**"TIQXMMI" MILLIY TADQIQOT UNIVERSITETI HUZURIDAGI
FUNDAMENTAL VA AMALIY TADQIQOTLAR INSTITUTI
HUZURIDAGI ILMIY DARAJALAR BERUVCHI DSc.03/31.03.
2022.T/FM.10.04 RAQAMLI ILMIY KENGASH**

**"TIQXMMI" MILLIY TADQIQOT UNIVERSITETI HUZURIDAGI
FUNDAMENTAL VA AMALIY TADQIQOTLAR INSTITUTI**

OTEEV TURSINBAY POLATBAEVICH

**AKSIAL SIMMETRIK FAZO-VAQTLARDA ZARRACHA VA
TORLARNING DINAMIKASI**

**01.04.02-Nazariy Fizika
01.03.01-Astronomiya**

**Fizika-matematika fanlari bo'yicha falsafa doktori (PhD) dissertatsiyasi
AVTOREFERATI**

Toshkent – 2024

UOʻK: 524.882: 530.12:

Fizika-matematika fanlari boʻyicha falsafa doktori (PhD) dissertatsiyasi avtoreferati mundarijasi

Content of the dissertation abstract of the doctor of philosophy (PhD) on physical and mathematical sciences

Оглавление автореферата диссертации доктора философии (PhD) по физико-математическим наукам

"TIQXMMI" MILLIY TADQIQOT UNIVERSITETI HUZURIDAGI FUNDAMENTAL VA AMALIY TADQIQOTLAR INSTITUTI HUZURIDAGI ILMIY DARAJALAR BERUVCHI DSc.03/31.03. 2022.T/FM.10.04 RAQAMLI ILMIY KENGASH

"TIQXMMI" MILLIY TADQIQOT UNIVERSITETI QOSHIDAGI FUNDAMENTAL VA AMALIY TADQIQOTLAR INSTITUTI

OTEEV TURSINBAY POLATBAEVICH

AKSIAL SIMMETRIK FAZO-VAQTLARDA ZARRACHA VA TORLARNING DINAMIKASI

01.04.02-Nazariy Fizika
01.03.01-Astronomiya

Fizika-matematika fanlari bo'yicha falsafa doktori (PhD) dissertatsiyasi AVTOREFERATI

Toshkent – 2024

Fizika-matematika fanlari bo'yicha falsafa (PhD) dissertatsiyasi mavzusi O'zbekiston Respublikasi Vazirlar Mahkamasi huzuridagi Oliy attestatsiya komissiyasida B2024.2.PhD/FM1093 raqami bilan ro'yxatga olingan.

Dissertatsiya ishi "Toshkent irrigatsiya va qishloq xo'jaligini mexanizatsiyalash muhandislari instituti" Milliy tadqiqot universiteti huzuridagi Fundamental va amaliy tadqiqotlar institutida bajarilgan.

Dissertatsiya avtoreferati uch tilda (o'zbek, ingliz, rus (xulosa)) Ilmiy kengashning internet sahifasida (www.ifar.uz) va "Ziyonet" axborot-ta'lim portalida (www.ziyonet.uz) joylashtirilgan.

Ilmiy rahbarlar:	**Ahmedov Bobomurat Jo'rayevich,** fizika-matematika fanlari doktori, professor **Djavlanbek Rayimbaev Radjapbaevich** Fizika-matematika fanlari doktori
Rasmiy opponentlar:	**Narzilloev Baxtiyor Murot o'g'li,** fizika-matematika fanlari doktori, **Tajimuratov Pulat Sadullaevich,** fizika-matematika fanlari bo'yicha falsafa doktori (PhD)
Yetakchi tashkilot:	**Al-Farobiy nomidagi Qozoq milliy universiteti**

Dissertatsiya "TIQXMMI" Milliy tadqiqot universiteti huzuridagi fundamental va amaliy tadqiqotlar instituti huzuridagi DSc.03/31.03.2022.T/FM.10.04 raqamli Ilmiy kengashning 2025-yil _____ soat _____ dagi majlisida bo'lib o'tadi. (Manzil: 100000, Toshkent shahri, Qori Niyoziy ko'chasi 39-uy, Fundamental va amaliy tadqiqotlar instituti, 108-katta majlislar zali. tel.: 71 237-09-62.

