Физика фундаментальных взаимодействий Секция-конференция отделения ядерной физики ОФН РАН, посвященная 70 летию В.А.Рубакова Президиум РАН, 17-21 февраля 2025 года

Ограничения на теории гравитации с помощью астрономических данных

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What The Universe Is Made Of



21%





taken from Yandex pictures



Figure 8: Representation of some possible ways of modifying GR through breaking the Lovelock's theorem along with some examples. @Rept.Prog.Phys. 86, 026901 (2023)

Extending PPN to different energy ranges

A system of tests to constrain an extended gravity theory on different energy scales with astronomical data



MDPI

Extended Gravity Constraints at Different Scales

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- + This paper is an extended version of our paper published in An extended version of a conference paper The paper represents an extended version of the lecture presented by SA at XXII International Meeting "Physical Interpretations of Relativity Theory-2021" (5-9 July 2021), held at Bauman Moscow State Technical University.

Simple Summary: Simple summary We review a set of the possible ways to constrain extended gravity models at Galaxy clusters scales (the regime of dark energy explanations and comparison with ACDM), for black hole shadows, gravitational wave astronomy, binary pulsars, the Solar system and a Large Hadron Collider (consequences for high-energy physics at TeV scale).

Abstract: We review a set of the possible ways to constrain extended gravity models at Galaxy clusters scales (the regime of dark energy explanations and comparison with Λ CDM), for black hole shadows, gravitational wave astronomy, binary pulsars, the Solar system and a Large Hadron Collider (consequences for high-energy physics at TeV scale). The key idea is that modern experimental and observational precise data provide us with the chance to go beyond general relativity.

Keywords: general relativity; extended gravity; black hole; turnaround radius; shadow of black hole;

Citation: Alexeyev, S.; Prokopov, V. Extended Gravity Constraints at Different Scales. Universe 2022, 8, 283. https://doi.org/10.3390/ universe8050283

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Academic Editor: Salvatore Capozziello and Daniele Vernieri

Received: 9 March 2022 Accepted: 11 May 2022 Published: 15 May 2022

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gravitational waves; binary pulsars
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PACS: 04.50.+h; 04.50.Gh; 04.80.Cc

1. Introduction

The theory of General Relativity (GR) is confirmed in all projects of experimental astronomy. However, the problems of dark energy, dark matter, the evolution of the early Universe, and the quantum theory of gravity remain open. For example, the theoretical description of the Universe's accelerated expansion (i.e., dark energy) is realised by adding the cosmological constant to the GR action L as

 $L_{GR\Lambda} = \sqrt{-g}(R + \Lambda),$

where R is Ricci scalar and Λ is the cosmological constant. The problem is that Λ -term is the best fit for the observational data. On the other hand, from the fundamental point of view, it appears to be a pure fine-tuning parameter. The next step is to consider an additional scalar field ϕ in the form of Brans–Dicke model

$$L_{BD} = \sqrt{-g} \bigg(\phi R + \frac{\omega}{\phi} \partial_{\mu} \phi \partial^{\mu} \phi + V(\phi) \bigg).$$
⁽²⁾

Such a model can reproduce the cosmological constant contribution with the help of taking the appropriate form of $V(\phi)$. Now, one has to find the origin of the scalar field in Equation (2). The same problem occurs with the inflation stage: accelerated expansion of

Horndeski gravity without screening in binary pulsars

Polina I. Dyadina,^{1,2*} Nikita A. Avdeev^{3*} and Stanislav O. Alexeyev^{2,4*} ¹Department of Astrophysics and Stellar Astronomy, Faculty of Physica, Lononomer Mescere State University, Leukockie Gery, 12, Mescow 19991, Bassia Sternberg Astronomical Institute, Lononeous Moccow State University, Universitetisky Prospeki, 13, Mescow 119991, Bassia "Department of Colenkia Hechanics, Lantonetro and Gaminetr, Faculty of Physics, Lononeous Mescow 119991, Bassia 19997, national Descriment of Ocumium Theory and High Energy Physics, Faculty of Piresics, Lononossov Moscow State University, Leninskie Gore, 1/2, Moscow 119991,

Accented 2018 November 11. Received 2018 November 11: in original form 2018 August 30

We test the subclasses of Horndeski gravity without Vainshtein mechanism in the strong field

us theories and show that data of the binary neutron star mera

GW170817 (Abbott et al. 2017a) and the concomitant m

Key words: gravitation-gravitational waves-methods: analytical-pulsars: general.

