Proposal for VLA observing time: A changing-look quasar SDSS J132457.29+480241.2

Xiangyu Jin

December 11, 2018

Abstract

We propose to study the radio luminosity of a changing-look quasar SDSS J132457.29+480241.2. Changing-look quasars are known as their changes in the broad emission line features. SDSS J132457.29+480241.2 is a changing-look quasar whose Hβ broad emission line disappears. Besides, it transits into a low/hard state AGN. We ask for 20 minutes VLA observation (D-Configuration) to study its jet properties as a low/hard state AGN and test whether it locates at the fundamental plane of black hole activity.

Scientific Justification

Active galactic nuclei (AGNs) are highly accreting supermassive black holes (SMBHs) located at centers of galaxies. They can be classified according to the features in their spectra. Type 1 AGNs show both broad and narrow emission lines and Type 2 AGNs only have narrow emission lines. According to the unified model for AGNs (Antonucci, 1993; Urry & Padovani, 1995) , all the AGNs have more or less the same structures, but due to different viewing angles, face-on objects are classified as Type 1 AGNs, and edge-on objects are classified as Type 2 AGNs (see Figure 1).

It is rare to see the same source classified as different AGN types in a short timescale (∼ 10 years), but in a few systems such features have been observed. This kind of AGNs is called a changing-look (CL) AGN. The first CL quasar[1] SDSS J015957.64+003310.4 ($z = 0.312$) is reported by LaMassa et al. 2015. Ruan et al. 2016 and MacLeod et al. 2016 use Sloan Digital Sky Survey (SDSS) data and find 10 more changing-look quasars. All of CL quasars show emerging or disappearing broad emission lines.

Here we investigate one CL quasar SDSS J132457.29+480241.2 (J1324 in short). This quasar shows a broad Hβ emission line in 2003 (on MJD 52759). Its broad Hβ emission line disappears in another observation (on MJD 56805) after around 4000 days (see Figure 2), with a dimming in its optical magnitude. Its black hole mass can be estimated from the optical spectrum (Greene et al., 2010) [2] .

We can also estimate its bolometric luminosity by $8.1\lambda L_{5100}$ (Runnoe et al., 2012)). Using the bolometric luminosity, the Eddington ratio can be derived from $\lambda_{\rm Edd} = \frac{L_{\rm bol}}{L_{\rm Edd}}$, where $L_{\rm Edd} \approx$

[1] Quasars here are used to refer AGNs with high luminosity ($\gtrsim 10^{45}\,\mathrm{erg\,s^{-1}}$).

[2] $M_{\rm BH,\,H\alpha} = 9.7\times10^6[\frac{\rm FWHM\,(H\alpha)}{1000\ \rm km\,s^{-1}}]^{2.06}\times[\frac{\lambda L_{5100}}{10^{44}\ \rm erg\,s^{-1}}]^{0.519}\,M_\odot$, where FWHM (H$\alpha$) is the FWHM of H$\alpha$ emission line, λL_{5100} is the luminosity at at 5100Å.

$1.26 \times 10^{38} \left(\frac{M_{BH}}{M_\odot}\right)$ erg s^{-1}. The Eddington ratio of J1324 also drops significantly when the feature of broad emission lines changes, which means an accretion state transition may happen in this quasar. It transits into a low/hard accretion state quasar. The following points of this quasar can be tested using the VLA observation:

Radio jets

When an AGN is in the low/hard accretion state, its accretion flows tend to be hot and have low radiative efficiency (Yuan, & Narayan, 2014). A jet is expected from an AGN in the low/hard accretion state, and is capable of producing radio emission. The Eddington ratio of J1324 is around 0.05 on MJD 52759, and becomes $\lesssim 10^{-2}$ on MJD 56805, which is the typical Eddington ratio range of a low/hard state AGN. It will be worthwhile to test whether this quasar has a jet, which has been seen from other black holes in the low/hard state.