Dissertatsiya bilan "TIQXMMI" Milliy tadqiqot universiteti huzuridagi fundamental va amaliy tadqiqotlar instituti Axborot-resurs markazida tanishish mumkin (_____ raqami bilan ro'yxatga olingan). (Manzil: 100000, Toshkent shahri, Qori Niyoziy ko'chasi, 39-uy, Fundamental va amaliy tadqiqotlar instituti, 108-katta majlislar zali; tel.: 71 237-09-62.

Dissertatsiya avtoreferati 2024-yil " 26 " dekabr kuni tarqatildi.
(2024-yil " 5 " dekabrdagi 17 raqamli reestr bayonnomasi)

B.A. Toshmatov
Ilmiy darajalar beruvchi ilmiy kengash raisi o'rinbosari f.-m.f.d.

Sh.N. Mardonov
Ilmiy darajalar beruvchi ilmiy kengash ilmiy kotibi f.-m.f.d.

B.M. Narzilloyev
Ilmiy darajalar beruvchi ilmiy kengash huzuridagi ilmiy seminar raisi f.-m.f.d.

KIRISH (**PhD dissertatsiya ishiga anotatsiya**)

Dissertatsiya mavzusining dolzarbligi va talablari. Hozirgi vaqtda dunyoda qora tuynuklar atrofidagi energetik jarayonlarni va koinotdagi kompakt obyektlar atrofidan kelayotgan signallarni qabul qilish intensivligidagi kvazi-davriy tebranishlarni (QDT) o'rganishga qiziqish ortib bormoqda. Ularni o'rganishda nafaqat jiddiy ilmiy nazariy tadqiqotlarni ta'minlaydi, balki muhim amaliy jihatlari ham mavjud. Shu sababli kvintessensiyadagi Kerr qora tuynuklarining (QT) atrofida Banados-Silk-West va Penrouz mexanizmlari tufayli zarrachalar tezlashishi, energiya olish, Reissner-Nordstrom (RN) QT atrofidagi tok tashuvuvchi tor halqalarning KDT va ularning tezlashishini o'rganish dolzarb hisoblanadi.

Xususan, dissertatsiya ishi energiyani olish mexanizmlari va kollimatsiyalangan astrofizik reaktiv oqimlarning(jetlarning) shakllanishini tushunish muammosidan ilhomlangan. Bunday reaktiv oqimlar turli tizimlarda, jumladan, akkretatsiya qilayotgan yosh yulduzlar, neytron yulduzlar, qora tuynuklar va kvazarlar hamda yadrosi faol galaktikalardagi ulkan qora tuynuklarda kuzatiladi. Magnitlangan plazmalarning akkretatsiya disklariga ta'siri ushbu oqimlarning hosil bo'lishida asosiy rol o'ynashi taxmin qilinadi. Ammo katta yutuqlarga va bir qancha taklif qilingan mexanizmlarga qaramay, jetlarning aniq qanday hosil bo'lish jarayoni hali ham noma'lumligicha qolmoqda.

Bu plazmalarning harakati magnitogidrodinamika (MGD) deb ataladigan murakkab va nochiziqli maydon nazariyasi bilan boshqariladi. Muayyan sharoitlarda plazmalar torga o'xshash xususiyatlarni namoyon qilishi mumkin. Bunday xususiyatlar plazma ichida o'rnatilgan magnit kuch chiziqlarining dinamikasi yoki plazmaning nisbatan yupqa, ajralgan oqim naychalarining harakatidan kelib chiqishi mumkin. Bu holatlarni taxminan bir o'lchamli torlar sifatida modellashtirish mumkin.