1 INTRODUCTION The general relativity (GR) is the universally recognized theory of gravity. It successfully describes a wide range of scales and gravitational regimes (weak field limit in Solar system and stro field regime of binary black holes). Together with Standard model they represent two pillars of modern physics Unformulty some plenneme carnet be explained complexity in the framework of these two approaches. The sociented expansion of our Universe has been found from the supernova type In (SN iso observations dissest al. 1099; 200; 200; Fernitaire et al. 1099; Special et al. 2007). So an extra composite called future energy plenemession in full synchrotroid. The while problem is defi-manter (Dort 1992; Zwicky 1993). It is the invisible nature, which fills up galaxies and maintenism list has been problem is defi-mation of the straight synchrotroid the straight synchrotroid the other problem is the straight synchrotroid the straight synchrotroid 2017; Shi, Li A Hina 2017). Furthermore, then its how is no any complete aff-consister quantum theory of garrity 1, these facts shall be straight and the consister quantum theory of garrity 1, these facts shall be straight and the consister quantum theory of garrity 1, these facts shall be straight and the stra Unfortunately, some phenomena cannot be explained completel self-consistent quantum theory of gravity. All these facts lead to an increasing number of modified gravitational theories. One of the most widespread approaches to create the modified gravity is to extend GR with higher order curvature corrections and additional degrees of freedom (Alexeney & Pomazanov 1997: Alexeney & Ranna 2012). But the simplest way to modify GR remains addi ramm 2012) but the simplest way to moving our remains autoing of a scalar field. The Hornderkä gravity is the most general scalar-tensor the-ory providing the second-order field equations which evades Os-

burst GRB 170817A (Abbott et al. 2017b) allow to restrict the assumeters or use Horndeski gravity. The most general form of Horndeski gravity predicts the exis-nce of a fifth force that is strongly constrained by precision tests at tence of a fifth force that is strongly constrained by precision tests at Solar system scales. If a theory involves a scalar field for description of DE, it should contain a mechanism for suppressing of the scalar interaction with visible matter on small scales, that it relates only

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ЖЭТФ, 2022, том 162, тып. 6 (12), стр. 878-880

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ТЕНИ ЧЕРНЫХ ДЫР КАК ИСТОЧНИК ОГРАНИЧЕНИЙ НА РАСШИРЕННЫЕ ТЕОРИИ ГРАВИТАЦИИ 2: SGR A*

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Поступила в реданцию 29 ститября 2022 г.

после переработки 8 октября 2022 г. Принята к публикация 9 октября 2022

Dourse costs portas antifassensauses [1] protestous Event Harizon Telescope (EHT) found nonvolues neuro There gains node simplifications [1] spheretic Event Hoster Tatlecope (EIT) faux non-wise suggestion and passion and passion and passion and transmiss factors (EIT). Similar transmiss factors (EIT) for the structure passion (EIT) and the structure passi максимум, которого можно достичь без учета вращения черной дыры.

DOI: 10.31857/S0044451022120070 EDN: LCRZOY

(4.3M < D < 5.3M) [2].

1. ВВЕДЕНИЯ Черная дара (ЧД) в центре нашей Галактики Sgr A* более чем в тысячу раз меньше черной ды-

и модель гравитации с конформной симметрией 19 новые наблютательные ленный Ser A* лополнитель ры в центре галактики М87 [3]. Таким образом, поных ограничений не накладывают сле получения изображений теней от черных дыр (ЧД) различных масс стало возможным сравнить их друг с другом, а также использовать их для бо лее точной проверки предсказаний различных рас-шивенных теорий гранитации. Отметим, что оцен-ОБОБЩЕННАЯ МЕТРИКА МОДЕЛИ БАМБЕЛБИ

В настоящей работе с привлечением новых дан-

ных [2] уточняются ограничения, наложенные нами

ранее [1] на молель Бамбелби (распирение ОТО с

[5]. В то же время, на модель Хоридески [6], петле

вую квантовую гравитацию (loop quantum gravit; LQG) [7], скалярнаую гравитацию Гаусса-Бонне [4

мощью векторного поля [4]) и телепаралле яквивалент общей теории относительности (TEGR)

