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Studies of active galactic nuclei in Kazakhstan

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ABSTRACT

This article presents an overview of some works on the study of active galactic nuclei in Kazakhstan. Since the number of works carried out is large and it is not possible to review them in one article, the author limited herself to a review of the one object studies (Mrk 1095 = Ark 120) and a short description of the theoretical model of active galactic nuclei (AGN) developed at FAI.

Spectral studies of Mrk 1095 revealed the presence of three emission objects near the galactic nucleus. This made it possible to determine the orbits of these objects and to calculate the mass of the central body. In addition, from the observational data a possibility of the binary nature of the central body was established.

At the end of the past century, scientists from FAI improved the unified AGN model. The theories put forward for this purpose made it possible to explain the presence of broad absorption lines (BAL) in the spectra of active galaxies.

Key words: active galactic nuclei, emission object, binary core system, theoretical model

1 Beginning of AGN observations at Fesenkov Astrophysical Institute

Fesenkov Astrophysical Institute (FAI) is located in Almaty, Kazakhstan. The institute owns three observation bases: Kamenskoye Plateau Observatory, Assy-Turgen Observatory, and Tien Shan Astronomical Observatory (TSHAO).

Observations of Markaryan galaxies at FAI began after the publication of the first list (Markaryan, 1967) and the results of their research (Vidman, Hachikyan, 1968a, b). Then it was decided to investigate 20 galaxies in the spectra of which no emission lines were detected. As a result of observations, emission lines were still found for 14 objects (Denissyuk, 2013). All observations were carried out at AZT-8 (D = 700 mm, F_{main} = 2800 mm, $F_{Cassegrain}$ = 11000 mm) with a high-power spectrograph. In 1967–68, on the basis of the image intensifier, Denissyuk (2003) developed and assembled a spectrograph of the original design in the workshops of FAI.

Following the first result of Denissyuk (2000), the detection of emission lines was confirmed by subsequent studies with the 6-meter telescope of the Special Astrophysical Observatory (SAO, Nizhny Arkhyz, Russia). From that moment, FAI began to conduct regular observations of galaxies from the Markaryan list and publish the results in the Astronomical Circular (Denissyuk, 1971a, b, c, 1973, 1974a, b, c).

These publications prompted B.E. Markaryan to propose FAI to conduct observations of galaxies found by his method. After that, Markaryan's permanent co-author V.A. Lipovetsky and the employee of SAO V.L. Afanasyev came to Alma-Ata to conduct a joint research. Since 1980, most of the galaxies from Markaryan's list have been observed at SAO with the 6-meter telescope. Such a telescope enables to collect 72 times more light than AZT-8. In total, according to Denissyuk (2000) and Denissyuk et al. (2015), the first spectral studies of 28% of Markaryan galaxies were conducted at FAI (Figure 1).

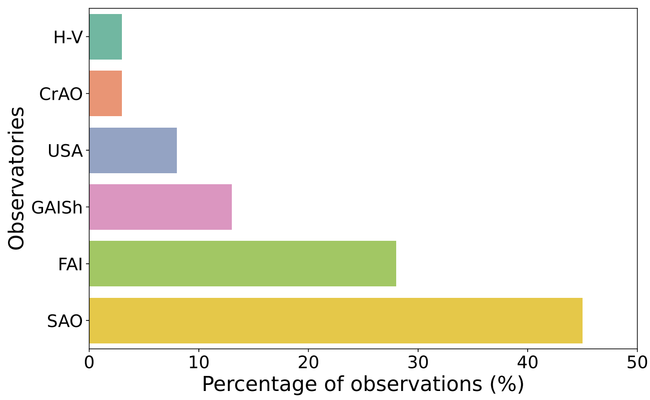

Fig. 1. Share of the first spectral studies of Markaryan galaxies in Union and foreign observatories (Denissyuk, 2000; Denissyuk et al., 2015). Here the abreviations denote: SAO – Special Astrophysical Observatory, FAI – Fesenkov Astrophysical Institute, GAISh – Sternberg Astronomical Institute, USA – United States of America, CrAO – Crimean Astrophysical Observatory, H-V – observations performed by E.E. Hachikyan and D.V. Vidman.

