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The Correlation between SMBH and SFR for Quasars

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Abstract

A Spectroscopic study has been focused in this article to study one of the main types of active galaxies which are quasars, and to be more precise this research focuses on studying the correlation between the main engine of Quasi-Stellar Objects (QSO), the central black hole mass (SMBH) and other physical properties (e.g. the star formation rate (SFR)). Twelve objects have been randomly selected for “The Half Million Quasars (HMQ) Catalogue” published in 2015 and the data collected from Salon Digital Sky survey (SDSS) Dr. 16. The redshift range of these galaxies were between (0.05 – 0.17). The results show a clear linear proportionality between the SMBH and the SFR, as well as direct proportional between the luminosity at V-band and the central black hole masses of the QSO. Furthermore, the calculation exhibits the ration between the SMBH and it hosts bulge approximately equal to 10^{-3}.

Key words: Galaxies – techniques: spectroscopy, Active galaxies: Quarars.

العلاقة بين الثقوب السوداء فائقة الكتلة و معدل تشكيل النجوم للكويزات

ياسر عز الدين

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الخلاصة

دراسة طيفية تم التركيز عليها في هذا البحث لدراسة احد الانواع الرئيسية للمجرات النشيطة هو الكويزات, ولكي نكون اكثر دقه, تم التركيز في هذا البحث للدراسة العلاقة بين المحرك الرئيسي للمجرات اشباه النجوم (الكويزارت) وهي التقوب السوداء المركزية ومعدل تشكيل النجوم. تم اختيار هذة المجرات بصورة عشوائية من " The Half Million Quasars (HMQ) Catalogue" والذي نشر في 2015 وتم جمع البيانات من الموقع Salon Digital Sky survey (SDSS) Dr. 16. وكان معدل الانزياح نحو الاحمر لهذة المجرات بين (0.05– 0.17). الحسابات اظهرت علاقة خطية مباشرة واضحة بين الثقوب السوداء فائقة الكتلة المركزية ومعدل تشكيل النجوم, بالاضافة الى وجود تناسب مباشر بين لمعانية عند حزمة V و الثقوب السوداء فائقة الكتلة للكويزات. اضافة الى ما ذكر سابقا, الحسابات اظهر ان معدل الثقوب السوداء فائقة الكتلة الى كتلة Bulge المستضاف فية يساوي تقريبا 10^{-3}.

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Introduction

Active galaxies evolution and its central black hole (BH) masses is an open case of discussion in both experimental observations (for example, the correlation between the supermassive black hole and the shape of galaxies) and outcome from cosmological models of the evaluation of galaxies see [**1**] and [**2**]. This kind of galaxy co-evolution can be caused by the connection between the growth of BH and the processing of star formation [**3**]. The former is usually quantified employing the star formation rate (SFR), and the last by the active galactic nucleus luminosity. Both processes are essentially fed by the cold gas contributing within the galaxy, therefore a high connection between these processes may be expected. Furthermore, a galaxy evolution models demand more interactive correlation, with the active galactic nucleus (AGN) having an organizing role over the quantity of obtainable cold gas, and consequently the galaxy SFR [**4**].

Explicitly, at some point an examination of this sort has to be studied using a huge number of samples. Due to a convenient baseline for correlation between physical properties, such an investigation cannot be undertaken directly.

The SMBH is the primary and power part of the galaxies. Such a region presents a high bound system, which will not allow any celestial bodies and electromagnetic emission to escape from it. The velocity dispersion and gas dynamic are the methods to estimate the central mass of the host galaxy, but in the case of active galaxies, reverberation mapping (RM) can be involved to determine these masses [**5**].

A previous study focused on Seyfert galaxies type-I and II to study the correlation between SFR and SMBH and the result showed a good relationship based on a statistical analysis in factor (ρ=0.609) for Seyfert type-I and (ρ=0.551) for Seyfert type-II (for more information see [**6**].