Bunday vaziyatlarda ushbu torlar energiya zichligi va tarranglik kuchlari bilan tavsiflanadi va massa yoki/va zaryad oqimlarini tashishi mumkin. Maqsad – ushbu fizik jarayonlarning asosiy jihatlarini torlar dinamikasidan foydalanib tushuntirishdir. Bu yondashuv MGD murakkabligiga nisbatan ancha sodda yondashuvni taklif qiladi va reaktiv jetlarning shakllanishi ortidagi asosiy mexanizmlarni o'rganish uchun istiqbolli vosita sifatida qaraladi.

Nisbiylikning muqobil va asosiy nazariyasi asosida ergosferadan energiya olish mexanizmlari va tok o'tkazuvchi torlarning dinamikasi keng o'rganilgan. Biroq, bu tadqiqotlarda Kerr-Kiselev qora tuynuklari atrofida zarrachalarning tezlashishiga va energiya olish jarayonlariga e'tibor qaratilmagan. Kerr-Kiselev qora tuynuklari yaqinida spinli zarralarining dinamikasi keng o'rganilmagan. Bundan tashqari, KDT larning kuzatuv ma'lumotlari asosida tok tashuvchi tor halqalardan foydalangan holda tortishish nazariyalarini va zaryadlangan qora tuynuklarning cheklovchi parametrlarini sinab ko'rish bo'yicha tadqiqotlar o'tkazilmagan. Elektromagnit o'zaro ta'sirlarni o'z ichiga olgan tadqiqotlar, masalan, vertikal o'q bo'ylab tok o'tkazuvchi tor halqalarning tezlashishi va ularning Reissner-Nordström qora tuynuklari atrofidan chiqarib yuborilishi kabi tadqiqotlar ham cheklangan.

Mamlakatimizda astronomiya va nazariy astrofizika bo'yicha amaliy tadqiqotlar olib borish, fundamental tadqiqotlar bo'yicha xalqaro hamkorlikka katta e'tibor qaratilmoqda. "O'zbekiston Respublikasini yanada rivojlantirish bo'yicha Harakatlar strategiyasida" (2017–2021-yillar) mamlakat ichida ilm-fan rivojiga alohida e'tibor qaratilgan, fundamental tadqiqotlarning asosiy yo'nalishlari belgilab berilgan va bunday tadqiqotlar natijalarini O'zbekiston hududida qo'llash usullari belgilab berilgan. Ushbu dissertatsiyada olingan natijalar tezlanuvchan kengayib borayotgan koinotni tushuntiruvchi modellardan biri bo'lgan kvintessensiyaning tabiatini, Kerr-Kiselev QT atrofida spinli zarralar dinamikasini, GRO 1655-40 dan keladigan KDTlarni tushunishga yordam beradi. Bundan tashqari, zaryadlangan halqalarning tebranish energiyasi uning translatsiya harakati orqali qora tuynukning vertikal o'qi bo'ylab plazma oqimlarining tezlashishini tushuntiradi va ularning Lorentz faktorini miqdoriy jihatdan aniqlaydi.

Mazkur tadqiqot O'zbekiston Respublikasi Prezidentining 2020-yil 29-oktabrdagi "Ilm-fanni 2030-yilgacha rivojlantirish konsepsiyasini tasdiqlash to'g'risida"gi PF-6097-son qarorida belgilangan vazifalarga, shuningdek ushbu sohadagi boshqa tegishli huquqiy va me'yoriy hujjatlar ijrosini ta'minlash doirasida yozilgan.

Tadqiqotning O'zbekiston Respublikasi fan va texnika rivojlanishining ustuvor yo'nalishlariga mosligi. Dissertatsiya tadqiqoti O'zbekiston Respublikasida fan va texnikaning ustuvor yo'nalishlari: O'zbekiston Respublikasi Prezidentining 2017 yil 07 fevraldagi O'zbekiston respublikasini yanada rivojlantirish bo'yicha "Harakatlar strategiyasi to'g'risida"gi PF-4947-son farmoniga muvofiq amalga oshirildi.