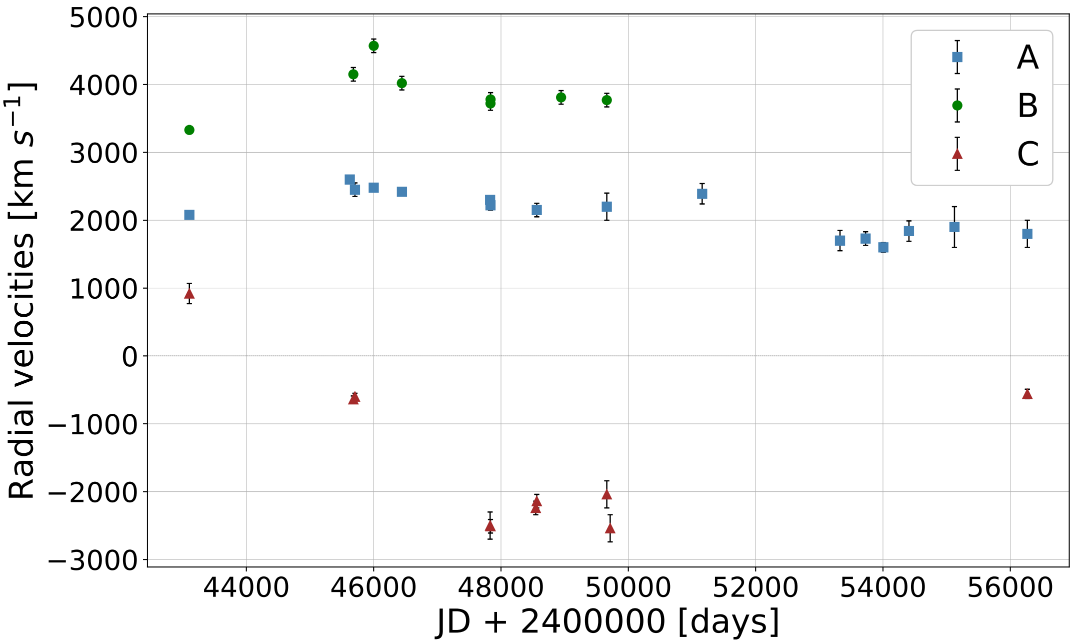

Fig. 2. The radial velocities of three emission objects in the spectrum of SG Mrk 1095: A (blue markers), B (green markers), C (red markers). The data for plotting the graph was taken from (Denissyuk et al., 2015).

For a deeper study of the variability found in the spectra of 43 galaxies more than 3500 spectrograms were obtained (Shomshekova, 2009). Part of these spectrograms were obtained with ST-7 CCD-camera, which substituted the image intensifier in 2000.

Currently, spectral observations of AGN at FAI are carried out with AZT-8 (Kamenskoye Plateau Observatory) and Zeiss-1000 (TSHAO). The receivers at the spectrograph exit are the CCD cameras SBIG ST-3200 (2184 × 1472, 6.8μ).

2 AGN study at FAI

2.1 Spectral research of Mrk 1095 (Ark 120)

Mrk 1095 = Ark 120 is a bright Seyfert galaxy of Sy1 type with equatorial coordinates $\alpha(2000) = 05^h13^m37.87^s$, $\delta(2000) = -00°12'15.12''$, and redshift $z = 0.03230$[1].

In the very first spectra of Mrk 1095, an emission detail was detected in the red wing of the H_α line. Later, two more details were detected (Denissyuk et al., 2015).

Spectral observations of Mrk 1095 have been carried out at FAI since 1976. In the course of the research, Denissyuk et al. (2015) calculated the radial velocities of emission objects, their orbits, and the mass of the central body. Since the emission details often do not have pronounced maxima, it was decided to build a smooth artificial spectrum (the spectrum of the subtracted wing) and subtract it from the real one. To construct an artificial spectrum, the blue wing of the H_α line was used, having been obtained from a high-quality multilayer spectrogram provided by B. Peterson. The red wing was obtained by reflecting the blue one. As a result of this subtraction, only the details necessary for the analysis remain.

