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A strategy for wormhole search using observational astronomy

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Abstract. We present a promising strategy for wormhole (WH) search using astronomical observations. By identifying a net effect of anomalous gravitational acceleration may allow for assumptions regarding the hidden WH nature of a black hole (BH). We provide an upper estimate of this effect for several stars in known BH systems such as S2 and S62 orbiting around Sgr A*; along with modeling a synthetic system consisting of a traversable WH, a star on our side and a perturbing object on the other side of a WH. We also consider recently discovered objects from GAIA catalogue data — GAIA BH1, BH2 and BH3. We show that in the traversable WH model a perturbing object (star) located on the other side of the WH throat is capable of causing a significant anomalous acceleration of an object (star) on the observer's side. This effect is observed to be more significant than other competing factors, including disturbances from nearby stars and the influence of the dark matter halo. The estimated magnitude of the anomalous acceleration varies from 10^{-4} to 10^{-2} cm/sec^2, which corresponds to the current accuracy of acceleration measurements. In the future, this may allow for a more precise estimation of the desired effect.

Keywords: gravitation, black hole physics; astrometry; binaries: general

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1 Introduction

A wormhole (WH) is a peculiar hypothetical object with non-trivial topology that connects distant regions of spacetime through a tunnel-like structure called a WH throat. WH-like objects are valid solutions of the Einstein field equations, hence they are consistent with General Theory of Relativity (GTR), though predicted by other theories of gravity as well. The study of WHs has its origins in the Einstein and Rosen paper (Einstein & Rosen 1935). This research has since progressed with significant theoretical advancements that present models explaining the mechanisms of the formation of WHs in the early Universe and their stability, including the development of a stable traversable throat.

So-called traversable WHs are of particular interest for investigating their observational properties on our side (hereinafter referred to as “side 1”), as these objects can exhibit electromagnetic or gravitational effects from perturbing objects on the other side (hereinafter referred to as “side 2”) of their throat.

Thus, a non-stationary gravitational source on side 2 (for example, a massive star with known orbital parameters around the WH) is capable of causing a certain perturbation in the movement of an object on side 1. This effect may be detectable during an observational program.

2 Anomalous acceleration

In order to estimate the anomalous acceleration caused by a perturbation, we will use a model based on a simple Schwarzschild WH in a short-throat and thin-shell approximation. Based on the methodology proposed by Dai & Stojkovic (2019), assuming a perturbing object on an elliptic orbit on side 2, the acceleration variation of an object on side 1 can be calculated using the formula:

$$\varDelta a = \mu\Big(\frac{R}{r_{\mathrm{p}}} - \frac{R}{r_{\mathrm{a}}}\Big) \cdot \frac{1}{r_1^2}, \tag{1}$$

where μ — effective mass of the object (star) on side 2, $r_{\mathrm{p}}, r_{\mathrm{a}}$ — it’s periapsis and apoapsis, r_1 — radial coordinate on side 1, R — radius of a WH throat.

2.1 Estimated effect

Since BH and WH cannot be distinguished with the current astrophysical data, this work will assume that what are currently interpreted as BH may actually be WH. We will refer to these objects as “WH candidates.”

As both WH and BH are associated with extreme states of matter, it is reasonable to search for the perturbing acceleration of massive objects (stars) near known BHs in order to test their nature. To obtain the estimated magnitude of the effect, we chose several stars orbiting WH-candidates in our Galaxy:

– S2 and S62 orbiting around Sgr A*

and recently discovered wide binary systems of BH and stellar companion from Gaia data:

– Gaia BH1 (El-Badry et al. 2023);
– Gaia BH2 (El-Badry et al. 2023);
– Gaia BH3 (Gaia Collaboration 2024).

By varying the parameters of the perturbing object (mass, semimajor axis) we estimated (using (1)) an average magnitude of acceleration variation $\Delta a \approx 10^{-4}$cm/sec^2, which grows up to $\Delta a_{\max} \approx 10^{-2}$ cm/sec^2 for S62 star in an extreme case with the best parameters of a perturbed possible (with mass of $\approx 50 M_\odot$ and semimajor axis of ≈ 0.01AU).

