Competition sensitive! Draft of 2018.05.10–11:24

Study of the population of AGNs with optical jets at milliarcsecond scales

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Contents

1 Introduction

Analysis of VLBI and *Gaia* Data Release 1 (DR1) position differences of active galactic nuclea (AGNs) has revealed (Petrov & Kovalev, 2017a; Kovalev et al., 2017) that position offsets are not random, but have a preferable direction parallel to the jet direction at parsec scales (see Figure 1. This anisotropy in the distribution of position offsets is highly significant: the probability to have it by chance is below 10^{-11}. At the same time, as it is shown in Figure 2, the VLBI/*Gaia* position offset directions and jet position directions with respect to a direction fixed in the celestial sphere, for instance, the celestial northern pole, do not show any anisotropy.

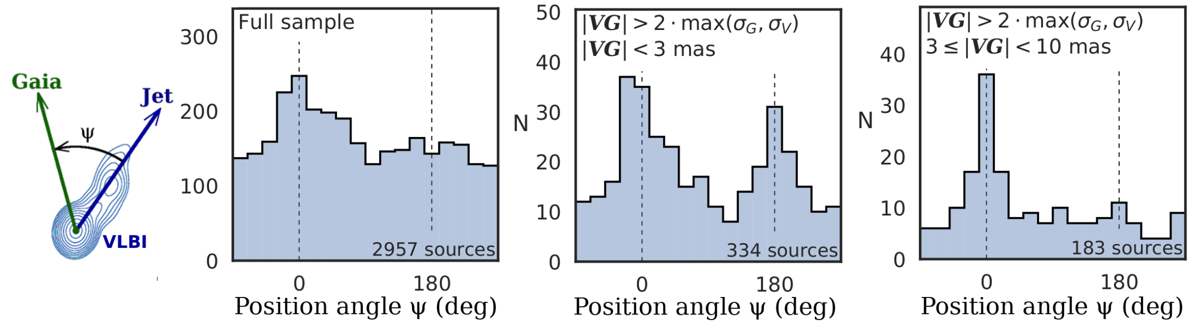

Figure 1: The distribution of VLBI/Gaia DR1 position offsets with respect to the jet direction at parsec scales determined with VLBI. *Left:* full sample. *Center:* subsample of the sources with offsets statistically significant at 95% level that are shorter 3 mas. *Center:* subsample of the sources with offsets statistically significant at 95% level that are in a range of 3–10 mas.

The distribution in Figure 1 is produced by subtraction of the quantities which distributions are shown in Figure 2. In the absence of a signal, the difference of two uniformly distributed variable will remain uniformly distributed. This implies that the anisotropy in the distribution is caused by the internal properties of the AGNs, and it is not an artifact of VLBI or *Gaia* techniques.

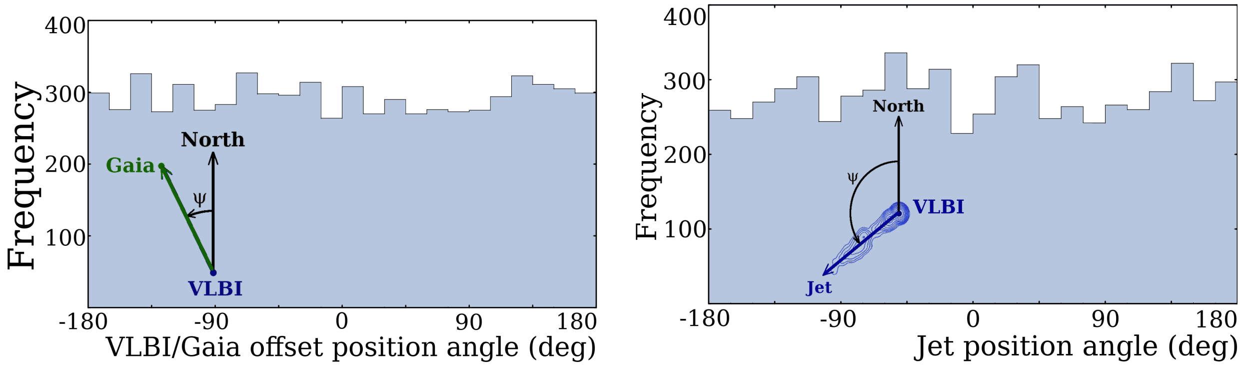

Figure 2: *Left:* the distribution of VLBI/Gaia position offsets with respect to the north direction. *Right:* the distribution of AGN jet directions measured with VLBI with respect to the north direction.

