Detection of a possible X-ray Quasi-periodic Oscillation in the Active Galactic Nucleus 1H 0707-495

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Abstract

Quasi-periodic oscillation (QPO) detected in the X-ray radiation of black hole X-ray binaries (BHXBs) is thought to originate from dynamical processes in the close vicinity of the black holes (BHs), and thus carries important physical information therein. Such a feature is extremely rare in active galactic nuclei (AGNs) with supermassive BHs. Here we report on the detection of a possible X-ray QPO signal with a period of 3800 s at a confidence level >99.9% in the narrow-line Seyfert 1 galaxy (NLS1) 1H 0707-495 in one data set in 0.2-10 keV taken with XMM-Newton. The statistical significance is higher than that of most previously reported QPOs in AGNs. The QPO is highly coherent (quality factor Q = 35) with a high rms fractional variability (~15%). A Monte Carlo technique is applied and suggests that the QPO significance level is higher than 99.9%, while an even more stringent test based on Bayesian statistics is also tried and indicates a small posterior predictive p-value of 2.5 × 10^{-3}.

Introduction

AGNs, powered by black hole (BH) accretion with BHs of 10^5 - 10^9 M☉ at the center of galaxies, are thought to be scaled-up versions of BHXBs. A compelling line of evidence for this postulation is the striking similarity in the variability of the X-ray radiation between AGNs and BHXBs. One characteristic and enigmatic feature of the variable X-rays is Quasi-Periodic Oscillation (QPO), which has been observed in the X-ray light curves of dozens of BHXBs. Also an inverse linear relation has been suggested between BH mass and the frequency of high-frequency QPO (HFQPOs). In AGNs with supermassive BHs (SMBHs), however, QPOs are rarely detected. So far, there is only one widely accepted case in which a significant QPO was unambiguously detected in the NLS1 galaxy RE J1034+396 with fQPO ~ 2.7 × 10^{-4} Hz (Gierlinski et al. 2008; see figure 1). By extending BH masses to SMBH range, Zhou et al. (2015) suggested that the fQPO ~ M_BH scaling relation is universal spanning ~6 orders of magnitude from stellar-mass BHs to SMBHs.

In this work, we report on the discovery of a significant QPO signal in one XMM-Newton observation of 1H 0707-495, a nearby (redshift 0.04), typical NLS1. We also re-examine the BH mass of 1H 0707-495 by analysing its available optical spectroscopic data, and compare the QPO with the fQPO - M_BH relation.

X-ray quasi-periodic oscillation

1H 0707-495 was observed with XMM-Newton with an exposure of ~100 ks on February 6 2008 in the full frame imaging mode (Obs ID: 0515804010). The combined PN-MOS1-MOS2 light curve is shown in Figure 2, and its power spectrum density (PSD) is shown in Figure 3. A strong peak at 2.6 × 10^{-4} Hz indicates a significant QPO signal. The quality factor (Q = \sqrt{Δν} / Δν ≥ 15) is high, and the rms fractional variability in the QPO is ~15%. A Monte Carlo technique is applied and suggests that the QPO significance level is higher than 99.9%, while an even more stringent test based on Bayesian statistics is also tried and indicates a small posterior predictive p-value of 2.5 × 10^{-3}.

Black hole mass estimation and the fQPO - M_BH relation

Using the empirical virial method based on optical spectroscopic data, the BH mass of 1H 0707-495 has been estimated in previous studies, as 2 × 10^6 M☉ from a 6df spectrum (Bian et al. 2003) and 4 × 10^6 M☉ (Done & Jin 2016) from CTO spectrum. We re-analyse both the spectra, as shown in Figure 4. The widths of the broad Hβ line are fitted to be 1022 km/s (CTO) and 1054 km/s (6df), which agree with each other within mutual errors. The BH mass is estimated using the broad Hβ line width and the luminosity at 5100 Å (L_5100 = 4.0 × 10^{43} erg/s) (Vestergaard & Peterson 2006), giving M_BH = 5.2 × 10^6 M☉ (CTO) and M_BH = 5.7 × 10^6 M☉ (6df), respectively.

Conclusion

1. A significant QPO signal with frequency 2.6 × 10^{-4} Hz is detected at a >99.9% confidence level in one NLS1 AGN 1H 0707-495.

2. We re-analyse all the available optical spectroscopic data and find M_BH = 5.2 × 10^6 M☉. The QPO follows the universal scaling relation between the (3.2 twin-peak) QPO frequency and BH mass spanning ~6 orders of magnitude in M_BH.

3. It is demonstrated that HFQPOs tend to occur in highly accreting systems, from BHXBs to AGNs.

Do HFQPOs tend to occur at the highest accretion state?

Figure 5 shows the distribution of the Eddington ratios for all the BH accretion systems with reliable QPO detections (blue). As a comparison, we overplot the Eddington ratio distribution for the AGN sample of González-Martín, & Vaughan, et al. 2012, in which QPOs were searched for but not found. Clearly the two distributions differ significantly; a two-sided Kolmogorov-Smirnov test yields a small p-value of 0.2%. This result suggests that the HFQPOs tend to occur at the highest accretion systems.

References


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