Cold Quasar Investigation: Comparing Star Formation Rates to Black Hole Growth

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ABSTRACT

Cold quasars are a rare population of luminous, unobscured quasars associated with host galaxies that have a high star formation rate. We aimed to study the host galaxies of 64 of these cold quasars in order to probe how the supermassive black holes and host galaxies were co-evolving. We compiled data from the XMM-XXL survey and cross-matched with the VHS, WISE, and HerMES surveys to obtain multiwavelength photometry spanning the X-ray to the infrared and including optical spectroscopy. From the data, we calculated the supermassive black hole's mass using broad emission from the MgII and Hbeta lines. We compared this with the stellar mass of the entire galaxy and find that the black holes are significantly more massive than would be predicted by local relations, indicating that the majority of black hole growth precedes the bulk of the the stellar mass formation. In addition to this, we created a spectral energy distribution for each galaxy to calculate the star formation rate. We compared the star formation rate with the black hole accretion rate and find that the stellar mass is rapidly increasing at a relative rate faster than the black hole growth, supporting the picture where the black hole grows first.

Keywords: active galactic nuclei – galactic evolution – starburst galaxies – star formation – quasars – supermassive black holes

1. INTRODUCTION

Likely every massive galaxy hosts a supermassive black hole (SMBH) at its center. The most active period of supermassive black hole accretion and feedback is predicted by theoretical models to occur after the galaxy has formed most of its stars (Hopkins 2007; Dekel 2014; Byrne et al. 2023). In these models, star formation is triggered by major mergers of two massive gas and dust-rich galaxies, followed by sudden rapid accretion onto the supermassive black hole (Sanders & Mirabel

ble for quenching star formation ("negative feedback") through the removal of gas, if the mass loading factor is significant (Carniani et al. 2017; Chen et al. 2022; Revalski et al. 2022) On the other hand, theoretical and observational studies also show that these winds may trigger star formation ("positive feedback") by compressing molecular clouds (Ciotti & Ostriker 2007).

AGN and quasars (we define a "quasar" as an AGN with $L_X > 10^{44}$erg/s) whose host galaxies are gas-rich and still forming stars at a rapid pace are also observed

Работа имеет отношение к вопросу о влиянии AGN на SFR

- AGN: Lx > 10^{44} erg/s

- Negative feedback (выметание газа из галактики)
- Positive feedback (сжатие газового слоя, газовых облаков)

Редкая разновидность unobscured AGN: новая категория ‘’cold quasars”

ЧТО ТАКОЕ "COLD QUASARS"?

- Cold quasars are type-1 blue quasars that reside in starburst galaxies.
- They lie at $z \sim 1\text{-}3$, have $L_{IR} > 10^{12}\ L_{\odot}$, and have star formation rates (SFRs) of $\sim$200-1400 $M_{\odot}\ yr^{-1}$ - $\sim$nine times as much star formation as the main sequence of star-forming galaxies at similar redshifts

(Kirkpatrick et al., 2000)

Проблема отделения излучения яркого ядра от галактики

ПОИСКИ *''COLD QUASARS''*

- Использовался XXL catalogue (XMM-Newton),
- Cross-correlation with WISE, Hershel, VISTA surveys
- Optical counterpart: SDSS
- Всего – 293 объекта ''as cold quasar candidates'', удовлетворяющие критериям
- 1. X-ray luminosity greater than 10^{44} erg/s
- 2. Detected in all three Herschel/SPIRE bands
- 3. Absolute B-band magnitude (M_B) < -23
- Спектр моделировался (рентген-оптика- ИК). Континуум – сумма излучения ядра и звезд, плюс данные об интенсивности и полуширины эмиссионных линий.
- The code uses stellar libraries from Bruzual & Charlot (2003) and IR-dust libraries from da Cunha et al. (2008).
- Оценка масс BH - по светимости и $FWHM_{MgII}$ и $FWHM_{H\beta}$ (Kollmeier,2006)
- **После отбора надежных оценок осталось 64 галактики**