Muammoni o'rganilganlik darajasi. Qora tuynuklar atrofida energiya olish jarayonlari turli tortishish nazariyalari doirasida keng o'rganilgan. Ushbu sohaga turli mintaqalar tadqiqotchilari tomonidan katta hissa qo'shilgan. Yevropada Oleg Zaslavskiy, Gregor Ovcharenko, Lyuk Blanchet, Aleksey Deriglazov, Eva Hekmann, Valeriya Kagramanova, Zdenek Stuchlik, Yan Sxe kabi olimlar e'tiborga molik tadqiqotlar olib borishgan. Xuddi shunday, Osiyoda ham Sushant Ghosh, Mubasher Jamil, Yaghoub Haydarzade, and Suzuki Shingo tomonidan muhim tadqiqotlar olib borilgan.

Qora tuynuklarning akretsiya disklaridagi radiatsiya mexanizmlari, xususan, umumiy va muqobil tortishish nazariyalari doirasida KDT ni yaratish va tahlil qilish ham keng o'rganilgan. Lucianno Rezzolla, Marek Abramovich, Gabriel Torok, Pavel Bakala, Zdenek Stuchlik va Martin Kolos kabi evropalik tadqiqotchilar bu sohaga katta hissa qo'shdilar. AQShda Sara Motta, Luidji Stella, Mario Vietri va Robert Vagoner kabi olimlar katta yutuqlarga erishdilar. Bundan tashqari, Shoji Kato va Jun Fukue kabi yaponiyalik tadqiqotchilar, shuningdek, Xitoydan Zhongxiang Wang, Xiang-Dong Li va Shuang-Nan Chjan kabi tadqiqotchilar tomonidan muhim ishlar olib borildi.

Mamlakatimizda qora tuynuklar atrofidagi turli tortishish nazariyalarining dinamikasi va energetik jarayonlar bo'yicha nazariy tadqiqotlar Bobomurat Ahmedov, Ahmadjon Abdujabborov, Javlon Rayimboyev, Farrux Atamuratov,

Bobir Toshmatov, Sanjar Shaymatov, Baxtiyor Narzilloyev va boshqalar tomonidan olib borilgan.

Dissertatsiya mavzusining dissertatsiya tugallangan oliy o'quv yurtlarining ilmiy izlanishlari bilan bog'liqligi. Ushbu dissertatsiya ishi O'zbekiston Respublikasi Fanlar Akademiyasining No. F2-FA-F113 va No. F2-FA-F029-sonli ilmiy loyihasi doirasida amalga oshirildi.

Dissertatsiya ishining maqsadi kvintessensial maydon mavjudligida aksial-simmetrik fazo-vaqtlarda qora tuynuklar atrofida spinli/spinsiz zarrachalar dinamikasi va qora tuynuklar atrofida energiya olish jarayonlari o'rganishdir.

Tadqiqotning vazifalari. Kvintessensial qorong'u energiyasidagi aylanadigan QT atrofida spinli va spinsiz neytral sinov zarralarining harakati va to'qnashuvini o'rganish; Gravitatsion va elektromagnit maydonni birlashtirgan Reissner-Nordstrom(RN) QT tizimida tok o'tkazuvchi zaryadlangan tor halqalarning harakatini o'rganish; KDT ma'lumotlari yordamida QT zaryadini va massasini uchun chegaralarni topish;

Tadqiqot obyektlari sifatida kvintessensiyada joylashgan relyativistik kompakt obyektlar, zaryadlangan QTlar, aylanayotgan neytral zarralar va tok o'tkazuvchi tor halqalar olingan.

Tadqiqot predmeti zarrachalar va tok tashuvchi torlarning tezlanishi hisoblanadi, Penrouz va BSW mexanizmlari orqali QTlardan energiya olish jarayonlari, QT binarlarida yuqori chastotali KDT hisoblanadi.

Tadqiqot usullari eksperimental ma'lumotlarni tahlil qilishning matematik usullari, umumiy nisbiylik nazariyasining matematik apparati va statistikaning raqamli usullaridan iborat.