The Fundamental plane of black hole activity

For the low/hard state black holes, the jets can produce radio emission, and the thermal gas in hot accretion flows can dominate the X-ray emission (Heinz & Sunyaev, 2003). A correlation between the radio luminosity, X-ray luminosity (scaled by the black hole mass), is discovered by Corbel et al. 2003; Gallo et al. 2003; Merloni et al. 2003 and named as the fundamental plane of black hole activity (see Figure 3). The best-fit relation is (Merloni et al., 2003):

$$\log L_{\mathrm{R}} = 0.60 \log L_{\mathrm{X}} + 0.78 \log M + 7.33 \tag{1}$$

where L_{R} is 5 GHz luminosity, in unit of erg s^{-1}, L_{X} is 2–10 keV luminosity, in unit of erg s^{-1}, and M is the measured black hole mass in unit of $M_\odot$. We derived the 2–10 keV luminosity ($\sim 7.2 \times 10^{43}$ erg s^{-1}) of J1324 from a Chandra observation on September 24, 2018. Its black hole mass $\sim 3.2 \times 10^{8}\, M_\odot$ is from Shen et al. 2011. Using the radio luminosity from VLA can help us study whether this quasar is located at the fundamental plane of black hole activity.

Technological Justification

The Karl G. Jansky Very Large Array (VLA) is a radio telescope located in New Mexico. It contains 28 antennas (including 1 spare antenna)[3], and the diameter of each antenna is 25m. Since VLA's high sensitivity, it will be an ideal tool to study the radio properties of this quasar.

Since the low/hard state black holes' radio spectra usually show a spectral index ~ 0 (Fender, 2001), which means their radio spectra are very flat. Therefore, we decide to observe J1324 at 5 GHz to test whether it has radio jet and whether it follows the fundamental plane of black hole activity.

The jet structure can evolve as the jet propagates from the central region of the AGN's host galaxy (Boccardi et al., 2017). Inside 10^5 R$_\mathrm{s}$ (~ 3 kpc for J1324), where R$_\mathrm{s}$ is the Schwarzschild radius, the jet is highly collimated. Radio lobes are generally formed at distances $\geq 10^9$ R$_\mathrm{s}$ (~ 30 kpc for J1324). For J1324, as it just transited into a low/hard state AGN, its jet is expected to be just launched (≤ 15 years) and radio structure will not be very large. At 1400 Mpc (J1324's luminosity distance[4]), even using VLA's best angular resolution[5], parsec and sub-parsec structures can not be resolved. In this way, we will view the J1324 (angular size $\sim 10''$) as a relative "point-like" source

[3]From the VLA website (https://public.nrao.edu/telescopes/vla/)

[4]J1324's redshift $z = 0.272$. The calculation of the luminosity distance (see http://www.astro.ucla.edu/ wright/-CosmoCalc.html) assumes $H_0 = 69.6$, $\Omega_M = 0.286$, and $\Omega_\Lambda = 0.714$.

[5]At 5 GHz, using the longest baseline of A-Configuration ($B_{\max} \sim 36$ km), VLA has angular resolution $\sim 0.35''$.

and study its overall radio luminosity. Based on this intention, VLA D-Configuration is suitable in this case since it has a high surface brightness sensitivity.

At C-band center 5 GHz, the primary beam size is $8.42'$. After searching J1324's coordinates in the FIRST[6] catalog, we know that there is no source brighter than 1 mJy (3-minute integrations, with map rms ~0.138 mJy/beam) at 1.4 GHz within this field of view. In this way, there is probably no bright source contamination at 5 GHz within this region. Given that J1324 is not a radio-loud quasar and it just transited into the low/hard state, we do not expect its radio luminosity to be very high. Assumed that it is located at the fundamental plane of black hole activity, the estimated 5 GHz flux density is 1.6 mJy. We want to get a RMS noise $\sim 10\,\mu$Jy. According to the thermal noise formula on a VLA website[7]:

