Radio-optical scrutiny of the central engine in compact AGN

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in collaboration with

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Introduction

The exact mechanism of energy release and its location in the AGN, the empirical relations between the central engine and the relativistic jet, and the physical processes behind these relations are still poorly understood, partly because they operate close to the BH within the central light year, at sub-milliarcsecond angles from Earth.

A combination of sub-milliarcsecond resolution very long baseline interferometry (VLBI) radio observations of the jets and optical spectroscopy of nuclear regions in the host galaxies can provide key evidence for identifying the structure and dynamics and exact radiation mechanisms operating in the innermost of the pc-scale region – the central engine of AGN.

The VLBI technique provides unparalleled resolution with which to observe the jets at sub-milliarcsecond scales, corresponding to pc-scales. Since 1994, the Very Long Baseline Array (VLBA) has conducted an extensive series of multi-epoch imaging at 15 GHz (known as **2 cm** and **MOJAVE** surveys [1,2,3]) with which one can measure kinematics, polarization and magnetic field structure of relativistic pc-scale jets.
The optical continuum and emission line characteristics of AGN provide valuable information on the properties of the central BH and dynamics of the surrounding environment, sub-pc-scale broad-emission-line region and the kpc-scale narrow-emission-line region.

Main objectives

We plan to carry out **homogeneous spectral classification** of the sample based on optical spectroscopy and on the radio structure of more thasn 250 radio-loud AGN (radio galaxies, BL Lacs and quasars). The key objectives are:

- To investigate the link between the **pc-scale radio jet** and **variability of optical continuum emission** with the aim to identify the *radiation mechanism of variable optical emission* and *its relation to the pc-scale jet* for different types of AGN.
- To model the physical conditions of the **jet-accretion disk system** and relate them to the broad-band spectra of AGN aiming to *distinguish between various models of continuum radiation from the accretion disk, jet and obscuring torus*.
- To study relations of the **jet orientation indicators** with **orientation-dependent spectral characteristics of broad-emission lines** for a large sample of radio-loud AGN, which will allow to better *constrain the geometry and kinematics of circumnuclear broad emission-line region*.
- To investigate the fundamental question of **whether the properties of the compact jets relate to the BH mass** for better *understanding of the role of BHs in the origin of radio-loudness of AGN and their cosmological evolution*.

Optical sample of compact AGN

We carried out spectral observations of ~ 80 AGN from the 2 cm and MOJAVE surveys using an intermediate resolution spectroscopy of optically bright (m < 18) AGN on the 2m class GHAO and OAN SPM (Mexico) telescopes. A wide range of emission lines, from Hb to CIV are detected. High-resolution spectra of ~ 30 AGN are taken from the HST/SDSS archives and [4]. At present, *we have spectra for more than 100 bright AGN* with redshifts up to *z* ~ 1.5 and radio luminosity at 15 GHz spanning the range from 10^{23} W Hz^{-1} to $10^{28.5}$ W Hz^{-1}.

Here, we present some results from optical spectroscopic observations of 25 AGN (21 AGN type 1 and 4 AGN type 2) with the Hβ emission line in their spectra.

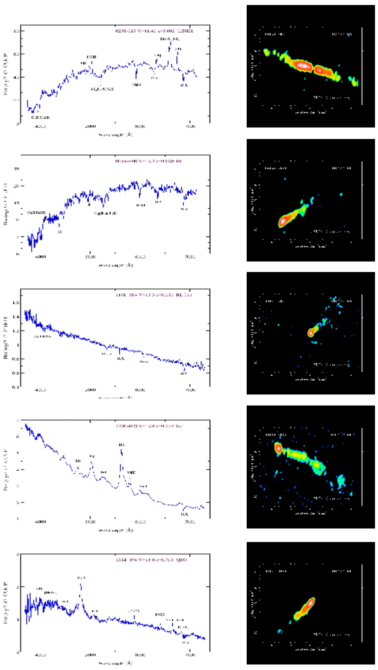

Fig. 1. Optical spectra and radio images of compact AGN.

Spectral classification

Identification of AGN from the 2 cm and MOJAVE samples using the NASA Extragalactic Database is not unique and leads to an ambiguous classification of significant percentage of AGN [5]. Therefore, we carried out a homogeneous spectral classification of 25 AGN [6, 7] which showed a large diversity of AGN types: *LINERs, radio galaxies, BL Lacs, Seyfert galaxies* and *quasars* (see Fig. 1).