As a result, the following velocity values were calculated:

- object A: $V_{A(init)} \approx 2000$ km s^{-1},
- object B: $V_{B(max)} \approx 3800$ km s^{-1},
- object C: $V_{C(init)} \approx 1000$ km s^{-1} $\rightarrow V_C \approx 2500$ km s^{-1}.

The velocity distribution of emission objects for the period 1976–2012 is shown in Figure 2. Orbits were calculated from the obtained radial velocities. For this purpose, a program was written that allows one to build orbits in the plane of the motion of emission objects in a recurrent way. The center of the selected coordinate system was the CB, the X-axis is the line of intersection of the orbit plane with the picture plane, the Y-axis is the direction to the observer. To determine the position of the object in the plane, the polar coordinates r and ϕ were used. The velocity was determined using the velocity modulus V and the angle γ between the velocity vector and the Y-axis, taking into account the angle ψ between the visual beam and the orbital plane. The starting point was determined using the following parameters: r, ϕ, γ, the radial velocity V_r, the initial moment of time t, the difference between the distances CB-observer and CB-object-observer expressed in units of time in terms of the speed of light τ and the mass of the CB.

To determine the position of an object in the plane, the inclination of the orbit to the visual beam is calculated:

$$\cos\psi = \frac{\tau c - r}{\tau \sin\phi}. \quad (1)$$

The absolute velocity modulus V at the initial moment t:

[1] http://simbad.u-strasbg.fr/simbad/sim-basic?Ident=ark+120&submit=SIMBAD+search

$$V = \frac{V_r}{\cos\gamma \cos\phi}. \quad (2)$$

After that, for the next time moment $t+dt$, the new coordinates of the object and the velocity vector V are recalculated. To calculate the velocity vector, it is necessary to take into account the acceleration along the radius vector:

$$a = \frac{M_{CB}G}{r^2}. \quad (3)$$

As a result, the authors concluded that objects A and C were initially removed from the center and their orbits are not closed. Therefore, it does not make sense to calculate the rotation periods or the distance to the apocenter. Nevertheless, an important result of this study is the estimate of the mass of the central body, which was a common parameter for all three objects: $M \approx (1.675 \pm 0.028) \times 10^8 M_\odot$.

According to Li et al. (2019), there is a high probability that the core of the Seyfert galaxy Mrk 1095 is a binary system. The authors collected the archival data from 1974, including an archive of FAI spectrograms. Based on all the collected data, it was revealed that the H_β line has two peaks in the galaxy's spectrum, which vary greatly in time and merge into one peak during some epochs. These changes are probably periodic. However, only two estimated periods were recorded during the entire observation period. Therefore, further observations are required to test this hypothesis.

2.2 Theoretical research of AGN

The main components of the spectra are known to be formed in the central AGN regions. However, since the sizes of these regions are small as compared to the distances to the objects, they are not resolvable by either ground-based or space telescopes. For this reason, the calculation and construction of theoretical models are extremely important for studying the physics of the central zones.

At FAI, the research on the development of models was conducted in two directions:

1. the matter outflow models in the radiation field of AGN;
2. the multicomponent evolutionary model of AGN taking into account the interaction of three components in the ~1 pc region: a stellar cluster, a gas medium, and a supermassive black hole.

Calculations in the first direction made it possible to interpret broad absorption lines (BAL) in the spectra of quasars. According to Vilkoviskij et al. (2004), the presence of such lines in the spectrum is associated with the escape of matter with velocities of an order of 600–2000 km/s in SG nuclei and 10^5 km/s in quasars. Broad absorption lines are observed in the UV part of the spectrum in ~12% of quasars and 50% of SG (Vilkoviskij, 2001).

In the 80–90s, the unified models were proposed (Antonucci R., 1993), which assumed objects of spectral types Sy1 and Sy2 as the same. The differences in the obtained data were explained by the fact that the object is observed in one case along the axis of the gas-dust "absorbing torus" (AT), in the other – near the equatorial plane of this torus. However, there was no model that would explain the presence of BAL in the spectrum.