$$\Delta I_m = \frac{\mathrm{SEFD}}{\eta_c \sqrt{n_{\mathrm{pol}} N(N-1) t_{\mathrm{int}} \Delta\nu}} \tag{2}$$

where SEFD is the system equivalent flux density in Jy, η_c is the correlator efficiency, n_{pol} is the number of polarization products, N is the number of antennas, t_{int} is the total on-source integration time in seconds and $\Delta\nu$ is the bandwidth in Hz. In our calculation, we adopt SEFD = 300 Jy, $\eta_c = 0.93$, $n_{\mathrm{pol}} = 2$ (for images in Strokes I, Q, U, V polarizations), $N = 27$ and $\Delta\nu = 1$ GHz, which is suitable for C-band. The corresponding on-source integration time are 12.4 min, which are quite consistent with the time 14 min calculated by VLA Exposure Calculator[8]. Since there should also reserve some time for calibration, we think 20 minutes observation time is reasonable for this quasar. If it is not detected in this observation, we can still set an upper limit on its radio luminosity and jet power, which can also test whether it follows the fundamental plane of black hole activity or not. If J1324's jet is detected in the VLA observation, a follow-up mm-VLBI observation can be proposed to study the parsec structure of the jet.

References

Antonucci, R. 1993, ARA&A, 31, 473

Boccardi, B., Krichbaum, T. P., Ros, E., et al. 2017, A&ARv, 25, 4.

Corbel, S., Nowak, M. A., Fender, R. P., Tzioumis, A. K., & Markoff, S. 2003, A&A, 400, 1007

Fender, R. P. 2001, MNRAS, 322, 31

Gallo, E., Fender, R. P., & Pooley, G. G. 2003, MNRAS, 344, 60

Greene, J. E., Peng, C. Y., & Ludwig, R. R. 2010, ApJ, 709, 937

Heinz, S., & Sunyaev, R. A. 2003, MNRAS, 343, L59

LaMassa, S. M., Cales, S., Moran, E. C., et al. 2015, ApJ, 800, 144

[6]First Catalog Search: http://sundog.stsci.edu/cgi-bin/searchfirst

[7]VLA Sensitivity: https://science.nrao.edu/facilities/vla/docs/manuals/oss/performance/sensitivity

