Study of Compact Astrophysical Objects Based on Spectropolarimetric Observations with the 6-m BTA

M. Yu. Piotrovich[1], V. L. Afanasiev[2], S. D. Buliga[1], and T. M. Natsvlishvili[1]

[1] Central (Pulkovo) Astronomical Observatory, Russian Academy of Sciences, Saint Petersburg, Russia,
mpiotrovich@mail.ru,
[2] Special Astrophysical Observatory, Russian Academy of Sciences, Nizhny Arkhyz, Russia

Abstract. An overview of the main results of spectropolarimetric observations of a number of active galactic nuclei (AGNs) and white dwarfs, carried out on the BTA-6m using SCORPIO and SCORPIO-2 focal optical reducers in the spectropolarimetry mode, within the framework of the cooperative programs of the Central astronomical observatory of RAS and Special astrophysical observatory of RAS is presented. The main contribution to the theoretical scientific basis of these programs belongs to Yu. N. Gnedin.

Keywords: methods: observational; white dwarfs, active galactic nuclei, polarimetry

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1 Introduction

One of the most important areas of modern astronomy is the study of physical processes in compact astrophysical objects such as white dwarfs, neutron stars, and black holes, including supermassive black holes located in the central regions of galaxies. The key direction in the study of these objects is the polarimetric observations. It is the observation of polarized radiation of astrophysical objects that makes it possible to determine the physical mechanism of generation of their radiation, as well as to determine the magnitude and geometry of the magnetic field in these objects.

In the period from 1999 to 2019, the authors carried out observations on the BTA-6m using 23 observational programs, and 66 observational and theoretical works were published on this topic. This paper provides an overview of the most important results.

2 Spectropolarimetric Observations of Magnetic White Dwarfs

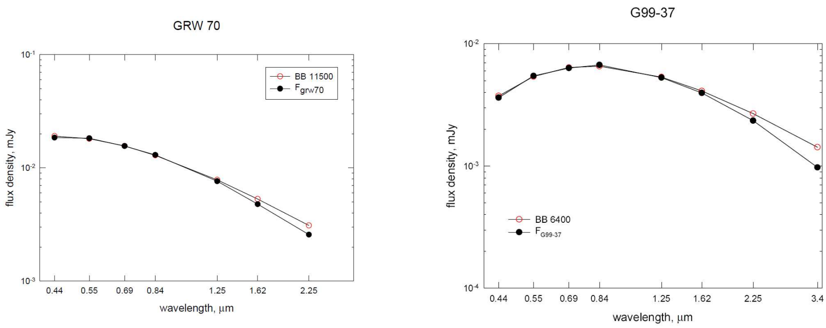

Fig. 1. Spectral energy distribution of magnetic white dwarfs GrW+70.8247 and G99-37 (black circles). The blackbody distribution is shown with open circles.

The paper by Gnedin et al. (2006) presented the results of spectropolarimetric observations of a number of magnetic white dwarfs carried out on the BTA-6m, as well as the results of photometric observations of these white dwarfs in the near infrared range, performed on the Russian telescope AZT-24, installed in Kampo Imperatore, Italy.

Two possible mechanisms were analyzed that can explain the results of spectropolarimetric observations and photometry in the infrared range (Fig. 1) of magnetic white dwarfs: vacuum polarization in a strong magnetic field and the existence of Rydberg atomic states with a large dipole moment and resulting collisions in a strong magnetic field of a white dwarf. Both mechanisms provide the observed rotation of the polarization ellipse and depression in the spectral distribution of the radiation energy of magnetic white dwarfs.

The paper by Afanas'ev et al. (2018) presents the results of spectropolarimetric observations of a number of magnetic white dwarfs (Table 1). Two characteristic dependencies of the degree of polarization on the radiation wavelength have been established. For one group of observed objects, an increase with wavelength of the degree of linear polarization of radiation was found, which can be explained by the contribution to the scattering process of the effect of orientation of the Rydberg states of atoms and molecules in the atmosphere of a white dwarf under the influence of a magnetic field. For the second group of objects, with increasing wavelength, the degree of circular polarization also increased (Fig.

Table 1. List of white dwarfs observed. m_V is the magnitude of the object , T_{exp} is the exposure time in seconds, B is magnetic field strength.