Table 1. Properties of Cold Quasar Candidates

Galaxy ID	RA (J2000)	Dec (J2000)	z	FWHM (km/s)	$M_\bullet$ ($10^8 M_\odot$)	M_* ($10^{11} M_\odot$)	SFR ($M_\odot$/yr)	BHAR 10^{44}erg/sec
N_4_19	02:27:40.9	-3:52:50.40	1.931	2922.9	(4.03 ± 1.3)	(2.03 ± 1.0)	(893 ± 364.8)	(1.70 ± 0.08)
N_9_19	02:27:32.3	-3:27:36.60	1.783	2426.4	(11.2 ± 2.8)	(15.4 ± 10)	(387.3 ± 162.9)	(3.20 ± 0.15)
N_11_7	02:24:28.8	-3:15:33.32	1.353	4915.5	(3.75 ± 2.6)	(0.59 ± 0.1)	(394.3 ± 152.3)	(0.66 ± 0.01)
N_11_22	02:24:22.2	-3:10:52.63	1.225	3093.3	(12.3 ± 9.6)	(8.00 ± 1.0)	(252.8 ± 95.5)	(2.88 ± 0.13)
N_12_35	02:25:36.5	-3:28:33.15	2.205	6744.6	(37.8 ± 11.2)	(4.55 ± 1.0)	(933.3 ± 387.6)	(1.72 ± 0.10)
N_12_40	02:25:14.5	-3:10:59.27	2.246	4359.7	(12.5 ± 1.7)	(0.62 ± 0.1)	(477.5 ± 212.0)	(1.30 ± 0.08)
N_18_41	02:22:34.7	-4:04:17.69	2.043	3921.7	(7.85 ± 5.89)	(0.86 ± 0.1)	(1326.6 ± 542.5)	(5.06 ± 0.16)
N_27_14	02:22:54.9	-4:35:8.03	1.221	13953.5	(15.3 ± 7.3)	(0.88 ± 0.1)	(187.7 ± 70.1)	(1.18 ± 0.32)
N_28_45	02:23:19.0	-4:46:14.24	1.979	10996.9	(29.3 ± 19.2)	(0.17 ± 0.1)	(163.7 ± 72.1)	(1.06 ± 0.06)
N_30_35	02:25:57.6	-4:50:05.46	2.275	6345.5	(58.1 ± 13.2)	(1.94 ± 1.0)	(382.2 ± 159.8)	(1.23 ± 0.14)
N_31_30	02:24:9.8	-4:47:18.15	1.819	6194.2	(25.4 ± 1.4)	(0.75 ± 0.1)	(922.6 ± 374.1)	(1.42 ± 0.09)
N_35_40	02:24:24.6	-5:04:14.59	2.048	11867.1	(30 ± 2.03)	(0.83 ± 0.1)	(518.8 ± 213.9)	(4.98 ± 0.23)
N_36_31	02:23:12.4	-5:06:25.09	2.205	7747.5	(37.7 ± 1.0)	(0.69 ± 0.1)	(411.0 ± 173.7)	(5.47 ± 0.37)
N_37_12	02:19:34.7	-5:06:28.04	2.293	9738.6	(43.1 ± 15.4)	(1.94 ± 1.0)	(588.3 ± 242.0)	(15.4 ± 1.3)
N_37_57	02:19:08.3	-4:55:01.41	1.843	12959.7	(45.7 ± 5.1)	(0.20 ± 0.1)	(154.1 ± 66.3)	(4.53 ± 0.17)
N_38_79	02:18:30.5	-4:56:22.9	1.397	4501.9	(26.5 ± 18.9)	(7.81 ± 1.0)	(302.2 ± 116.7)	(1.31 ± 0.08)
N_39_5	02:19:26.7	-4:45:05.17	1.467	5057.7	(56.2 ± 7.9)	(0.23 ± 0.1)	(600.0 ± 233.9)	(2.26 ± 0.06)
N_39_19	02:19:03.5	-4.:39:35.06	1.843	11151.0	(52.0 ± 18.4)	(1.45 ± 1.0)	(432.0 ± 176.6)	(1.82 ± 0.07)
N_41_24	02:16:43.7	-5:22:36.36	1.851	10073.2	(49.6 ± 2.1)	(2.36 ± 1.0)	(433.8 ± 177.4)	(1.74 ± 0.16)
N_42_6	02:18:34.5	-5:25:52.49	1.537	5372.5	(3.26 ± 1.9)	(0.39 ± 0.1)	(617.5 ± 243.5)	(2.24 ± 0.10)
N_44_59	02:26:44.2	-4:07:20.29	1.478	5953.4	(16.4 ± 4.6)	(2.36 ± 1.0)	(396.8 ± 155.3)	(2.11 ± 0.10)

The highest redshift sources usually host the most massive black holes and lie furthest away from the local relation

To reach the local relation by z = 0, the stellar mass in cold quasar candidates needs to dramatically increase. M•, on the other hand, is already on par with some of the most massive black holes in the local universe.