In 1999, E.Y. Vilkovisky and his colleagues proposed a model for objects with BAL. A mathematical description of the spectra and model is given in Vilkoviskij, Karpova (1996); Vilkoviskij et al. (1996, 1999).

The advantage of this model is the certainty of the source of absorbing matter. The absorbing matter is believed to be formed from gas-dust clouds of the inner surface of the AT. In addition, the results of spectral observations of the polarization of BAL are explained. A schematic view of the AGN structure, according to the unified model, is shown in Figure 3.

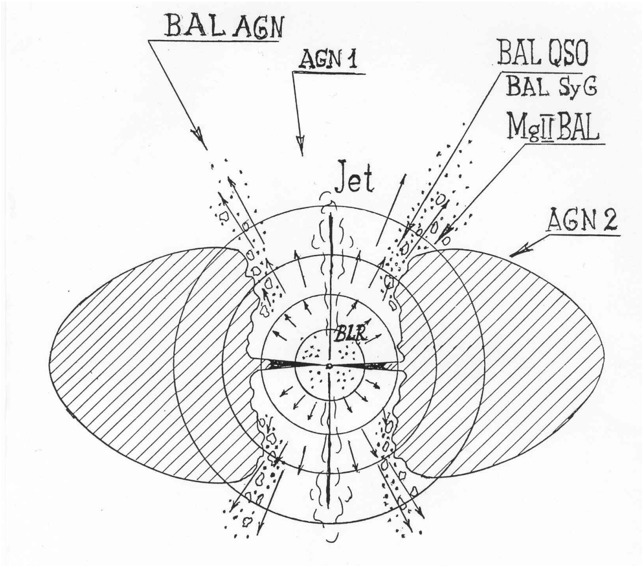

Fig. 3. Unified AGN model. The figure is adopted from Vilkoviskij et al. (2004). Here the abreviations denote: BAL AGN – active galactic nuclei with broad absorption lines, AGN 1 – active galactic nuclei of type 1, AGN 2 – active galactic nuclei of type 2, BAL QSO – quasars with broad absorption lines, BAL SyG – Seyfert galaxies with broad absorption lines, BLR – broad line region.

Figure 3 shows a black hole with an accretion disk in the center. The gas-dust absorbing torus is shown by hatching in the form of a cross-section. The directions of the hot gas flows are drawn with arrows, and the clouds are shown as dots/ellipses. The captions indicate the observed spectral types of the object, depending on the viewing angle.

This theory is based on the solution of the system of equations of radiation gas dynamics in two-phase media (cold clouds in hot gas), radiation transfer equations both in spectral lines and in the continuum, as well as photoionization balance equations. It allows us to obtain both the dynamics of the absorbing flow and the resultant absorption spectrum.

Vilkoviskij et al. (2005) assumed that three systems interact in each AGN: a massive black hole (MBH), a compact star cluster (CSC), and a gas subsystem (an accretion disk (AD), a gas-dust torus (GDT), hot gas and cold clouds). The system evolves according to the following scenario. The hot gas flows out along the polar axis of the AD and CSC and contacts the

GDT. A layer is formed at the point of contact. Inside the layer the cold clouds are captured by hot gas, thereby forming a two-phase medium. Thus, it turns out that, depending on the viewing angle, different types of AGN are observed: near the torus axis – Sy1, near the torus equator – Sy2, and at intermediate angles the outflow of matter is observed. This scheme is also valid for quasars.

According to Vilkoviskij (2001), a possible explanation of the different properties of BAL in quasars and SG in the framework of the above model is that the temperature, velocity, and mass flows of hot gas in SG are less than in quasars.

The theory explains the absorption spectra in the UV range of both quasars and SG, supporting the universal unified model of SG with BAL as an intermediate type between Sy1 and Sy2.

3 Current studies

Studies of AGN are continuing at FAI: observations and the recalculation of the recorded relative fluxes of AGN into absolute ones for the entire observation time are being carried out.