пиренных теорий гранитации. Отметим, что оцен-ка массы Sgr A* от Event Horizon Telescope (EHT) сходится с оценкой, полученной по результатам насостатов с одагования на результатия на близдений з трансториями знезд, правидоопихся во-наут Sgr A*, что джет возможность бозее точно про-ни не заявсят от метрической функции B(r), если верять применимость различных распиренных тео-на рассматриваемом масштабе B(r) > 0 и нет дру рий гравитиции, налагая дополнительные ограни- гих особых точек (регулярность над горизонт учения на них. Наполники, что ограничения на рас-мер тели ЧД при наблюдении Sgr A* состивляют ской только компонентой B(r), поэтому рассмотрил предложенное равес альтернативное обобщение [1]:

1. INTRODUCTION Despite of the applying the non-rotating metrics he results of the black hole shadows modelling btained earlier [1] appeared to be in the agreement with the results of observations of M87⁴ and Sgr.A⁴ 2, 3]. However, to improve the accuracy of theoretical trogradski instabilities (Horndeski 1974). It represents a covariar Subance values (1) appendix to de in the aggregate (2, 3). However, to improve the accuracy of theoretical modelling one has to extend the consideration on briefly describe the required transformations. The first ralization of Galileon gravity. Horndeski gravity suggests so lutions for some GR's problems. For example, the scalar field car play the role of DE and explain the accelerating expansion of the Jniverse (De Felice & Tsujikawa 2012). Therefore, during las rotating black hole metrics. few years in connection with all these circumstances, the Horn Earlier the gravity model $L = R + R^2$ (Starobinsky sode) was extended with the quantum field correcleski gravity attracts a large number of researchers. This theory as recently been studied extensively in the context of cosmology The first displayed in the quantum field corrections were contained [4]. The BH solution was obtained and has $d = \frac{1}{2}$ (Germani & Martin-Morano 2017: Kennedy, Lombriser & Taylo (Germini & Muttin-Mermon 2017), Kennedy, Lembines & Taylor 2017, Nuens, Muttenwons & Lobo 2017, and physics of black boles (Teryakous 2017, Teryakous & Lando 2018). Taking into account the generativity and importance of Henolski inzdul, its natural to ask how this theory poss different experimental gavai-tional tests and impost excitosion on its purposes. The Mornakou Wankmars et al. 2013, the contain accounts background (CMI) data Schwadth, Fuzza & Marrout 2016, Reek, Zamaharonegraf & Monstenary 2016), so contain accounts and 2016, Reek, Zamaharonegraf & Monstenary 2016), so contain accounts and 2016, Reek, Zamaharonegraf & Monstenary 2016, part of 1916, part of 1916, part of 1917, part of 1916, Restorement 2016, part of 1916, part of 1916, part of 1917, part of 1916, Restorement 2016, part of 1916, part of 1916, part of 1917, part of 1916, Restorement 2016, part of 1916, part of 1916, part of 1916, Restorement 2016, part of 1916, Restorement 2016, part of 1916, the form (in (-,+,+,+) signature); $ds^2 = -f_t dt^2 + f_t dr^2 + r^2 d\Omega^2$, where the metric functions are: $f_r \simeq \left(1 - \frac{2G_s M}{r}\right)^{-1} - \frac{\beta \hbar G_s^2 M}{r^3} + O(G_s^3), \quad (2) \quad \text{the transformation the functions } f_r, f_r and the squared model coordinate <math>r^2$ takes the form: $f_r \Rightarrow \tilde{F}(r, \theta, \theta)$ the recent works of Ezquiaga & Zumalacarregui (2017) and Baker $f_t \simeq \left(1 - \frac{2G_{\pi}M}{r}\right) - \frac{\hat{\alpha}\hbar G_{\pi}^2 M}{r^3} + O(G_{\pi}^3).$ (3) et al. (2017) related to the verification of the Horndeski theory using LIGO data for event GW170817 (Abbott et al. 2017a) and the concomitant gamma-ray burst GRB 170817A (Abbott et al. 2017b). In these papers, authors investigate the speed of gravitational waves in

Table 1 Solution ty The values $\hat{\alpha}$ and $\hat{\beta}$ are the linear combinations of r_{c} auge coefficients from Table 1 in [4], M is the BH Kerr 5.196 mass and G, is the effective gravitational constant. Scalar 0.0318 0.0318 5.193 As such way of the gravity models extending is con-Fermion 0.0849 -0.12735.228 5.259 sidered to be perspective it is important to check the 0.1698 -0.2546 Vector accuracy of the discussed model predictions and to 5.813 Graviton 4.52 -1.846 compare them with the real EHT data.

