Brief information about the project

Title	AP25795219 «Exploring the q-metric with high-resolution multi-wavelength observations».
Relevance	This research focuses on testing the q-metric against observational data from the EHT and GRAVITY experiments, providing new insights into the gravitational properties of compact objects like black holes and neutron stars. By bridging the gap between theoretical models and real-world observations, the study will enhance our understanding of how quadrupole moments affect gravitational fields, light-bending, and shadows. These findings contribute to advancing theoretical astrophysics and observational methods, while also fostering international collaboration in Kazakhstan's scientific community.
Goal	The aim of the project is to constrain the q-metric, a theoretical model of deformed compact object spacetime, using high-resolution observational data from the EHT and the GRAVITY instrument. This will provide a more accurate understanding of the gravitational properties of these objects and bridge the gap between theoretical models and real-world observations.
Tasks	The project objectives are divided into three exact and closely connected tasks, corresponding to each year of the project implementation. Task 1: Constraining the q-metric by analyzing radio-interferometric data from the Event Horizon Telescope, focusing on the photon ring, black hole shadow, and bright spots observed around M87 and SgrA*. Task 2: Comparing theoretical models of orbital motion with observed near-infrared GRAVITY data, specifically examining dynamics of bright near-infrared flares and S-star clusters near SgrA*, to derive constraints on the q-metric. Task 3: Predicting observable phenomena, such as light-bending and gravitational lensing effects, unique to the q-metric, which can serve as direct observational probes of spacetime deformations near compact objects. In the first task: In this task, we will focus on analyzing the high-resolution images of black hole shadows, such as those of M87 and Sgr A*, obtained by the EHT. We will model how the quadrupole moment affects the size, shape, and angular structure of the shadow. By comparing the q-metric's predictions with the actual observed images, we aim to determine the quadrupole moment of these astrophysical compact objects. This analysis will allow us to differentiate between simple models, like Schwarzschild and Kerr metrics, and the more complex q-metric that incorporates quadrupole deviations. In the second task, we will use the near-infrared flare dynamics data of close orbital motion near SgrA* detected in 2018 by the GRAVITY instrument at ESO and precise astrometric data, which tracks stars like the S2 star orbiting around Sgr A*. We will investigate how the quadrupole moment influences the orbits of flare components and stars in close proximity to supermassive black holes. Using the q-metric, we will compute deviations in flare's component and stellar motion due to the presence of a quadrupole moment and compare these

	predictions with GRAVITY's observational data. This will help us estimate the quadrupole moment and enhance our understanding of the gravitational field near the Galactic center. In the third task, we will develop and refine numerical models that simulate how light is bent and focused in the presence of a compact object with a quadrupole moment. These simulations will apply the q-metric to calculate the expected lensing effects and compare them with existing gravitational lensing observations of compact objects. By testing the q-metric's predictions against these observations, we will further validate the model and obtain a more precise estimate of the quadrupole moment's influence on light propagation in curved spacetime.
Expected and Achieved Results	1. First-ever constraint on the q-metric derived from the analysis of radio-interferometric data from the Event Horizon Telescope, including the study of the photon ring, black hole shadow, and the interpretation of the bright spots observed around sources M87 and SgrA*. 2. First-ever constraint on the q-metric through comparison of orbital motion with observed near-infrared GRAVITY data, specifically from bright flares and S-star clusters near Galactic center supermassive black hole SgrA*. 3. Predictions of observable signatures, such as light-bending and gravitational lensing effects, unique to the q-metric that could serve as direct probes of spacetime deformations near compact objects.
Names and Surnames of Research Group Members with Their Identifiers (Scopus Author ID, Researcher ID, ORCID, if available) and Links to Corresponding Profiles	**Muratkhan Aray**, PhD in physics and astronomy. ScopusID: 57219511165, (Scopus h-index=2, WoS h-index= 3), WoS/PublonsID: V-1168-2018; ORCID:0000-0001-9920-5193. **Tursunov Arman** PhD, RNDr., DSc., researcher at the Max Planck Institute for Radio Astronomy (MPIfR) in Germany, assistant professor at the Silesian University in Opava (Czech Republic). ScopusID: 36943530700; (Scopus h-index=19, WoS h-index=18); WoS: JPK-4731-2023.
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Patent information	-