The suggested explanation is the presence of optic jets at scales 1–100 mas, i.e. within the point spread function (PSF) of *Gaia*, since as a detailed analysis given in Petrov & Kovalev (2017b) has shown, other possible *systematic* effects, namely the core-shift and the contribution of source structure on VLBI positions, are more than one order of magnitude too small to explain the phenomenon. The presence of observed VLBI/*Gaia* offsets does not automatically mean that optical and radio emission is generated in different regions. Even in the case if radio and optical emission is co-spatial, i.e. location of the core and the jet in radio and optical ranges coincide, position estimates from VLBI and *Gaia* may be different because a response on an extended source of a power detector used by *Gaia* and an interferometer that records voltages is fundamentally different. When the source structure is confined within the PSF, the position determined by a power detector corresponds to the position of an image centroid, while position determined by an interferometer is very close to the position of the most compact image component.

> Therefore, VLBI/*Gaia* position difference is an offset of an optical image centroid with respect to the position of a radio core associated with the jet origin.

Optical and X-ray jets at AGNs are not uncommon. They are known at about 20 sources and studied in detail in (**refs**). Known optical jets at scales 0.2–20 arcsec are co-spatial with radio jets. In order to explain histogram 1, we suggest that known optical jets are the tail of the distribution, and at scales 1–200 mas the optical jets are ubiquitous. Figure 3 presents the simplified diagram. The green ellipse shows the position of the radio core — the area of the optically thick jet. The radio core is assumed to be displaced with respect to the accretion disk toward jet direction. In general, the radio core is displaced with respect to the optical core along the jet, but multifrequency VLBI observations allows to evaluate the magnitude of this shift (**refs**) and relate position of the radio core to position of the the optical core. The optically thin jet is shown with blue color. The optical position measured by *Gaia* denoted by a cross, is the centroid of the three-component image: accretion disk, core, and the jet. It depends on fluxes and relative distances of the components. We introduce two fundamental observables O_j and O_t — projection of the *Gaia* position with respect to the VLBI position into the parsec-scale jet direction determined from VLBI images.

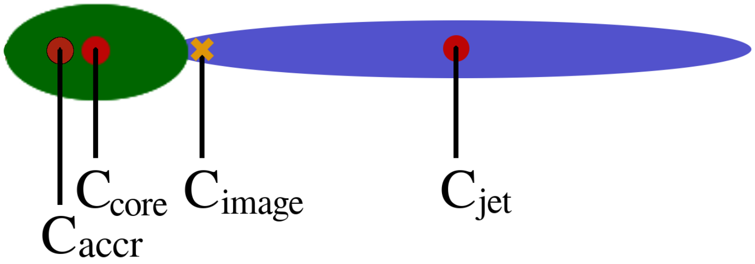

Figure 3: The diagram of the core-jet morphology. Red circles are centroids of the accretion disk, core, and optically thin jet. The image centroid is the centroid of these three components.

If emission of the optical jet is negligible, the image centroid will be close to the accretions disk, and O_j will be negative. Strong emission from the optical jet can shift the image centroid along the jet and make O_j positive. Thus, O_j is a measure of optical jet dominance. This is a new source of information, not known before *Gaia* data release, and the focus of our project is to use it for the AGN population study.

The presence of optical structure results in a number of observational consequences. One of them is a prediction of a jitter in optical positions of radio-loud AGNs due to variability (Petrov

& Kovalev, 2017b). Analysis of light curves and position jitter from *Gaia* with respect to VLBI positions will allow us to measure *quantitatively* the distance of the jet centroid with respect to the jet base, distance between the jet base and the accretion disk, and the share of jet flux in optical range to the total flux for the sources with strong variability or flaring events during *Gaia* mission. We will be able to check these prediction in 2022 after *Gaia* DR4. We made another prediction: the anisotropy in VLBI/*Gaia* jet directions will not disappear with the grow of accuracy, but offsets will be determined just more precisely. In particular, we predicted the peaks in the histogram will become sharper. Figure 4 demonstrates the same histogram, but generated using *Gaia* DR2 that was made publicly available. The anisotropy indeed became more profound than in *Gaia* DR1 due to higher position accuracy of DR2!