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2. OBTAINING A ROTATING SOLUTION

To obtain the rotating version of the black hole

solution in the extended $R + R^2$ model which would

step is to represent (u, r, θ, ϕ) in Eddington-Finkel-

(1) To enable rotation, you need to apply the following

complex transformation: $r \rightarrow r' = r - ia\cos(r)$

 $u \rightarrow u' = u + ia\cos\theta$, a is rotation parameter. After

radial coordinate r^2 take the form: $f_r \to \tilde{F}(r, \theta, q)$.

 $ds^2 = -f_t du^2 - 2\sqrt{f_r f_t} du dr + r^2 d\Omega^2$. (4)

AND ATOMIC NUCLEI. THEORY

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Received February 1, 2024; revised February 12, 2024; accepted February 20, 2024

Abstract-The first images of the shadows of black holes have opened up new possibilities for testing extended

Montext— The true magace of the nanowa-solution has not solve the very possibility of the single wateree theories of gamying Using the Newmann-Solution (metrics with rotation for the *R* + *R*) model with quantum (field corrections are obtained. We have shown that not all previously obtained solutions are consistent with the experimental results of the Event Horizon Telescope. So the more accurate variant to select extended theories of gravity based on black hole rotation taking into account is proposed.

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ЖЭТФ, 2024, том 165, выт. 4, етр. 508-515

НЕЛОКАЛЬНЫЕ ГРАВИТАЦИОННЫЕ ТЕОРИИ И ИЗОБРАЖЕНИЯ ТЕНЕЙ ЧЕРНЫХ ДЫР

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Поступния в редакцию 28 ноябоя 2023 г. после переработки 4 декабря 2023 г. Принята к публикации 4 декабря 2023 г

С помощью метода Ньюмена - Яниса получено новое вращающееся решение «черная дыра» (ЧД) в гра витации с нелокальными поправками. Предложан способ учита поправок от квантовой гравитации при моделировании теней ЧД с использованием вращающихи метрик ЧД. Метоа применим и для других непокальцих моделей с аналогичной структурой ЧД-решений. Показано, что в будцем при усвоичениеми точности наблюдений и следовательно, необходимости более точного их теоретического моделі в некоторых случаях удобнее учитывать полевые и/или нелокальные поправки вместо введения новы

DOI: 10.31857/S0044451024040059

 $L = R + c_1 R^2 + c_2 R_{\mu\nu} R^{\mu\nu} + c_3 R_{\mu\nu\alpha\beta} R^{\mu\nu\alpha\beta} +$ $+ \alpha R \log \frac{\Box}{\alpha^2} R + \beta R_{\mu\nu} \log \frac{\Box}{\alpha^2} R^{\mu\nu} +$ $+ \gamma R_{\mu\nu\alpha\beta} \log \frac{\Box}{a^2} R^{\mu\nu\alpha\beta}$, где
 R— скаляр Речче, $R_{\mu\nu}$
е $R_{\mu\nu\alpha\beta}$ — тензоры Реч чи и Римана соответственно, c₁, α, β и γ — числовья

1 BREJEHNE

нелокальные операторы появляются в вффективном

созффициенты, определенные в [4]. Решения вид Идея использования нелокальных членов в действии расширенных моделей гразитации обсуждает- вид (в сигнатуре (-,+,+,+)) CS. TOROTHEO TOODOTWETETERO ROBARS [1] MCTOTEOO $ds^2 = -f_t dt^2 + f_r dr^2 + r^2 d\Omega^2$, ся доколько продолжительное время [1]. полотько-вание такого подхода.дает еще одну возможность Do-строить модель темной энергия. Нелокальные кон-где f_{s}, f_{c} — метраческие функция. CONVINUES SCHOOL SOBALSCA SAUDEMED IS MORE SAN PARдалл-Сандрума [2]. Отметим, что рассмотрени