High star forming galaxies can be distinguished by the emission-line ratio of the optical spectrum. The origin of the ongoing SFR is the molecular clouds intensity, so the cloud content close to the bulge is indication for star formation activity. Many references are presented as previous efforts to study the relation, but there is no explanation about them.

In this article, the sections have been arranged as follows: section two will present data collection and reduction. Section three will present the mathematical functions used to calculate the supermassive black hole masses and the star formation rate for QSO samples employed in this paper. Section four shows the calculated outcome in addition to the discussion of the goodness coefficient correlation between the parameters. Lastly, in section five the conclusions of the relation between SMBH and SFR are presented.

2. Data Collection and Reduction

This section will give a view about the survey used in this research to collect the data, as well as the pipeline that reduces the data (e.g., subtract the stellar continuum, as well as the Fe II lines, fitting the emission and absorption lines, fitting the power, …etc).

2.1 Data Collection

This project focuses on one of the main types of active galaxies named quasars, its number is (12) sources, as shown in Tables (1 and 2). These data were assembled from various Salon Digital Sky Surveys (SDSS) [**7**] and [**8**], but listed in quasars catalogue [**9**].

2.1.1 Salon Digital Sky Survey

The SDSS is a public survey that provides free sensitive spectroscopic and photometric optical data. This survey has started scientific operation since May 2000, and covers about 10^4 square degrees of the northern sky of the earth [**10**]. In this survey, 2.5 meter wide angle optical telescope located in New Mexico, USA has been used. This telescope provides photometric images in five different bands (u, g, r, i and z), with a medium seeing of 1.5" and providing a magnitude of approximately 22.2 mag in r band. The spectroscopic data of observed objects performed via 3 arcsec fiber, calibrated within error of in order of 2 percent. The SDSS spectral covered wavelength domain between 3800 and 9200 Å, within an instrument resolution of ~ 2000.

2.2 Data Reduction

The physical parameters related to SDSS optical spectrum cannot be measured directly without going through the stages of data processing (data reduction), because of the raw spectrum that comes from quasars and contain stellar continuum, Fe[ii] emission line, as well as the power- low that domains these spectra, which should be subtract. To apply these corrections, a pipeline built via Python (released by Guo et al. and Shen et al. [**11**] and [**12**], modified and used to fit the samples in this project. This pipeline can compute the physical information, such as flux density (f_v), full width at half max (FWHM), dispersion velocity (σ), and determine the emission-lines. As clarified earlier, this code was modified to fit the QSO spectra relying on different stages as presented in Figure 1. These processes are briefed as follows:

1. Subtract the stellar-continuum.
2. Subtract the emission-lines of [Fe_{II}].
3. Fit the power-low template and settle the spectrum to the zero-level to measure the intensity of required emission lines and the FWHM.