Object	m_V	Observation date	T_{exp} [s]	B [MG]
SDSS J111341.33+014641.7	19.2	21.05.2007	3300	$> 50^a$
SDSS J121209.31+013627.7	18	22.05.2007	2400	10^b
SDSS J135141.13+541947.4	16.4	23.05.2007	2400	773^b
PG 1636+351	14.9	23.05.2007	2400	$\sim 30^c$
PG 1658+441	14.6	22.05.2007	2100	2.3^d
WD 1748+708	14.5	22.06.2012	2400	$> 100^e$

(a) Schmidt et al. (2003); (b) Kepler et al. (2013); (c) our estimation; (d) Kawka et al. (2007); (e) Angel (1978);

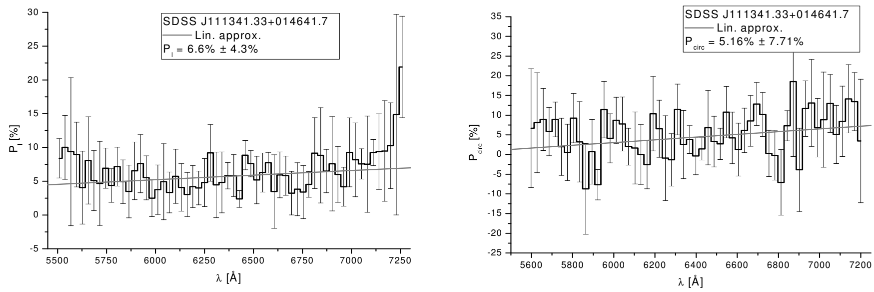

Fig. 2. Dependencies of linear and circular polarization of SDSS J111341.33+0146141.7 on wavelength.

2), which most likely indicates the presence of a protoplanetary disk around a magnetic white dwarf, in which the orientation of circumstellar dust particles leads to the observed effect.

3 Spectropolarimetric Observations of Active Galactic Nuclei

In the paper by Afanasiev et al. (2011) the results of spectropolarimetric observations of 15 active galactic nuclei are presented. The obtained dependencies of the degree of polarization on the radiation wavelength are analyzed taking into account the effect of the Faraday rotation of the polarization plane at the mean free path of a photon in a magnetized accretion disk (Fig. 3). As a result, based on traditional models of accretion disks, the magnitude and distribution of the magnetic field and a number of physical parameters of the accreting plasma in the region of optical radiation generation were determined.

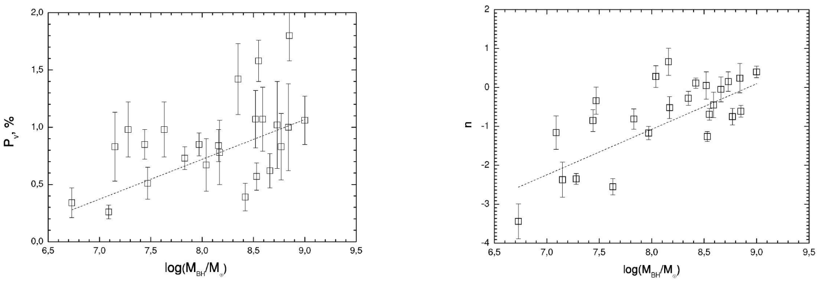

Fig. 3. Linear polarization and power-law index n versus black hole masses.

Table 2. Constraints on the magnitude of the spin of a supermassive black holes in the objects of our sample.

Object	a	B_{in}, G	B_H, G
PG 0007+106	$0.85 \leq a \leq 0.920$	$(5.4 - 9.4) \times 10^3$	$(3 - 5.9) \times 10^4$
PG 0049+171	$0.92 \leq a \leq 0.998$	$(5.3 - 9.1) \times 10^3$	$(3.4 - 6.7) \times 10^4$
PG 0157+001	$0.83 \leq a \leq 0.998$	$(3.7 - 8) \times 10^4$	$(1.2 - 5.9) \times 10^5$
PG 0026+129	$0.75 \leq a \leq 0.930$	$(1 - 1.6) \times 10^4$	$(4.5 - 9.95) \times 10^5$
PG 0804+761	$0.66 \leq a \leq 0.830$	$(0.9 - 1.2) \times 10^4$	$(3.2 - 6.2) \times 10^4$
PG 0844+349	$0.40 \leq a \leq 0.998$	$(1.3 - 3.8) \times 10^5$	$(0.39 - 1.9) \times 10^6$
PG 0953+414	$0.60 \leq a \leq 0.960$	$(0.5 - 1.65) \times 10^5$	$(1.65 - 9.7) \times 10^5$
PG 1022+519	$0.65 \leq a \leq 0.830$	$(0.8 - 1.1) \times 10^5$	$(2.9 - 6) \times 10^5$
PG 1116+215	$0.60 \leq a \leq 0.750$	$(2.8 - 3.5) \times 10^4$	$(0.84 - 1.56) \times 10^5$
PG 2112+059	$0.85 \leq a \leq 0.930$	$(1.2 - 1.45) \times 10^4$	$(6.4 - 9.3) \times 10^4$
PG 2130+099	$0.55 \leq a \leq 0.650$	$(1.7 - 1.9) \times 10^4$	$(5 - 7) \times 10^4$
PG 2209+184	$0.80 \leq a \leq 0.950$	$(4.5 - 6.4) \times 10^3$	$(2.3 - 4.2) \times 10^4$
PG 2214+139	$0.85 \leq a \leq 0.985$	$(0.9 - 1.5) \times 10^4$	$(0.5 - 1.0) \times 10^5$
PG 2233+134	$0.61 \leq a \leq 0.850$	$(5 - 8) \times 10^4$	$(1.8 - 4.2) \times 10^5$

