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Radio-optical scrutiny of the central engine in compact AGN

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Abstract. We combine Very-Long-Baseline Interferometry (VLBI) data for $\sim$ 100 active galactic nuclei (AGN) available from the Very Large Baseline Array (VLBA) 2 cm imaging survey and optical spectroscopy to investigate the relationships in the emission-line region–central engine–radio jet system. Here, we present the diversity of spectral types among the brightest AGN in our sample. We also discuss correlations between the mass of the central engine and properties of the parsec-scale radio jet for 24 AGN selected by the presence of Hβ broad-emission lines in their spectra.

Key words. Galaxies: active – black holes – jets

1. Introduction

It is well known that supermassive central nuclei (or 'black holes') are responsible for activity in AGN producing the bipolar relativistic jets of plasma material. We still don't know what triggers the jet activity; the 'magic' mechanism which transforms the disk energy into the kinetic energy of the jet. To understand the underlying physics it is crucial to study the black hole–jet and black hole–disk couplings, looking for correlations between physical and geometrical characteristics of the disk–black-hole–jet system.

A wealth of information about the structure and kinematics of parsec-scale jets is now available from the VLBA 2 cm survey[1] (Kellermann et al. 1998, Zensus et al. 2002) and its statistically complete subsample named the MOJAVE [2] survey. More than 200 core-dominated radio-loud AGN have been monitored at 2 cm (15 GHz) wavelength since 1994 providing the physical and detailed kinematical characteristics of compact core-jet structures (Kellermann et al. 2004). Most of them have superluminal features which implies that the jets are aligned at small angles to the line of sight. To relate the properties of parsec-scale jets to the properties of black holes and its optical environment, we combine data available from the radio and optical domains (Arshakian et al. 2004), i.e. from the VLBI monitoring and optical spectroscopy of compact AGN which is capable of providing valuable information on the properties of the central engine and

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[1] http://www.cv.nrao.edu/2cmsurvey

[2] http://www.physics.purdue.edu/astro/MOJAVE

the geometry and kinematics of parsec-scale narrow-/broad-line regions (BLRs). Here, we present some early results on inter-connections between the mass of black holes and properties of parsec-scale jets in compact AGN.

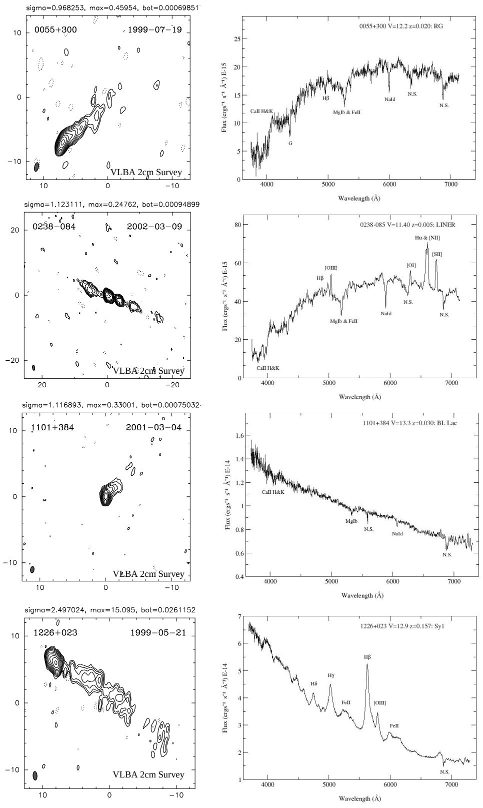

Fig. 1. The VLBI images of selected AGN (left, axes are in milliarcseconds) combined with their optical spectra. Spectral classification shows diversity of AGN types: a radio galaxy (NGC 315: 0055+300), LINER (NGC 1052: 0238−085), BL Lac (Mrk 421: 1101+384) and quasar (3C 273: 1226+023).

2. The optical sample of compact AGN

The 2 m class optical telescopes GHAO (Cananea, Sonora, Mexico) and OAN SPM (Baja California, Mexico) were used to carry out spectral observations of optically bright AGN ($m < 18$) from the VLBA 2 cm sample. So far, ∼ 70 AGN have been observed using intermediate-resolution spectroscopy (12 Å to 15 Å) with the wavelength coverage ∼3800 Å to 8000 Å. High-resolution spectra of ∼ 30 AGN were taken from the HST/SDSS archives and Marziani et al. (2003). The spectral classification of ∼ 100 radio sources showed a large diversity of AGN types: LINERs, Seyfert galaxies, BL Lacs, quasars and radio galaxies (Fig.1). The complete, detailed list of all objects in the sample will be reported in Arshakian et al. (in preparation). From this sample we selected 24 AGN having the Hβ emission line in their spectra. 21 of the 24 AGN are type 1 (seven Seyfert 1 and 14 quasars), the remaining three AGN are type 2 (two LINERS and one Seyfert 2). The 15 GHz radio luminosity of 24 AGN varies over (2×10^{24} to 2×10^{28}) W Hz^{-1} over the redshift range 0 to 0.8.