ЭТО ВАЖНЕЙШИЙ ВЫВОД РАБОТЫ:
НА БОЛЬШИХ Z ОТНОШЕНИЕ МАССЫ SMBH
К МАССЕ ЗВЕЗДНОГО НАСЕЛЕНИЯ ВЫШЕ

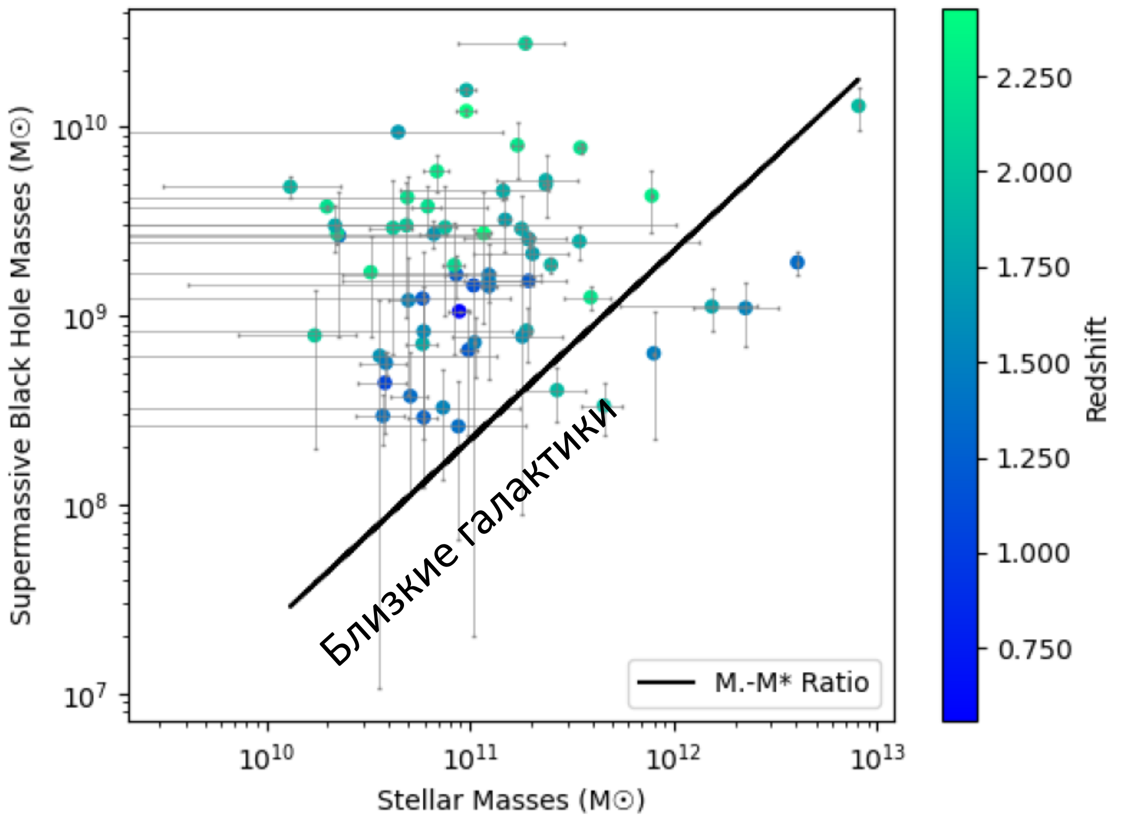

Figure 1. The comparison of supermassive black hole mass, $M_\bullet$, to stellar mass, M_*, for our final sample of 64 cold quasar candidates. Points have been shaded by redshift, corresponding to the colorbar on the right. The black linear line represents the $M_{\rm bulge} - M_\bullet$ relationship measured from local galaxies (Kormendy & Ho 2013). Nearly all of the cold quasar candidates lie above the local relation, regardless of redshift. This indicates that the stellar mass must increase more, proportionally, for the galaxies to reach the local relation by $z = 0$.