Tadqiqotning ilmiy yangiligi quyidagilardan iborat:

Ilk bor to'qnashuvchi zarrachalarning massa markazi energiyasi kvintessensial maydon parametri ortishi bilan kamayishi ko'rsatilgan;

ilk bor eng katta spinga ega bo'lgan aylanuvchi zarralar KK qora tuynuk atrofidagi barqaror orbitalarda QTga eng yaqin turishi mumkinligi ko'rsatilgan;

ilk bor ISCO energiyasining qora tuynuk spinining ortishi bilan kamayishi va OSCO energiyasining qora tuynuk va zarracha spiniga bog'liq emasligi ko'rsatilgan;

birinchi marta, RN yalang singulyarliklarida, zaryadlangan tor halqa harakati uchun ikkita yopiq toroidal soha topildi;

ilk, GRO1655-40 manbasidan kuzatilgan yuqori chastotali KDT ma'lumotlarning RN QT sohasida barqaror muvozanat atrofidagi tor halqa garmonik tebranishlari bilan muvofiqligi topilgan;

birinchi marta RN qora tuynuk zaryadi Q elektrostatik itarilish tufayli tor halqasining tezlanish tezligiga hissa qo'shmasligi ko'rsatilgan.

Tadqiqotning amaliy natijalari quyidagilardan iborat:

Birinchi marta, GRO 1655-40, XTE 1550-564, GRS 1915-105 mikrokvazarlaridagi qora tuynuklarning (BH) massasi bo'yicha cheklovlar ikki cho'qqili QDT kuzatuv ma'lumotlaridan foydalanib aniqlandi;

Birinchi marta, RN qora tuynuk atrofida tor halqasining tezlanishiga qora tuynuk va sim halqasining zaryadlari o'zaro ta'sirining ta'siri ko'rsatilib, bu faqat

yadrosi aktiv galaktikalardan (YAGdan) keladigan relativistik oqimlarni tushuntirishning ehtimoliy izohlaridan biri sifatida taklif etildi;

Birinchi marta, kvintessensiya maydoni Penrouz jarayoni orqali energiyani chiqarish samaradorligini pasaytirishi aniqlangan.

Tadqiqot natijalarining ishonchliligi quyidagilar bilan ta'minlanadi: umumiy nisbiylik va nazariy fizikaning zamonaviy usullari hamda yuqori samarali sonli usullar va algoritmlardan foydalanilganligi; olingan nazariy natijalarning kuzatuv ma'lumotlari va boshqa mualliflarning natijalari bilan muvofiqligini sinchkovlik bilan tekshirilganligi; xulosalar gravitatsion kompakt obyektlarning maydon nazariyasining asosiy qoidalariga juda mos kelishi.

Tadqiqot natijalarining ilmiy va amaliy ahamiyati.

Olingan natijalar umumiy nisbiylik nazariyasida Kerr-Kiselev QT atrofida spinli va spinsiz sinov zarralarining dinamikasini va energetik jarayonlarini tushunishga yordam beradi;

QT parametrlari uchun olingan cheklashlar BH atrofidagi fazo-vaqtning tortishish xususiyati haqida ma'lumot olish imkonini beradi, qaysi tortishish effekti dominant rol o'ynashini aniqlash imkoniyatini beradi;

Olingan natijalar, QT juftliklaridan olingan yuqori chastotali KDT kuzatuv ma'lumotlari asosida yulduz massasidagi qora tuynuklarning parametrlari va ularning atrofidagi fazo-vaqt xususiyatlarini aniqlashga yordam berishi mumkin. Shuningdek, bu natijalar akretsion disklardagi tebranishlarning fizik mexanizmlarini tushuntirish imkonini beradi.

Tadqiqot natijalarini qo'llash.