 $f_t \simeq \left(1-\frac{2G_nM}{r}\right) - \frac{\dot{\alpha}\hbar G_n^2M}{r^3} + \mathcal{O}(G_n^3),$ нелокальных членов позволело установать новые ограничения на гравитационные модели, используя данные физики высоких энергий [3]. Таким образом, $f_r \simeq \left(1 - \frac{2G_nM}{r}\right)^{-1} - \frac{\hat{\beta}\hbar G_n^2M}{r^3} + O(G_n^3).$

Величины $\hat{\alpha}$ н $\hat{\beta}$ — это линейные комбинации ка лвбровочных коэффицеентов из табл. 1 в работе [4] М — масса черной дыры (ЧД), G_n — эффективна

(1)

Extended Gravity and Black Hole Shadows: Rotation Accounting

ABSTRACT

regime of binary pulsars. We find the rate of energy losses via the gravitational radiation predicted by such theories and compare our results with observational data from quasi-circular binaries PSR J1738+0333, PSR J0737 - 3039, and PSR J1012 + 5307. In addition, we consider few specific cases: the hybrid metric-Palatini f(R)-gravity and massive Brans-Dicke

153N 1547-4771, Physics of Particles and Nuclei Letters, 2024, Vol. 21, No. 4, pp. 581-583. © Pieiades Publishing, Ltd., 2024 PHYSICS OF ELEMENTARY PARTICLES

DOI: 10.1134/\$154747712470064X

- •Galaxy clusters scales: ways to explain dark energy & comparing with ΛCDM.
- Shadows of black holes: deviations from GR.
- •Gravitational wave astronomy: deviations from GR.
- Binary pulsars: deviations from GR.
- •Solar system: Newtonian limit and deviations from it.
- •Large Hadron Collaider: gravity at TeV scale.

Turnaround radius



A. Chernin et al, MNRAS, Vol.449, P.2069 (2015),
С.А., Б.Латош, В.Ечеистов, ЖЭТФ, т.152, с.1271 (2017),
S.A., K.Kovalkov, IJMP A, v.35, p.204057 (2020).

Idea:

to calculate turnaround radius using 2 independent methods

- To calculate gravitational potential ϕ . At turnaround radius $d\phi/dr=0$, $d^2\phi/dr^2 > 0$.
- To use astronomical data on gravitational lensing for the experimental estimation of turnaround radius value.
- At 1st step to use ΛCDM asymptote for estimation.

NOTE: Calculations of ϕ are based on metrics ==> one can compare different models.



DGP model (see O.Zenin's talk for details)

Constrainss from turnaround radius (*о.зенин, СА, ЖЭТФ, принято к печати (2025*)) + Constrainss from solution by itself (*r. Gannouji, EPJ C 78, 318 (2018*))

Confirmation of DGP (4+)D regime at high scale (near Vainstein radius)

- •Galaxy clusters scales: ways to explain dark energy & comparing with ΛCDM.
- Shadows of black holes: deviations from GR.
- •Gravitational wave astronomy: deviations from GR.
- Binary pulsars: deviations from GR.
- •Solar system: Newtonian limit and deviations from it.
- •Large Hadron Collaider: gravity at TeV scale.

Constraints on gravity models from black hole shadows



Pic is taken from https://www.eso.org/public/images/shadow-evt/

A. F. Zakharov, Sov. Phys. JETP, 64, 1 (1986).

A. F. Zakharov, A. A. Nucita, F. De Paolis, G. Ingrosso, New Astron. 10, 479 (2005)

A. F. Zakharov, IJMP D 54, 2340004 (2023)

A.Zakharov, Phys. Rev. D, Vol.90, P.062007 (2014)

V.Prokopov, SA, O.Zenin, JETP, Vol.135, p.842 (2022) ...

С.А, А. Байдерин, А.Немтинова, О.Зенин, ЖЭТФ 165, 508 (2024)

Idea:

- The general form of spherically-symmetric metrics:
 - $ds^{2} = -A(r)dt^{2} + B(r)dr^{2} + r^{2}(d\theta^{2} + \sin^{2}\theta d\phi^{2}).$
- Equation of motion: $\left(\frac{d\hat{r}}{d\tau}\right)^2 + \frac{L^2}{B(\hat{r})\hat{r}^2} = \frac{E^2}{A(\hat{r})B(\hat{r})}, \quad \frac{d\phi}{d\tau} = \frac{L}{\hat{r}^2},$
- Introduce: D = L/E