[8]VLA Exposure Calculator Website: https://obs.vla.nrao.edu/ect/

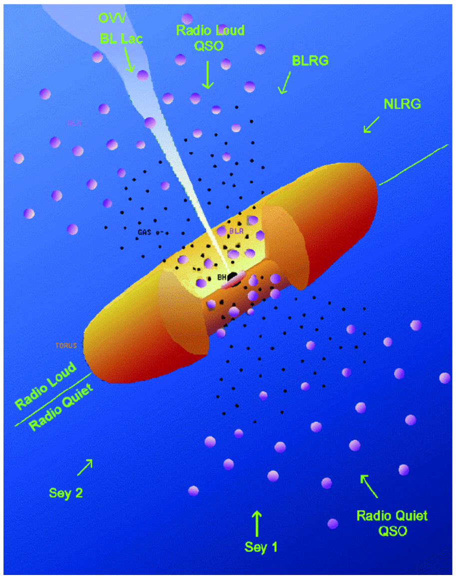

Figure 1: The standard AGN unification scheme. Credit: M. Polleta

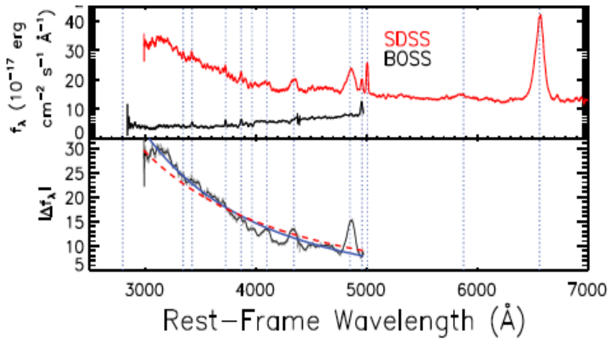

Figure 2: The optical spectrum of J1324 (MacLeod et al., 2016). The upper panel shows SDSS spectrum (on MJD 52759) in red and BOSS spectrum (on MJD 56805) in black. The flux different Δf_λ is show in the lower panel. The blue curve is the best-fitting power law $f_\nu \propto \nu^\beta$, and the red-dashed curve is a power-law with $\beta = 1/3$, which is derived from a standard thin disc model. The broad Hβ (4861 Å) emission line in the SDSS spectrum disappears in the BOSS spectrum.

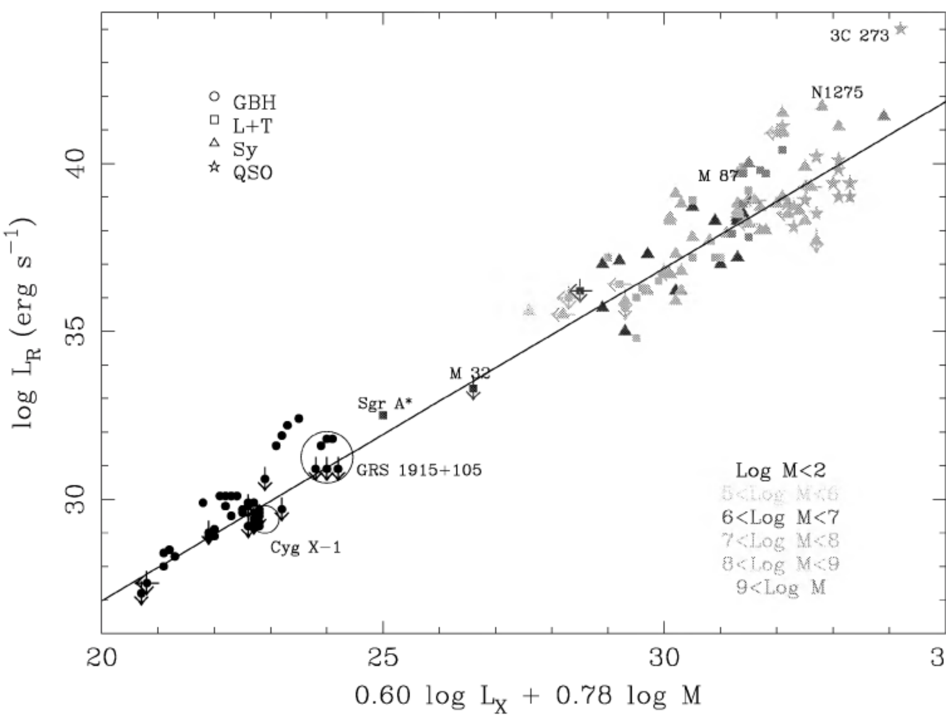

Figure 3: The fundamental plane of black hole activity (This figure is from Merloni et al. 2003). L_R is the 5 GHz luminosity, L_X is the 2–10 keV luminosity and M is the measured black hole mass. The solid line shows the equation 1.

MacLeod, C. L., Ross, N. P., Lawrence, A., et al. 2016, MNRAS, 457, 389.

Merloni, A., Heinz, S., & di Matteo, T. 2003, MNRAS, 345, 1057.

Ruan, J. J., Anderson, S. F., Cales, S. L., et al. 2016, ApJ, 826, 188

Runnoe, J. C., Brotherton, M. S., & Shang, Z. 2012, MNRAS, 422, 478

Shen, Y., Richards, G. T., Strauss, M. A., et al. 2011, ApJS, 194, 45

Urry, C. M., & Padovani, P. 1995, PASP, 107, 803

Yuan, F., & Narayan, R. 2014, ARA&A, 52, 529.