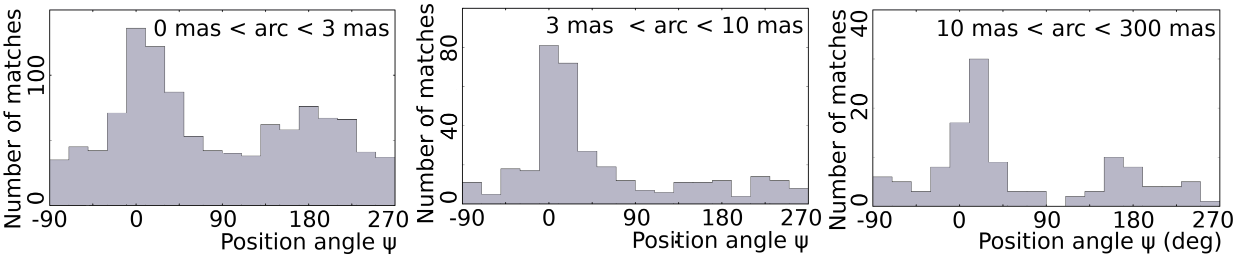

Figure 4: The distribution of statistically significant VLBI/Gaia position offsets using *Gaia* DR2. The peaks of the distributions are sharper than the same histogram generated using *Gaia* DR1, because position errors of *Gaia* DR2 are significantly lower.

While analysis of light curves and position jitter will allow us to determine parameters of optical jets for individual sources, we focus this project to study optical jets of the population of radio-loud AGNs.

2 Problem Statement

Cross-matching VLBI and *Gaia* DR2 catalogues of AGN positions, we cross-matched 8801. We determined jet directions of 4027 matches and computed $\mathcal{O}_{\rm j}$ and $\mathcal{O}_{\rm t}$ observables. Of them, 1649 sources have offsets greater $2\max(\sigma_G, \sigma_V)$, i.e. statistically significant. We split the sample of 4027 AGNs into three subsamples: P_s with $\sigma(\mathcal{O}_{\rm j}) > 2\max(\sigma_G, \sigma_V)$ (734 sources), N_s with $\sigma(\mathcal{O}_{\rm j}) < -2\max(\sigma_G, \sigma_V)$ (383 sources), and 2910 others. According to the argumentation presented in the previous section, we consider the sources of the first sub-sample P_s as having significant contribution from both optically thick and optically thin jet in the optical range. We consider that the sources from the second sub-sample N_s have a low contribution from jets. We split the remaining sources into two sub-samples: P_n if $\mathcal{O}_{\rm j} > 0$ (1529 sources) and N_n if $\mathcal{O}_{\rm j} \leq 0$ (1381 sources). The last two sub-samples discriminate the populations of sources with significant and insignificant jet contribution, but $\mathcal{O}_{\rm j}$ is not significant for a given source.

> The goal of our project is to investigate the differences in statistics of AGN properties in samples P_s against N_s and P_n against N_n, i.e. investigate whether the presence of the significant contribution of optical emission from the jet affects properties of radio-loud AGN.

The motivation of our study is to find the use of a new information about AGN properties, $\mathcal{O}_{\rm j}$ and $\mathcal{O}_{\rm t}$ observables, that was not available before September 2016 and try to exploit it to better understanding the AGN nature. It was assumed that optical emission from AGNs has a thermal component from the accretion disk and a non-thermal component from the jet. However, in the past there were no method to measure the contribution of the non-thermal emission. The basic question that we are going to investigate is how the presence of a strong optical jet affects other properties of AGNs. Are the radio-loud AGNs with strong optical jet dominance are different than the AGNs with weak jets? Studying sub-samples with $>$ 1000 objects is promising to provide robust statistics.

3 The objectives of the proposed work

4 Our Approaches and Methodologies

5 Deliverables

6 Expected significance of the proposed work

7 Management plan

7.1 Data sharing plan

The major results of this project will be accessible as electronic attachments to peer-reviewed publications. In addition, to provide a wide visibility of results to the community, we will maintain the project web site that will contain these results as well as auxiliary data products … Examples of our past data-sharing practices can be found at `http://astrogeo.org`

8 References

Kovalev, Y.Y., Petrov, L., Plavin, A. V, (2017). “VLBI-Gaia offsets favour parsec-scale jet direction in Active Galactic Nuclei”, Astron. & Astrophys., 598, L1.

Petrov, L., Kovalev, Y.Y., (2017a). “On significance of VLBI/Gaia offsets”, Mon. Not. Roy. Astr. Soc. Let., 467, L71–L75.

Petrov, L., Kovalev, Y.Y., (2017b). “Observational consequences of optical range milliarcsecond-scale structure in active galactic nuclei discovered by Gaia”, Mon. Not. Roy. Astr. Soc., 471, 3775–3787.