SFR

- SED for cold quasars is dominated by a power-law in the mid-infrared, but the quasar does not contribute to the heating of the dust beyond $\lambda > 50\ \mu m$, even assuming the most generous far-IR AGN heating models (Kirkpatrick 2020).
- Therefore, the 250 µm emission can be attributed to the star-forming host.
- We integrate the scaled template from 8 − 1000 µm to obtain LIR. We convert LIR to a SFR using
- $SFR\ [M_\odot/yr] = 1.59 \times 10^{-10} * LIR\ [L_\odot]$ which assumes a Kroupa IMF.

Оценки темпа роста массы

- BHAR – темп аккреции на BH, определяемый по Lx. We converted K-corrected Lx to BHAR, assuming a 10% radiative efficiency.

Корреляции не видно. В большинстве случаев относительный темп роста массы звездного населения выше, чем относительный темп роста массы ядра.

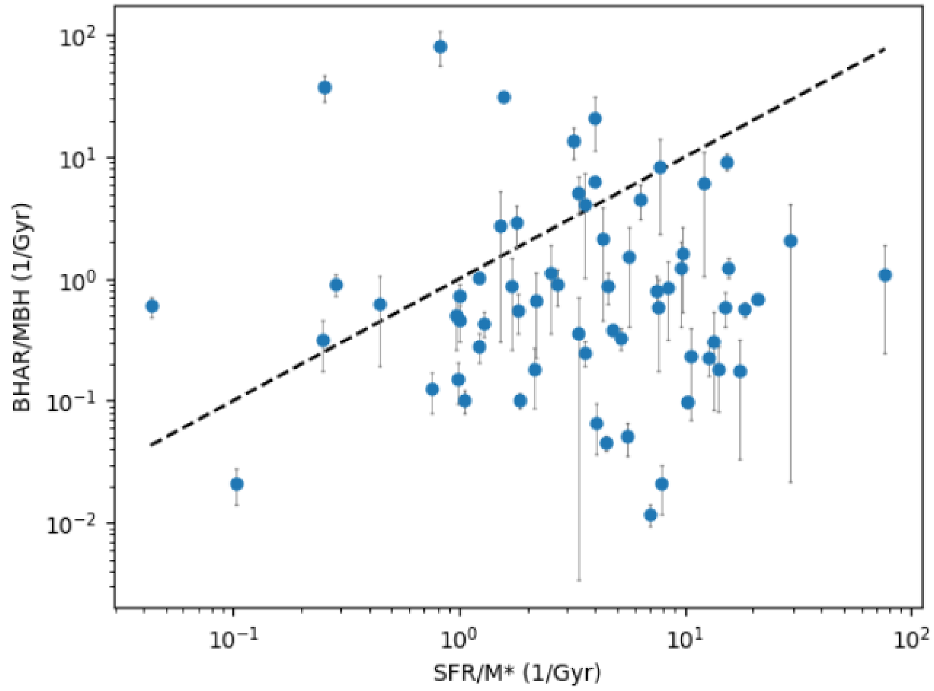

Figure 2. The comparison of normalized black hole accretion rate vs. specific star formation rate for our sample. A one-to-one correlation is plotted as the dashed line. Our cold quasar candidates are proportionally growing their stellar mass much faster than their black hole mass.

- Положение рассматриваемых галактик относительно MS, построенной Elbas et al.2011 для ((U)LIRG-галактик.
- Our cold quasar candidates primarily lie in the starburst regime, above the main sequence.