Kvintessensiyada joylashgan aylanuvchi qora tuynuk atrofida zarracha dinamikasi va RN qora tuynugi atrofidagi zaryadlangan tor dinamikasini turli tortishish nazariyalarida o'rganish natijalari quyidagicha qo'llanilgan:

Turli qora tuynuklar atrofida kvintessensiya sharoitida zarrachalar dinamikasini aniqlash yondashuvi kuzatuv ma'lumotlari asosida qora tuynuklar atrofidagi fazo-vaqt xususiyatlari va tortishish modellari bo'yicha tadqiqotlarda bir qancha mualliflar tomonidan qo'llanilgan: Physics Letters B, 771, 365-373, (2017), International Journal of Modern Physics D, Volume 26, Issue 6, id. 1750051-23, (2017), The European Physical Journal C, Volume 78, Issue 9, article id. 750, 13 pp, (2018), Physical Review D, Volume 95, Issue 6, id. 064015,(2017), The European Physical Journal C, Volume 78, Issue 6, article id. 513, 12 pp, (2018), Physical Review D, Volume 102, Issue 10, article id.104062, (2020). Natijalar QTlarning kuzatuv ma'lumotlari asosida QT atrofidagi ko'plab qorong'u materiya modellarida mumkin bo'lgan tahlillarni amalga oshirish uchun taqdim etilgan.

Bir nechta mualliflar ko'plab QTlar atrofida fazo-vaqt xususiyatlarini, shuningdek tortishish modellarini o'rganishda RN QTs atrofida zaryadlangan torlar dinamikasini tahlil qilish yondashuvidan foydalanganlar (Classical and Quantum Gravity, Volume 37, Issue 24, id.245007, 21 pp, (2020), Physics of the Dark Universe, Volume 44, id.101483, (2024), The European Physical Journal C, Volume 82, Issue 5, article id.494, (2022), Physics of the Dark Universe, Volume 26, article id. 100331, (2019), Chinese Journal of Physics, vol. 70, pp. 55-68, (2021). Olingan natijalar qora tuynuklarni o'rab turgan mukammal suyuqliklarning

turli modellarini qora tuynuklarning kuzatuv ma'lumotlari asosida tahlil qilish imkonini yaratish uchun taqdim etilgan.

Biz spinli sinov zarrachalarining ISCO (eng ichki barqaror orbitasi) va OSCO (eng tashqi barqaror orbitasi) xususiyatlarini, ularning orbitadagi energiya va impuls momentlarini o'rgandik. OSCOlarning mavjudligini kvintessensiya maydoni sabab bo'lgan kosmologikga o'xshash gorizont orqali tushuntirish mumkin. Natijalar shuni ko'rsatadiki, ISCO va OSCO kvintessensiya maydoni parametrlari va bosim-hajm nisbati, maydon holati parametrlari ma'lum kritik qiymatlarda birlashadi, bu qiymatlar zarracha va qora tuynukning aylanishiga bog'liq. Natijada, biz spinli zarrachalarning to'qnashuvlarini ko'rib chiqib, massa markazi energiyasini va kritik impuls momentlarini tahlil qildik, bu esa qora tuynuk yaqinidagi zarrachalarning to'qnashuvlarini tushunishga yordam beradi. Eng katta spinga ega zarrachalar KK qora tuynugi atrofidagi barqaror orbitalarga eng yaqin tura olishi ko'rsatildi. ISCO energiyasi qora tuynukning aylanish tezligi oshishi bilan kamayadi, ayniqsa yuqori spinli zarrachalar uchun bu kamayish keskinroq. Ammo OSCO energiyasi qora tuynuk va zarrachalarning aylanishiga bog'liq emas. Shuningdek, ISCO va OSCO energiyalari kvintessensiya maydoni parametri oshishi bilan kamayadi.

Kvintessensiya maydoni parametri yuqori qiymatga ega bo'lganda OSCO va ISCO birlashadi; bu yuqori chegaraning qiymati zarracha aylanishi oshishi bilan ortadi, chunki kvintessensiya maydoni va zarracha aylanishi o'rtasidagi qo'shimcha o'zaro ta'sir mavjud. Bundan tashqari, zarrachalar aylanishining oshishi energiya qiymatlarining kamayishiga olib keladi. OSCO va ISCO energiyalari ω_q ning oshishi bilan ortadi, lekin OSCO energiyasi ISCO energiyasiga qaraganda sezgirroqdir.