The relationship between the anomalous acceleration (in cm/sec^2) for objects on side 1 (Sgr A* (S2, S62), Gaia BH1, Gaia BH2, Gaia BH3) and the mass (in units of solar mass) of the perturbing object located on side 2 is illustrated in Fig. 1.

The synthetic scenario involves a binary system: the first component of the pair is a WH with a mass of $5M_\odot$ and the second component is a neutron star with a mass of $1.4M_\odot$. The binary system has an orbital period of 1.5 hours. The parameters of the perturbing object on side 2 are: orbital eccentricity $e = 0.4$ and an orbital period of 1 day. In this case, the magnitude of the anomalous acceleration can reach 1.148 cm/sec^2. If the mass of the perturbing object is fixed at $50M_\odot$, then with an eccentricity of $e = 0.4$, the magnitude of the desired effect can reach 1.683 cm/sec^2.

2.2 GAIA BH systems

Table 1. Gaia BH parameters and estimated acceleration accuracy.

	M	m	e	P	σ_a
Gaia BH1	$9.62 \pm 0.18 M_\odot$	$0.93 \pm 0.05 M_\odot$	0.451 ± 0.005	$185.59 \pm 0.05d$	$1.9 \cdot 10^{-1}$cm/sec^2
Gaia BH2	$8.94 \pm 0.34 M_\odot$	$1.07 \pm 0.19 M_\odot$	0.5176 ± 0.0009	$1276.7 \pm 0.6d$	$1.8 \cdot 10^{-2}$cm/sec^2
Gaia BH3	$32.7 \pm 0.82 M_\odot$	$0.76 \pm 0.05 M_\odot$	0.7291 ± 0.0048	$4253.1 \pm 98.5d$	$4.5 \cdot 10^{-2}$cm/sec^2

Strong limitations on the ability to extract the net effect described above are associated with the low accuracy of the accelerations known, stemming from uncertainties in the orbital solutions for the systems under investigation. The highest

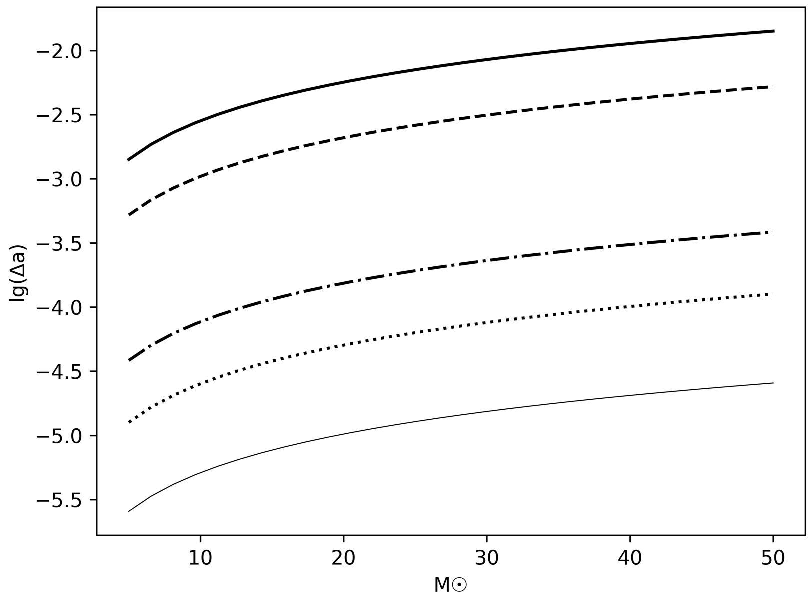

Fig. 1. Dependence of the anomalous acceleration on mass of perturbing object (in logarithmic scale). From top to bottom: solid line — S62, dashed line — Gaia BH2, dash-dot line — Gaia BH1, dotted line — Gaia BH3, thin solid line — S2.

achieved precision is associated with the S2 star, attributed to the extensive observational data collected. However, the detection of the possible effect remains at the limits of our capabilities.