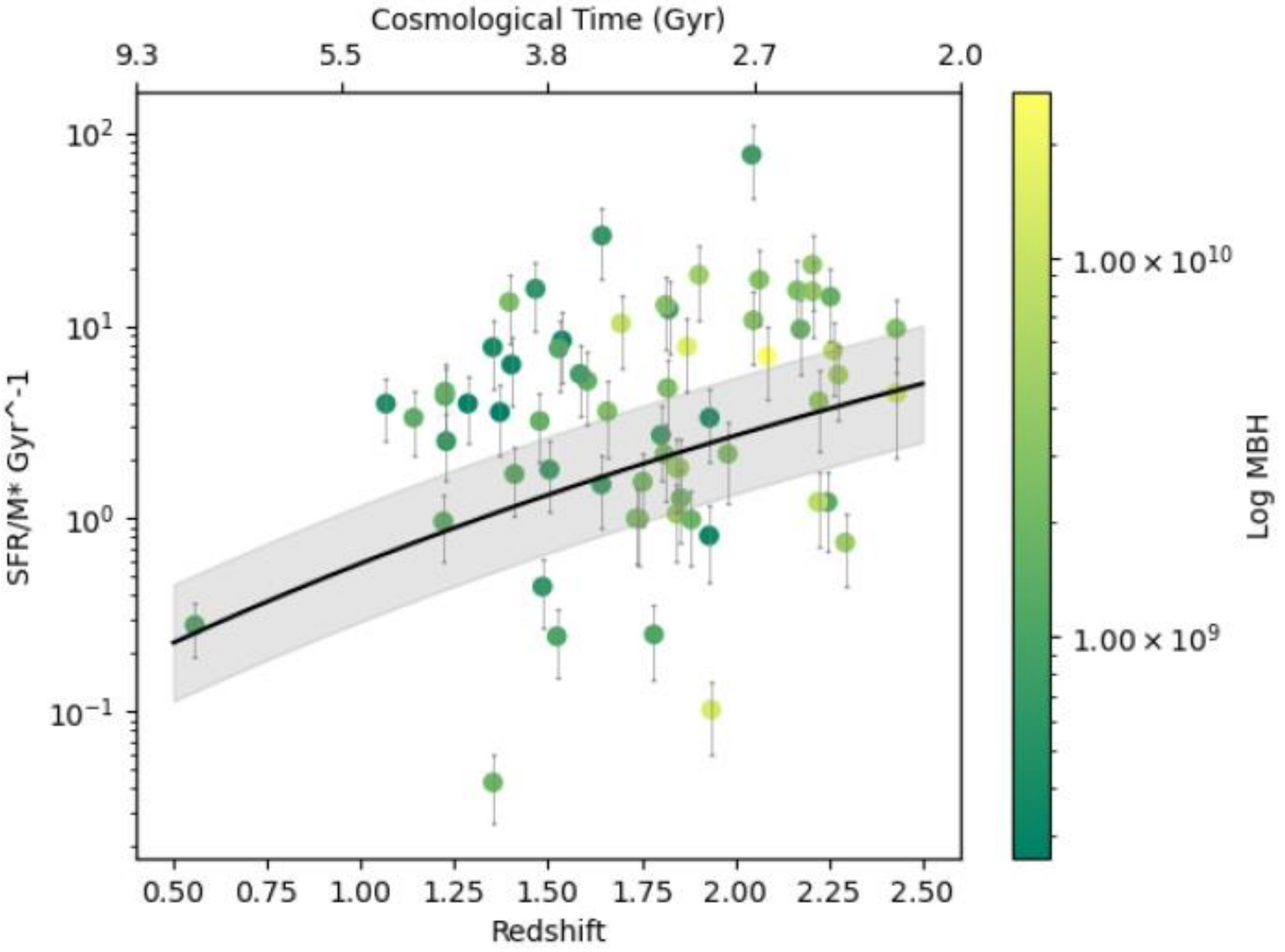

Figure 3. The location of these galaxies on the main sequence relation (black line and grey shaded region) from (Elbaz et al. 2011). Galaxies have been shaded by their black hole mass. There is a significant distribution of the galaxies above the main sequence line.

Сравнение отклонений от зависимостей для нормальных галактик

- По вертикали:

отношение SFR/M_* к ожидаемому значению для галактик на MS.

По горизонтали:

отношение M_{BH} к ожидаемому значению для локальной зависимости M_{BH}- M_*.

- **Except for a few outliers, all of our cold quasar candidates have overmassive black holes and are starbursting**.