Biz KK qora tuynuklari yaqinida spinli zarrachalar to'qnashuvini o'rgandik. Birinchidan, biz zarralarning gorizont yaqinida to'qnashishi mumkin bo'lgan impuls momentlarining kritik qiymatlarini tahlil qildik. Biz qora tuynuk spinining ortishi bilan impuls momenti kamayishini aniqladik. Aksincha, u kvintessensial maydon parametrining oshishi hisobiga ortadi. Holat tenglamasi parametrining impuls momentumiga ta'siri musbat spinli zarralar uchun deyarli ahamiyatsiz. Bundan tashqari, biz spinli zarrachaning musbat va manfiy spin parametrlari bilan to'qnashuvlarida massa markazi energiyasi tahlil qildik. Energiya $\omega_q \rightarrow -1$ bilan ortib borishi aniqlandi; xususan, energiya radial ravishda kamayadi, lekin bir oz masofada, qorong'u energiyaga o'xshash manfiy bosimga ega ekzotik materiya mavjudligi sababli yana ortadi. Kvintessensial maydon parametrining oshishi hisobiga energiya ham ortadi. Biroq, kvintessensial maydon va holat tenglamasi parametrining energiyaga ta'siri qora tuynuk gorizonti yaqinida ahamiyatsiz. Biroq, qora tuynukning aylanishi energiyaning pasayishiga olib keladi. Massa energiyasi markazi $L > 0$ & $s < 0$ L>0 holatlariga nisbatan $L < 0$ & $s > 0$ konfiguratsiyasida kattaroqdir. Boshqa barcha kombinatsiyalardan $L_1 > 0$ & $s_1 > 0$ va $L_2 < 0$ & $s_2 < 0$ holatlarida energiya asosan kattaroqdir.

Tadqiqot natijalarining aprobatsiyasi. Dissertatsiya natijalari 1 ta xalqaro va 1 ta mahalliy konferensiyada muhokama qilingan.

Tadqiqot natijalari bo'yicha 6 dan ortiq ilmiy nashrlar chop etilgan bo'lib, ulardan 3 tasi xalqora hakamlik jurnallarida ilmiy maqolalar hisoblanadi.

Dissertatsiyaning hajmi va tuzilishi. Dissertatsiya kirish, uchta bob, xulosa va foydalanilgan adabiyotlar ro'yxatidan iborat. Dissertatsiya hajmi 88 bet.

DISSERTASINING ASOSIY MAZMUNI

Kirish qismida dissertatsiya mavzusining dolzarbligi va talabi, dissertatsiyada qo'yilgan asosiy maqsadlar va ilmiy yangilik hamda amaliy natijalar ko'rib chiqilgan, natijalarning ishonchliligi va ularning nazariy va amaliy ahamiyati bayon qilingan, tadqiqotning qo'llanilishi natijalar va dissertatsiya tuzilishi keltirilgan. Ilmiy o'rganishlar davomida biz geometrik birliklardan foydalanamiz, shunda tortishish doimiysi va yorug'lik tezligi $G = c = 1$. birga teng bo'ladi.

Dissertatsiyaning "**Kvintessensiyada aylanadigan qora tuynuk atrofida energiya olish va zarrachalarning tezlanishi**" deb nomlangan **birinchi bobida** Banados-Silk-West(BSW) va Penrouz mexanizmlari orqali kvintessensiyada aylanadigan qora tuynuklardan energiya olish jarayonlari o'rganilgan.