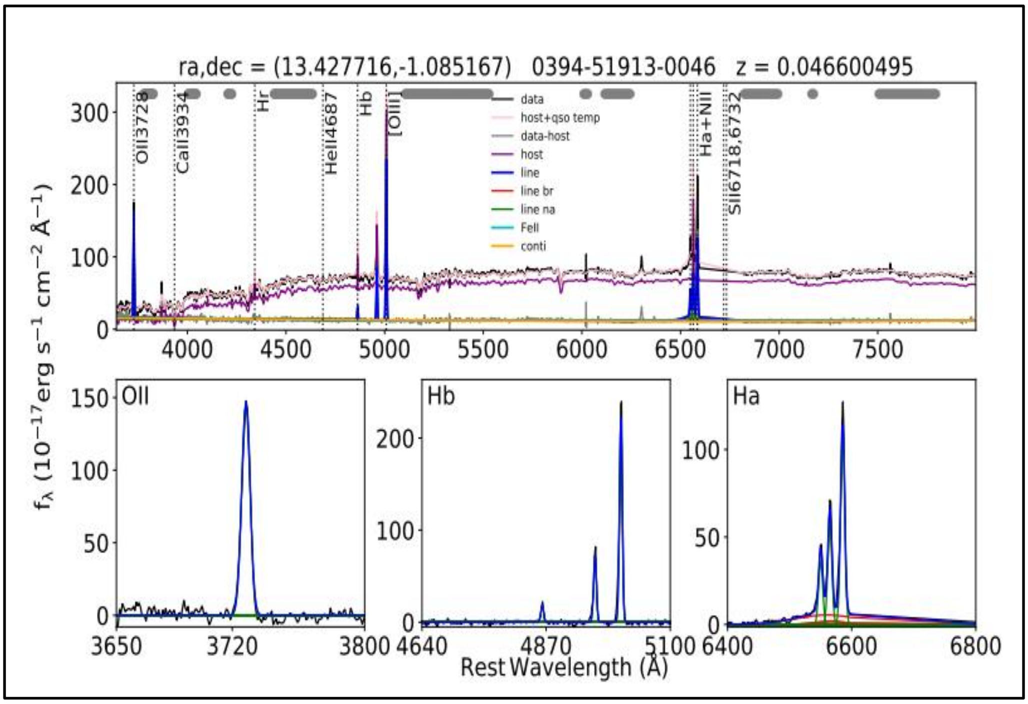

Figure 1: Spectral modeling of (name of the source) . The observed quasar is presented in a black line. Staller-continuum present in a faint brown line. The fitting profiles are shown in various colors. FeII shows in teal color.

To check more information about the photometric data reductions please see [**13**].

3. The Mathematical Model to Calculate the Central Black Holes Masses and Star Formation Rate

In this section, we will present the mathematical models used in this research to calculate the SMBH and the SFR

3.1 The Supermassive Black Hole (SMBH)

There are many proofs to indicate that most of galaxies host a supermassive black hole (SMBH) at the central part of these sources [for example see: [**14**], [**15**], [**16**]and reference therein]. This huge mass is responsible for keeping the galaxy hold together by very powerful gravitational force with a roughly mass of 10^7 M_{sun} - 10^9 M_{sun} [**17**], [**18**] and even more . In this article, in order to estimate these masses, a function that scales the correlation between the central black hole mass and the velocity dispersion of stars at the bulge of the host has been followed [**19**]:

$$\frac{M_{BH}}{M_{\odot}} = 2.1 \times 10^8 \left(\frac{\sigma^*}{200 \ {km}/{s}}\right)^{5.64} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Or

$$\frac{M_{BH}}{M_{\odot}} = 1.7 \times 10^9 \left(\frac{L_V}{10^{11} \ L_{VM_{\odot}}}\right)^{1.11} \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Or

$$\frac{M_{BH}}{M_{\odot}} = 2.9 \times 10^8 \left(\frac{M_{bulge}}{10^{11} \ M_{\odot}}\right)^{1.05} \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

$\frac{M_{BH}}{M_{\odot}}$: Represents the black hole mass at the center of galaxy with respect to the mass of the sun.

$\frac{L_V}{L_{VM_{\odot}}}$: Represents the luminosities of the quasars in V-band with respect to the luminosity of the sun in the same band.

$\frac{M_{bulge}}{M_{\odot}}$: Represents the mass of bulge with respect to the mass of the sun.

To calculate the dispersion velocity (σ*) of the gas cloud around the SMBH, a Gaussian shape has been fitted over the emission-line of [OIII] to calculate the full width half max (FWHM) [**20**]

$$\sigma^* = \frac{(\sqrt{FWHM[O_{III}]})^2 - (150)^2/2.35}{1.34} \ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

3.2 Star Formation Rate Calculation

Quasars may be distinguished by high star formation activity. Furthermore, this is a big case of discussion as the interactions between the host interstellar medium and the jet, as clarified in [**21**].