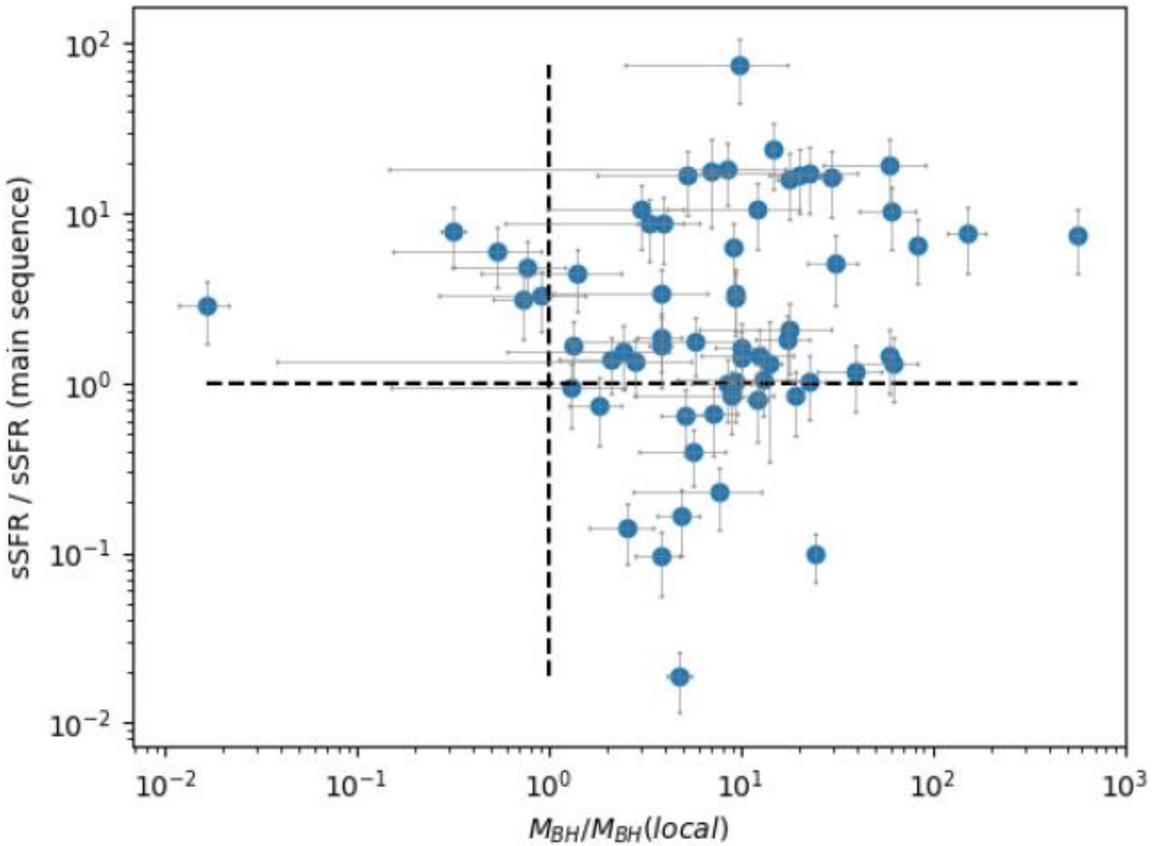

Figure 4. The distance of each galaxy's sSFR from the main sequence versus the distance of each galaxy's supermassive black hole from the local relation (Kormendy & Ho 2013). The main sequence and local relation are shown as the dashed lines. Most of our cold quasar candidates have overmassive black holes given their stellar mass, and they are starbursting, lying in the upper right quadrant. This points to a picture whereby the black hole growth precedes the bulk of the stellar growth.

Основные выводы

- 1. From Figure 1, the supermassive black holes are concluded to be extremely overmassive as compared to local relations. This signifies that the black holes have grown first in these galaxies, and are now completing their evolutionary track.
- 2. Using Figure 2, it can be seen that these galaxies’ star formation rates are growing proportionally faster than their black holes, implying that their stellar masses need to increase (in some cases double) in order to reach the local relation.
- Figure 3 portrays an interesting conclusion, showing that there are some cold quasars that are starbursting, and a few are quenching or along the main sequence.