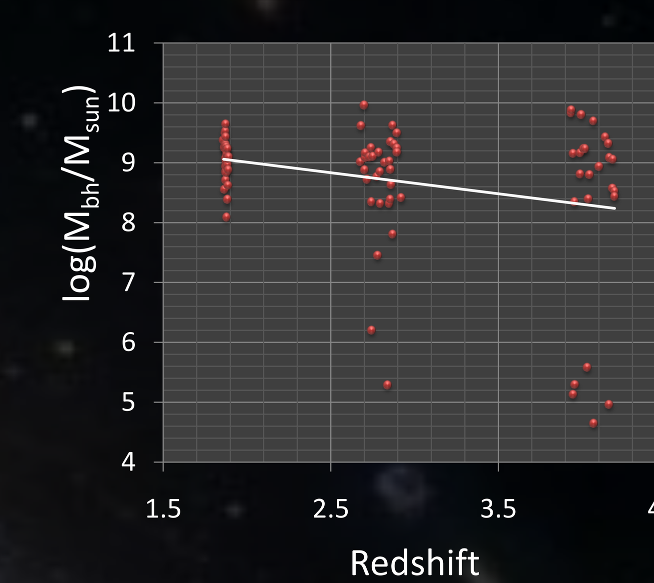
Black hole consumes a star
⇩
Change is the continuum spectra
⇩
Delay…
⇩
Change in the BLR spectra

$$R_{BLR} = Delay \times c$$

- Approach is time consuming
- R_{BLR} corresponds to the continuum spectra luminosity at 1350 Å (see the formula above).[4]

Results

We plotted the mass of the black holes versus redshift:

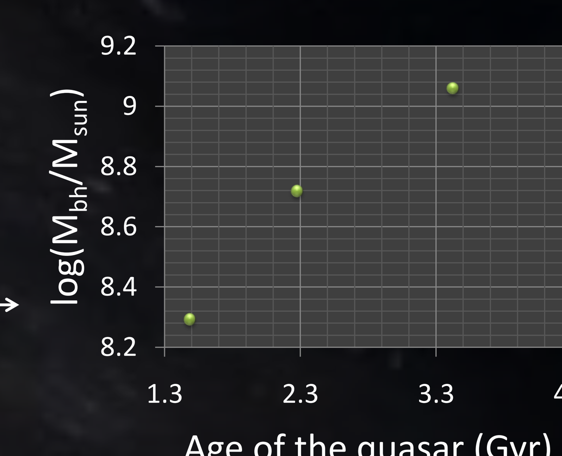


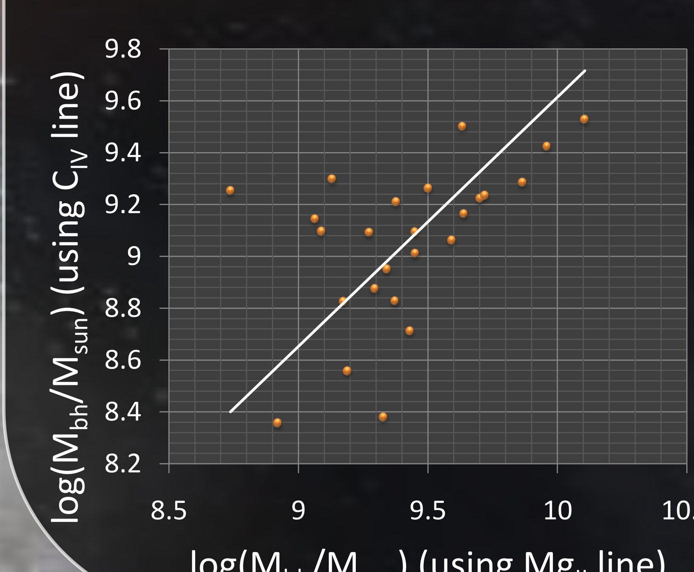
From the graph we see that the black holes are lighter at higher redshifts, which is what we would expect, as they are younger and have consumed less material.

We have separated 88 quasars into three bins:

- $1.861 < z < 1.890$ (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

The plot of black hole mass versus the age of host galaxy. We can see that older black holes are heavier.





Plot of masses found using C_{IV} line vs. masses found using Mg_{II} line. There is a clear correlation. Scattering of masses may be due to the uncertainities in the method.

Conclusions and future work

Our data points are quite scattered, which we believe is due to relatively small sample size. 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-Luminosity Relations in AGN." ApJ, 533, 631, 2000