To calculate the star formation rate (SFR) of the samples that involved in this research, the luminosity of $[H_\alpha]$ λ6563A° has been used [**22**]:

$$\mathrm{SFR}_{H_\alpha}[\mathrm{M}_{\odot}\ \mathrm{yr}^{-1}] = \frac{\mathrm{L}_{H_\alpha}}{1.27 \times 10^{41} erg.S^{-1}} \ldots\ldots\ldots\ldots (5)$$

To determine the luminosity L_{H_α} has been used:

$$\mathrm{L}_{H_\alpha} = 4\pi \times \mathrm{D_L} \times \mathrm{S}_{H_\alpha}\ (\mathrm{erg.S^{-1}}) \ldots\ldots\ldots\ldots\ldots\ldots. (6)$$

Where:

D_L: Represents the luminosity distance in unit (Mpc)
S_{H_α}: Represents the flux density for H_α in unit (erg. cm^{-2}. s^{-1})
Note: to calculate the D_L for each individual galaxy, it has been combined with the cosmology constants H_0 = 70 km s^{-1} Mpc^{-1}, Ω_m = 0.3(Omega$_M$), and Ω_Λ = 0.7(Omega$_{vac}$) [**23**] [**24**], and the redshift for each source.

4. Results and Discussions:

The data in this project has focused on main group of active galaxies, which are QSO. Twelve quasars have been randomly selected to see how much the central black hole affects galaxy star formation and other physical parameters. According to Figure 2, it has been found that there is a direct relationship between SMBH and SFR. The dispersion velocity of [O_{III}] gas cloud in broad and narrow line region are directly affect by the gravitational bound of the central black hole as presented in Figure 3.

Observation suggests that there is a strong connection between the growing SMBH and the mass of the bulge as shown in Figure 5. Furthermore, the ratio between these masses is approximately equal to 10^{-3}. This outcome is matching with Shankar, Francesco et. Al [**25**] conclusions.

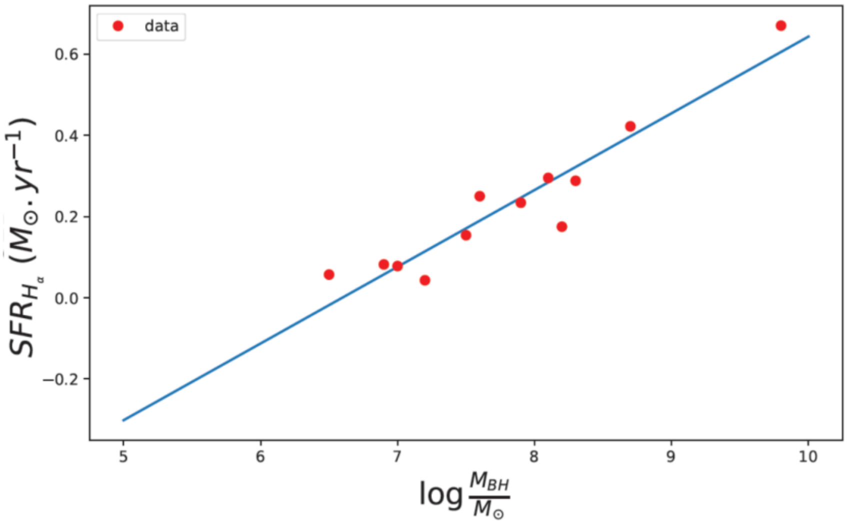

Figure 2: Represents the correlation between SMBH and $SFR_{H\alpha}$.

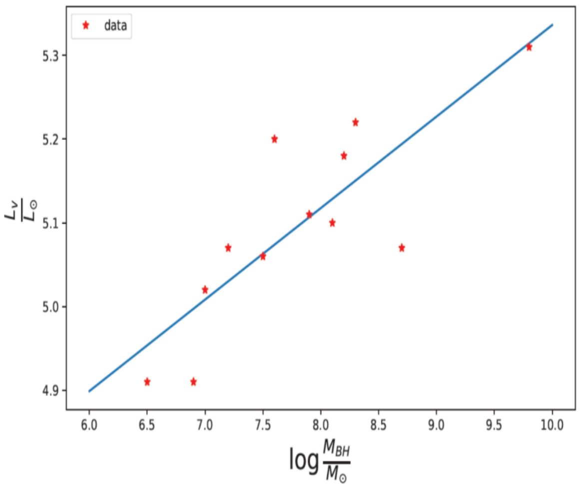

Figure 3: Shows the correlation between dispersion velocities and the central black hole masses.