We measured the width of the Hβ broad emission lines and luminosities of continua at 5100 Å and [O III] emission lines. The broad Hβ profile were prepared for measurements by removing the narrow lines and Fe II blends. An empirical Fe II template (Véron-Cetty et al. 2001) from I Zw 1 was used. This template was broadened by convolution with Gaussian profiles of constant velocity width and scaled to fit the broad Fe II features at 4450 Å to 4700 Å and 5150 Å to 5350 Å. The subtraction of this template removes Fe II from Hβ and [O III] 5007 profiles. The [O III] λ5007 profile was used as a template to remove narrow line component of Hβ from broad profile. The redshift of [O III] λ5007 was used to determine the wavelength of narrow component of Hβ.

3. Relations between $M_{\rm BH}$ and properties of the pc-scale radio jet

The reverberation mapping technique (e.g. Kaspi et al. 2000) allows the mass of black holes to be estimated from the width of Hβ emission line and continuum luminosity at 5100Å. The black hole mass estimator works under the assumption that the motion of the

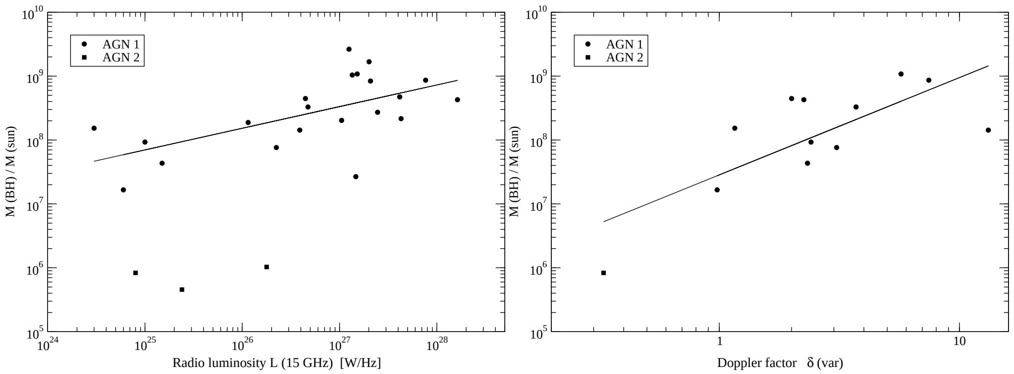

Fig. 2. The black hole mass versus radio luminosity at 15 GHz for 24 AGN (left panel), and the black hole mass versus Doppler factor (right panel) for 12 AGN with known estimates of a Doppler boosting determined from the radio flux density variability. Type 1 AGN are marked by circles, and squares denote type 2 AGN.

broad emission line region is virialised. We estimated the masses of selected 21 radio-loud flat-spectrum type 1 AGN to be in the range $M_{\rm BH} \sim (10^7$ to $3 \times 10^9)$ $M_\odot$ using the reverberation mapping technique. This method underestimates the masses of three type 2 AGN (Fig. 2, left panel) derived from narrow Hβ emission lines.

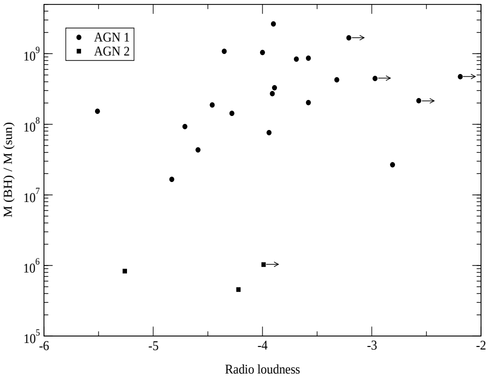

Fig. 3. The black hole mass versus radio-loudness. Designations are the same as in Fig.2