During the period from 1967 to 2000, a large library of 3527 analog frames was collected. As part of the FAI program, it is planned to digitize them for storage, further simplified access, and combining with modern data for joint long-term analysis needs. Moreover, it is planned to create a Virtual Observatory (VO), which will store both digitized frames and modern observations. All data in the VO will be systematized and stored with convenient access for everyone, including educational institutions.

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References

Antonucci R., 1993. Ann. Rev. Astron. Astrophys., vol. 31, no. 1, pp. 473–521.

Denissyuk E.K., 1971a. Astron. Tsirk., vol. 615, pp. 4–6. (In Russ.)

Denissyuk E.K., 1971b. Astron. Tsirk., vol. 621, pp. 7–8. (In Russ.)

Denissyuk E.K., 1971c. Astron. Tsirk., vol. 624, pp. 1–2. (In Russ.)

Denissyuk E.K., 1973. Astron. Tsirk., vol. 759, pp. 2–3. (In Russ.)

Denissyuk E.K., 1974a. Astron. Tsirk., vol. 809, pp. 1–2. (In Russ.)

Denissyuk E.K., 1974b. Astron. Tsirk., vol. 809, pp. 2–3. (In Russ.)

Denissyuk E.K., 1974c. Astron. Tsirk., vol. 837, pp. 2–3. (In Russ.)

Denissyuk E.K., 2003. Astron. Astrophys. Trans., vol. 22, no. 2, pp. 175–180.

Denissyuk E.K., 2000. News of the Academy of Sciences of the Republic of Kazakhstan, vol. 4, pp. 7–13. (In Russ.)

Denissyuk E.K., 2013. Astrofizicheskie issledovaniya kosmicheskikh ob'ektov, vol. 10, pp. 15–26. (In Russ.)

Denissyuk E.K., Valiullin R.R., Gaisina V.N., Kusakin A.V., Shomshekova S.A., 2015. Astrofizika v Kazakhstane. Astrofizicheskomu institutu im. V.G. Fesenkova – 65 let, pp. 275–292. (In Russ.)

Denissyuk E.K., Valiullin R.R., Gaisina V.N., 2015. Astron. Rep., vol. 59, no. 2, pp. 123–132.

Li Yan-Rong, Wang Jian-Min, Zhang Zhi-Xiang, Wang Kai, Huang Ying-Ke, et al., 2019. Astrophys. J. Suppl. Ser., vol. 241, no. 2, p. 33.

Markaryan B.E., 1967. Astrophysics, vol. 3, pp. 24–38.

Shomshekova S.A., 2009. News of the Academy of Sciences of the Republic of Kazakhstan, vol. 4, pp. 17–20. (In Russ.)

Vidman D.V., Hachikyan E.E., 1968a. Astrofizika, vol. 4, pp. 587–593. (In Russ.)

Vidman D.V., Hachikyan E.E., 1968b. Astrofizika, vol. 5, pp. 113–122. (In Russ.)

Vilkoviskij E.Y., Karpova O.G., Nosov I.V., 1996. Astrofizicheskii Zhurnal, vol. 73, pp. 341–347. (In Russ.)

Vilkoviskij E.Y., Karpova O.G., 1996. Astron. Lett., vol. 22, no. 2, pp. 148–151.

Vilkoviskij E.Y., Efimov S.N., Karpova O.G., Pavlova L.A., 1999. Mon. Not. Roy. Astron. Soc., vol. 309, no. 1, pp. 80–88.

Vilkoviskij E.Y., 2001. ASP Conference Series., vol. 247, pp. 387–390.

Vilkoviskij E.Y., Efimov S.N., Baturina E.B., 2004. News of the Academy of Sciences of the Republic of Kazakhstan, vol. 4, pp. 25–28. (In Russ.)

Vilkoviskij E.Y., Efimov S.N., Lovleis R.V., Pavlova L.A., Romanova M.M., Baturina E.B., 2005. News of the Academy of Sciences of the Republic of Kazakhstan, vol. 4, pp. 387–390. (In Russ.)