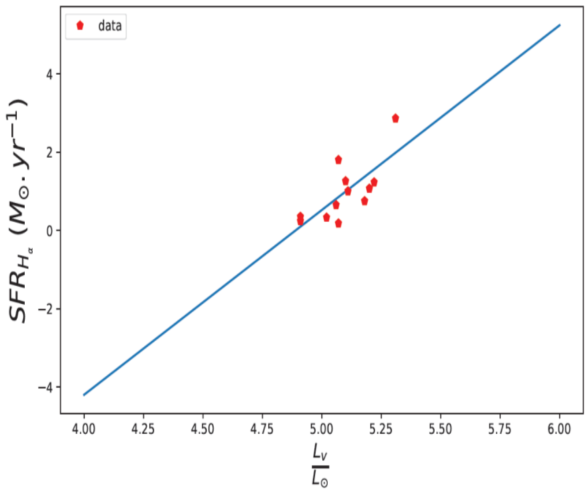

Figure 4: Exhibits the direct proportional between the luminosity at V-band and the central black hole masses of the QSO.

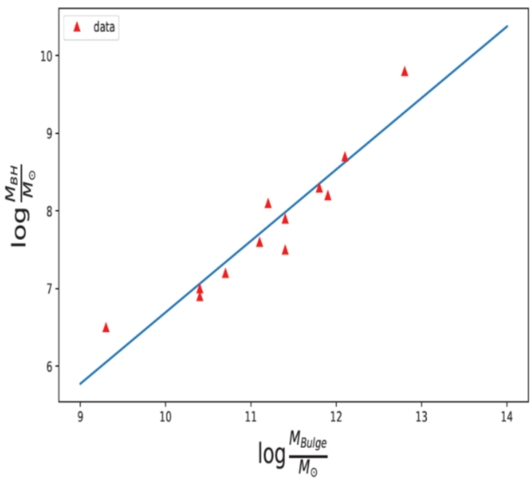

Figure 5: Shows the relation between central black hole mass and its bulge host mass.

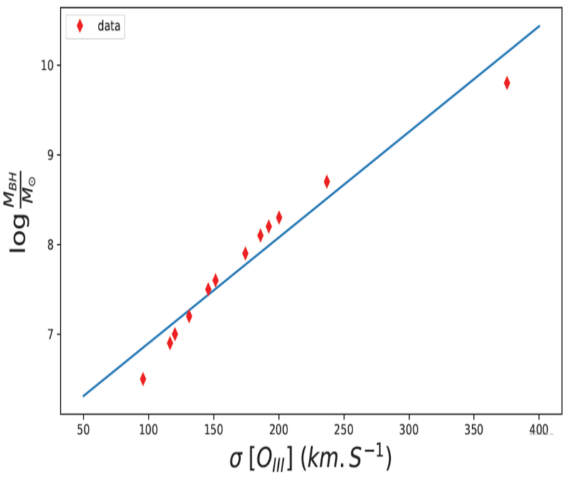

Figure 6: Presents the relation between QSO luminosities at V-band and the SFR.

Figures (4 and 6) showed interesting results, as they showed that by increasing the central mass of black holes, this will lead to an increase in the luminosity of the galaxies more than the V-band, and this in turn will lead us to conclude that high-luminosity galaxies have a higher rate of star formation than galaxies that have less luminosity [**26**].