• To calculate the shadow size one has to find maximal root of

$$u(r) = \left(\frac{d\hat{r}}{d\phi}\right)^2 = \frac{\hat{r}^4}{D^2 A(\hat{r}) B(\hat{r})} - \frac{\hat{r}^2}{B(\hat{r})}, \qquad u(r) = 0, \quad \frac{du(r)}{dr} = 0, \quad \frac{d^2 u(r)}{d^2 r} > 0.$$







Constraints on gravity models from black hole shadows



Pic is taken from https://www.eso.org/public/images/shadow-evt/

$$ds^2 = igg(1-rac{2M}{r}+rac{Q^2}{r^2}igg)dt^2 - rac{dr^2}{ig(1-rac{2M}{r}+rac{Q^2}{r^2}ig)} - r^2d\Omega^2
onumber \ ds^2 = rac{\Delta}{
ho^2}ig(dt-a\sin^2 heta d ilde{arphi}ig)^2 - rac{\sin^2 heta}{
ho^2}ig((r^2+a^2)d ilde{arphi}-adtig)^2 - rac{
ho^2}{\Delta}dr^2 -
ho^2d heta^2$$

Newman-Janis algorythm (NJA) --> Approved NJA

P Mathematical Physics

Note on the Kerr SpinningParticle Metric

E. T. Newman and A. I. Janis

Citation: J. Math. Phys. **6**, 915 (1965); doi: 10.1063/1.1704350 /iew online: http://dx.doi.org/10.1063/1.1704350 /iew Table of Contents: http://jmp.aip.org/resource/1/JMAPAQ/v6/i6 Published by the American Institute of Physics.

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Regular Article - Theoretical Physics

From static to rotating to conformal static solutions: rotating imperfect fluid wormholes with(out) electric or magnetic field

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Received: 31 January 2014 / Accepted: 16 April 2014 / Published online: 6 May 2014 \fi The Author(s) 2014. This article is published with open access at Springerlink.com

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$\begin{array}{l} \mbox{Horndesky theory} \\ \mbox{The dependence of the shadow} \\ \mbox{size } r_{s} \mbox{ against rotation } a \end{array}$



SA, A.Baiderin, O.Zenin, submitted to JETP



SA, A.Baiderin, O.Zenin, submitted to JETP

$\begin{array}{c} Horndesky \ theory \\ \mbox{The dependence of shift } D \ \mbox{and distortion } \delta \\ \ \ \mbox{against rotation } a \end{array}$









a=0.5

-2

0

х

a=0.94

6

Bumblebee model The dependence of the shadow size r_s against rotation a



SA, A.Baiderin, O.Zenin, submitted to JETP

а



 $\begin{array}{l} \textbf{Bumblebee model} \\ \textbf{The dependence of shift D and} \\ \textbf{distortion } \pmb{\delta} \text{ against rotation } \pmb{a} \end{array}$



6

4

SA, A.Baiderin, O.Zenin, submitted to JETP



Loop Quantum Gravity The dependence of the shadow size r_s against rotation a



SA, A.Baiderin, O.Zenin, submitted to JETP



-4

-2

0

Loop Quantum Gravity The dependence of shift D and distortion δ against rotation a







f(Q) gravity The dependence of the shadow size r_s against rotation a



SA, A.Baiderin, O.Zenin, submitted to JETP



f(Q) gravity The dependence of shift (up case) and distortion (down case) against rotation a



 $\alpha = -0.008$

X



•Generally for considered models some of them (Horndesky model and Gauss-Bonnet scalar gravity) weaken the effect of rotation and bumblebee model enhances it.

•This conclusion matches the previous one at non-local gravity models study: extended gravity theories by themselves correct the effect of rotation in both directions. This fact seems to be important as the accuracy of shadow images permanently increases.

Comment on the Newman-Janis algorithm status

$r^{2} - r^{2} + a^{2} \cos^{2}\theta$

partial symmetry group of rotating solution

- •Galaxy clusters scales: ways to explain dark energy & comparing with ΛCDM.
- Shadows of black holes: deviations from GR.
- •Gravitational wave astronomy: deviations from GR.
- Binary pulsars: deviations from GR.
- •Solar system: Newtonian limit and deviations from it.
- •Large Hadron Collaider: gravity at TeV scale.

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Thank you for your attention!



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