Gaia astrometry has identified several Galactic wide-binary systems containing dormant BHs, which may be suitable for further examination due to the precision of Gaia data. We evaluate the accuracy of indirect acceleration measurements from Gaia orbital solutions and present this data in Table 1.

3 Competing effects

The dark halo density distribution in the center of our Galaxy is estimated to be around $10^{-2} M_\odot$ per pc^3. The region under consideration (for S2 and S62) does not exceed 0.05 pc in radial distance and contains dozens of stars; hence, we neglect the dark halo's gravitational influence.

The stellar density in the center of our Galaxy appears to have a flat distribution for late-type stars (i.e., the number of stars per unit of observable area remains constant within the cluster). The effective boundary of the central cluster, according to various estimates, ranges from 0.02 to 0.05 pc. For early-type stars, there is a decline that follows a power law $r^{-\Gamma}$.

To estimate the contribution of the stellar medium, we will analyse the star S2 at the pericenter of its orbit around Sgr A* inside both homogeneous and non-homogeneous spheres with corresponding density profiles: flat with characteristic density of 2.5 stars per arcsec^2 and declining $\rho(r) \approx r^{-\Gamma}$, where Γ varies from 0.8 to 0.9 according to various estimates.

The equations of motion in this case should be as follows:

$$\begin{aligned} \frac{\partial^2 x}{\partial t^2} &= -\frac{\mathrm{GM}\cdot x}{r^3} - \frac{4}{3}\pi G\rho x, \\ \frac{\partial^2 y}{\partial t^2} &= -\frac{\mathrm{GM}\cdot x}{r^3} - \frac{4}{3}\pi G\rho y, \end{aligned} \tag{2}$$

for a homogeneous sphere and:

$$\begin{aligned} \frac{\partial^2 x}{\partial t^2} &= -\frac{\mathrm{GM}\cdot x}{r^3} - \frac{4\pi G\cdot \mathrm{const}}{r^2} \cdot \frac{x}{r} \int\limits_0^r dr r^{2-\Gamma}, \\ \frac{\partial^2 y}{\partial t^2} &= -\frac{\mathrm{GM}\cdot y}{r^3} - \frac{4\pi G\cdot \mathrm{const}}{r^2} \cdot \frac{y}{r} \int\limits_0^r dr r^{2-\Gamma}, \end{aligned} \tag{3}$$

for a non-homogeneous sphere, where $\mathrm{const} = \frac{(3-\Gamma)M}{4\pi R^{3-\Gamma}}$ is a scaling constant, based on the estimate of enclosed mass M.

Integrating the motion of the star, using (2) and (3), and then numerically differentiating the result twice leads to the determination of the star's acceleration within a perturbing stellar medium. We can then calculate the acceleration variation as the average difference between the acceleration in the frame of Keplerian motion and the perturbed one.

The computed values for the homogeneous and non-homogeneous stellar medium are $8.6\cdot 10^{-9}$ cm / sec^2 and $1.0\cdot 10^{-6}$cm/sec^2, respectively. This indicates that neither can provide a sufficient impact to fully account for the contribution from the desired effect.

4 Summary

In this study, we introduce a sensitive test to determine whether a BH may be a potential WH-candidate, assuming the presence of a perturbing object on side 2 to estimate the detectable features on side 1. For this purpose, we analyze the supermassive BH Sgr A* located at the center of our Galaxy with two stars: S2 and S62 on its orbit, as well as three recently identified stellar-mass dormant BHs based on Gaia data.

All the candidates indicate potential results for a possible anomalous acceleration effect, demonstrating the ability to extract its manifestation despite the presence of other disturbing factors. We demonstrate that the influence of nearby stellar sources or dark matter halo can not provide enough force to obscure the desired perturbation. This makes examining the stellar motion around BHs a robust test for non-BH nature in future observations.

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