The relation between $M_{\rm BH}$ and total radio luminosity at 15 GHz, $L_{\rm 15GHz}$, is shown in Fig. 2 (left panel). The positive correlation for type 1 AGN is fitted by $L_{\rm 15GHz} \propto M_{\rm BH}^{2.9\pm0.9}$ relation. Depending on the sample of flat-spectrum quasars and the radio-loudness criterion used, the studies of the $M_{\rm BH} - L_{\rm radio}$ relation for flat-spectrum quasars produced contradictory results Jarvis & McLure (2002) The relation $L_{\rm 5GHz} \propto M_{\rm BH}^{2.5}$ is suggested by Dunlop et al. (2003) as an upper and lower envelope but separated by some five orders of magnitude in radio power. Our result, the power-law index 2.9 ± 0.9 is in agreement with 2.5 within 1σ error limit. The apparent $L_{\rm 15GHz}$ of majority compact AGN are Doppler boosted, $L_{\rm 15GHz} = \delta^k L_{\rm int}$, where δ is a Doppler factor, k is a constant and $L_{\rm 15GHz}$ is the intrinsic luminosity. To understand the positive correlation in the $M_{\rm BH}-L_{\rm 15GHz}$ plane, we test relations $M_{\rm BH}-L_{\rm int}$ and $M_{\rm BH} - \delta_{\rm var}$ for 12 AGN (Fig. 2, right panel) with known Doppler factors $\delta_{\rm var}$ available from Lähteenmäki & Valtaoja (1999). No correlation is found with intrinsic luminosity, while $M_{\rm BH} \propto \delta_{\rm var}^{1.5\pm0.4}$. More massive central nuclei produce jets having a high Doppler factor which is a function of the jet speed and jet viewing angle. The positive $M_{\rm BH} - \delta_{\rm var}$ correlation can be naturally explained if the mass of the black hole correlates positively with the speed of the jet. More data are needed to confirm this result. No clear dependence of the radio loudness (the ratio of the nuclear luminosities at 5 GHz and optical B band) on $M_{\rm BH}$ is found for type 1 AGN (e.g. Ho 2002). It is interesting to see how the black hole mass correlates with radio-loudness of AGN in our

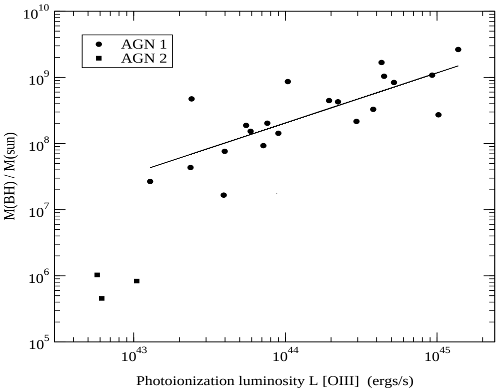

Fig. 4. The black hole mass against [O III] emission-line luminosity. The correlation is fitted with the $M_{\rm BH} \propto L_{\rm [O\,III]}^{0.76}$ relation for 21 type 1 AGN.

sample. In Fig. 3, the $M_{\rm BH}$ is plotted against radio-loudness defined as the ratio of the radio flux density at 15 GHz to the X-ray flux between (2 and 10) keV (see Terashima & Wilson 2003). Among radio-loud type 1 AGN, there is a positive trend of increasing $M_{\rm BH}$ with radio-loudness, but a larger sample is needed to confirm this correlation. No significant correlation is found between $M_{\rm BH}$ and apparent speed of the brightest component in the pc-scale jet.

Another positive correlation is found between $M_{\rm BH}$ and [O III] emission-line luminosity (Fig.4) in the form $M_{\rm BH} \propto L_{\rm [O\,III]}^{0.76\pm0.14}$ ($\rho \sim 0.7$). The $L_{\rm [O\,III]}$ is thought to be proportional to the total photoionizing luminosity, $L_{\rm tot}$, of the central engine and/or shock waves from the jet. On the other hand the $L_{\rm [O\,III]}$ is a measure of the total kinetic power of the jet (Rawlings & Saunders 1991), $Q_{\rm jet} \propto L_{\rm tot} \propto L_{\rm [O\,III]}$. It appears that the mass of the central engine in compact AGN controls both the radiating power and the jet kinetic power, $M_{\rm BH} \propto L_{\rm tot}^{0.76} \propto Q_{\rm jet}^{0.76}$. If the $M_{\rm BH} \propto L_{\rm [O\,III]}^{0.76}$ correlation will stand for a larger sample of AGN then it can be used for estimating the black hole masses directly from [O III] emission-line luminosities.

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