In the paper of Gnedin et al. (2012), restrictions on the spin value a of supermassive black holes are obtained for a number of active galactic nuclei. The estimates are made on the basis of both spectropolarimetric data obtained mainly at the BTA-6m telescope and using data on the kinetic power of relativistic jets. The values of magnetic fields in the innermost stable Keplerian orbit B_{in} in the accretion disk and on the event horizon B_H of the supermassive black hole have been determined (Table 2). It is these data that make it possible to obtain strong constraints on the spins of supermassive black holes in active galactic nuclei.

Table 3. Results of our estimations.

Object	B_{max}, G	i	$P_V, \%$	PA_V, deg.	a	n
NGC 7469	1.8×10^4	85°	0.22 ± 0.08	119.8 ± 15.9	0.9	
PG 1425+267	1.2×10^3	85°	1.63 ± 0.47	78.1 ± 8.3	0.8	0.86 ± 0.27
PG 1354+213	3.4×10^3	85°	1.19 ± 0.42	110.1 ± 8.9	0.99	1.22 ± 0.33
QSO B1422+2309	1.58×10^3	77°	0.40 ± 0.12	22.4 ± 12.0	0.9	1.01 ± 0.30
PG 1704+608	1.38×10^3	82°	0.73 ± 0.02	119.7 ± 6.2	0.99	-1.16 ± 0.32

In the paper by Afanas'ev et al. (2014), based on the analysis of spectropolarimetric observations of a number of AGNs, it is shown that the measured AGN polarization and its wavelength dependence are in good agreement with the model of a standard accretion disk, taking into account the effect of Faraday depolarization at the photon mean free path. As a result, estimates were obtained for the magnetic field in the accretion disk near the innermost stable orbit and for the spin of the accreting central SMBH. Table 3 shows the estimation results. B_{max} is the magnetic field of the accretion disk corresponding to the temperature maximum, i is the inclination angle of the accretion disk, P_V is the polarization degree, PA_V is the value of the positional angle of the plane of polarization, a is the value of the spin of SMBH, n is the exponent in the power-law dependence of the linear polarization value on the radiation wavelength.

In the paper by Afanasiev et al. (2018), based on spectropolarimetry data of 47 active nuclei of type I galaxies observed with the 6-m BTA telescope, estimates of the magnitude of the spins of supermassive black holes in the center of these galaxies were obtained. The spins were determined based on the standard model of the Shakura-Sunyaev accretion disk. It was shown that about 70% of the studied AGNs have Kerr SMBHs with a dimensionless spin of more than 0.9. If one constructs a histogram (Fig. 4), one can see that the maximum number of AGN has a spin close to 1, i.e. are Kerr BHs. This is in good agreement with the results of other authors obtained for other AGNs by other methods.

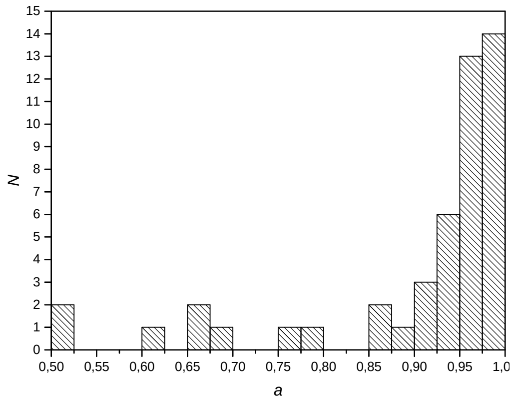

Fig. 4. Histogram showing the number of SMBHs in AGN N depending on the magnitude of its spin a.

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