Radio and optical nuclear emission

A possible method of identifying the radiation mechanism in AGN is to search for a relationship between the beamed radio synchrotron emission and the optical continuum emission for different types of AGN (Fig. 2). Optical luminosity correlates positively with both radio core and jet luminosities at pc-scales. Optical and radio fluxes are known to be strongly variable and they have not been

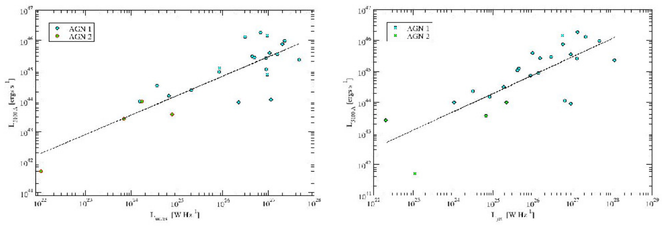

Fig. 2. Optical continuum luminosity (L_{5100A}) versus unresolved radio core luminosity (L_{unres}, left panel) and jet luminosity (L_{jet}, right panel) at 15 GHz. The optical continuum is correlated with the radio core luminosity and jet luminosity at the confidence level of 91% and 97% respectively.

observed simultaneously This indicates that the real correlations should be much stronger suggesting that *the optical continuum emission is non-thermal and originates near the jet*.

BH masses and their relation to radio-optical properties

We use the reverberation mapping technique [8, 9] to estimate the BH masses of compact AGN using the luminosity and FWHM of the Hβ emission line. For 21 AGN type 1 the estimated masses are in the range $\mathbf{M_{BH} \sim (10^7 \text{ to } 3\times10^9)\, M_{sun}}$. The relation between M_{BH} and total radio luminosity at 15 GHz, L_{15GHz}, is fitted by $\mathbf{L_{15GHz} \propto M_{BH}^{1.1\pm0.38}}$ **r**elation (Fig. 3, left panel). The apparent L_{15GHz} of majority compact AGN are Doppler boosted, $L_{15GHz} = \delta^k L_{int}$, where δ is a Doppler factor, *k* is a constant and L_{int} is the intrinsic luminosity. To understand the positive correlation in the M_{BH}-L_{15GHz} plane, we test relations M_{BH}-L_{int} and M_{BH}-δ_{var} for 11 AGN (Fig. 3, right panel) with known variable Doppler factors available from [10]. No correlation is found with intrinsic luminosity, while $\mathbf{\delta_{var} \propto M_{BH}^{0.38}}$. This 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.

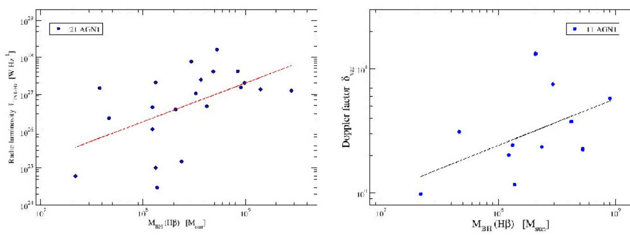

Fig. 3. Total VLBI radio luminosity (L_{15GHz}, left panel) and Doppler factor (δ_{var}, right panel) of the jet as a function of black hole mass, M_{BH}.

Another positive correlation is found between M_{BH} and [OIII] emission-line lumi-nosity (Fig.4) in the form $\mathbf{L_{[OIII]} \propto M_{BH}^{0.88\pm0.24}}$. The $L_{[OIII]}$ is thought to be proportional to the total photoionizing luminosity (L_{tot}) of the central engine and/or shock waves from the jet. On the other hand the $L_{[OIII]}$ is a measure of the total kinetic power of the jet [11], $Q_{jet} \propto L_{tot} \propto L_{[OIII]}$. It appears that the mass of the central engine in compact AGN controls both the radiating power and the jet kinetic power, $\mathbf{M_{BH} \propto L_{tot}^{1.1} \propto Q_{jet}^{1.1}}$. If the $L_{[OIII]}$-M_{BH} correlation will stand for a larger sample then it can be used for *estimating the black hole masses of radio-loud AGN directly from $L_{[OIII]}$*.

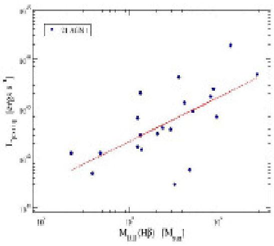

Fig. 4. [O III] emission-line luminosity against black hole mass.

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