Table 1: Shows the coordinates, observing parameters, redshifts, dispersion velocity and flux density for the quasars.

n	Name	Coordinate		z	$f_{v[OII]}$ $*10^{-17}$	$f_{v[H\alpha]}$ $*10^{-17}$	$\sigma_{[OIII]}$ [Km.s-1]	D_L Mpc
		RA (Hours)	DE (degree)					
1	SDSS J001056.25-090109.9	00:10:56.25	-09:01:09.94	0.082	117.6	1918.1	145.8	372.9
2	SDSS J000249.06+004504.8	00:02:49.06	+00:45:04.83	0.087	451.6	981.2	375.3	397.0

3	SDSS J000602.30+155930.3	00:06:02.30	+15:59:30.35	0.054	105.2	288.5	95.70	240.8
4	SDSS J000927.34+070227.7	00:09:27.34	+07:02:27.70	0.057	71.4	99.5	131.1	254.7
5	SDSS J000046.47+143813.0	00:00:46.46	+14:38:13.05	0.137	59.6	23.1	174.3	646.0
6	SDSS J000139.20+115403.4	00:01:39.20	+11:54:03.45	0.179	41.80	22.8	185.9	866.3
7	PGC 1138468	00:16:30.41	-00:38:01.67	0.064	226.0	899.1	192.3	287.4
8	PGC 1142784	00:16:55.18	-00:27:39.10	0.065	312.0	234.3	151.4	292.1
9	PGC 93294	00:43:11.60	-09:38:16.04	0.054	144.4	714.0	120.2	240.8
10	PGC 2800645	00:43:23.82	-09:51:53.51	0.050	177.5	269.2	116.4	222.3
11	PGC 1875833	00:01:39.05	+29:43:21.51	0.122	94.50	153.0	200.2	569.8
12	SDSS J084748.28+182439.9	08 47 48.28	18 24 39.9	0.085	414.8	6025.2	236.9	329.0

Table 2: Presents the physical measurements for the sample that involves in this project (absolute magnitude in V-band, star formation rate, the central black hole mass and quasars-luminosity at V-band.

n	Name	M_V [Mag]	$SFR_{H\alpha}$ $[M_\odot.yr^{-1}]$	$\log\frac{M_{BH}}{M_\odot}$	$\log\frac{M_{Bulge}}{M_\odot}$	$\frac{L_V}{L_{VM_\odot}}$
1	SDSS J001056.25-090109.9	17.80	0.154	7.5	11.0	5.06
2	SDSS J000249.06+004504.8	18.23	0.670	9.8	13.3	5.31
3	SDSS J000602.30+155930.3	16.23	0.057	6.5	9.90	4.91
4	SDSS J000927.34+070227.7	18.77	0.043	7.2	10.7	5.07
5	SDSS J000046.47+143813.0	18.65	0.234	7.9	11.4	5.11
6	SDSS J000139.20+115403.4	18.44	0.295	8.1	11.6	5.1
7	PGC 1138468	17.41	0.175	8.2	11.7	5.18
8	PGC 1142784	18.02	0.250	7.6	11.1	5.20
9	PGC 93294	15.37	0.078	7.0	10.5	5.02
10	PGC 2800645	17.96	0.082	6.9	10.4	4.91
11	PGC 1875833	17.86	0.288	8.3	11.8	5.22
12	SDSS J084748.28+182439.9	17.57	0.422	8.7	12.2	5.07

5. Conclusions:

Quasi-Stellar Objects (QSO) are the most powerful galaxies among the other types. These objects have jet “in most cases” outflow from the center, this jet is created rabidly, which will cause a collision between the atoms leading to the emission of enormous energy. These outflows are considered to be the main connection between the AGN and the other part of the galaxies. In this article, it has been shown how the SMBH strongly affects the other parts and properties.

According to the result section, the following has been concluded:

1. It has been found that the central black hole is directly affecting the H_α molecular clouds in broad and in narrow line regions, therefore by growing the SBMH the star formation increases.
2. The galaxies luminosities at V-band (L_V) are directly affected by the star formation. Additionally, this conclusion matches with the result of Weidner 2004 and the references therein [**27**].

3. By increasing the luminosities of quasars that gave an indication growing the SMBH.
4. The result exhibits that the ration between the SMBH and its host bulge approximately equal to
10^{-3}, and that means the stellar properties are strongly correlated to the central black hole. Furthermore, some of the gas cloud that created the stellar population in the region of bulge was feeding the central black hole mass.

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