Uzoqdagi Ia-tipidagi o'ta yangi yulduz portlashlari evolyutsiyaning hozirgi davridagi koinotning tezlashgan kengayishini tushuntirish uchun juda kichik reliktli itaruvchi kosmologik konstanta $\Lambda > 0$, boshqacha qilib aytganda, tortishish ta'sirini ko'rsatadigan qorong'u energiya zarurligini tasdiqlaydi. Ushbu natijalar PLANCK kosmik rasadxonasi tomonidan kosmik mikroto'lqinli fon termal anizotropiyalarini kuzatish orqali qo'llab-quvvatlanadi. Qorong'u energiya kuzatilishi mumkin bo'lgan koinotning umumiy energiya tarkibining 73% dan ortig'ini tashkil qiladi va qorong'u energiya holatining tenglamasi vakuum energiyasiga o'xshaydi. Biroq, qorong'u energiya kvintessensiya deb ataladigan narsa bilan bog'liq va bundan mustasno emas. Kvintessensiya tortishish kuchi bilan bog'langan skalyar maydon sifatida aniqlanadi, bu tortishish maydoni ortishi bilan kamayadi. Kosmik itarilishning kosmologik va astrofizik hodisalari kosmologik doimiyning so'nggi qiymatini $\Lambda \approx 1.3 \times 10^{-56} \ sm^{-2}$ bo'lishini ta'minlaydi.

Kvintessensial statik qora tuynuk uchun yechim Nyuman va Janis tomonidan ishlab chiqilgan standart usullardan foydalangan holda aylanishga umumlashtirilishi mumkin. Standart Boyer-Lindquist koordinatalaridagi kvintessensial aylanuvchi fazo vaqtining chiziqli elementi shaklni oladi.

$$ds^2 = g_{tt}dt^2 + g_{rr}dr^2 + 2g_{t\phi}drd\phi + g_{\theta\theta}d\theta^2 + g_{\phi\phi}d\phi^2 \qquad (1.1)$$

bilan

$$g_{tt} = -1 + \frac{2Mr + Cr^{1-3\omega_q}}{r^2 + a^2cos^2\theta},$$

$$g_{rr} = \frac{r^2 + a^2cos^2\theta}{a^2 - 2Mr + r^2 - Cr^{1-3\omega_q}},$$

$$g_{t\phi} = -a\frac{2Mr + Cr^{1-3\omega_q}}{r^2 + a^2cos^2\theta}sin^2\theta,$$

$$g_{\theta\theta} = r^2 + a^2cos^2\theta,$$

$$g_{\phi\phi} = (r^2 + a^2 + a^2 \sin^2\theta \frac{2Mr + Cr^{1-3\omega_q}}{r^2 + a^2\cos^2\theta})\sin^2\theta \ . \ (1.2)$$

Bu yerda M va a qora tuynukning massasi va nisbiy impuls momentidir. $\omega_q \in (-1. -1/3)$ holat parametrining o'lchovsiz kvintessensial tenglamasi va u kvintessensial maydonning holat tenglamasini $p = \omega_q \rho$ ko'rinishida boshqaradi, bu erda p va ρ mos ravishda kvintessensial maydonning bosimi va energiya zichligi. Kvintessensial maydonning mavjudligi geometriyaning Ricci tekis bo'lmasligiga olib keladi. Kvintessensial maydon parametri $C = 0$ bo'lganda, aylanuvchi kvintessensial geometriya bizga ma'lum Kerr geometriyasiga keladi; Bundan tashqari, $a = 0$ va $C = 0$ chegaralarini hisobga olgan holda, Shvartsshild metrikasiga ham erishish mumkin.

Endi, aylanuvchi qora tuynukdan energiya olishning BSW mexanizmiga asoslanib, aylanuvchi qora tuynuk yaqinida massasi $m_1 = m_2 = m_0$ bo'lgan ikki zarrachaning to'qnashuvi uchun E_{CM} massa markazi energiyasini hisoblaymiz. Turli impuls momentlari L_1 va L_2 ga ega bo'lgan zarrachalar cheksizlikdan $\frac{E_1}{m_1} = \frac{E_2}{m_2} = 1$ bilan keladi va qora tuynukga yaqinlashadi, shuningdek, zarrachalarning harakati va ularning to'qnashuvi ekvator tekisligida $\theta = \frac{\pi}{2}$ sodir bo'ladi, deb hisoblaymiz.

Massa markazi energiyasini quyidagi mashhur formuladan foydalanib topish mumkin

$$\frac{E_{CM}^2}{2m_0^2} = 1 - g_{\mu\nu}u_1^\mu \ u_2^\nu \quad (3)$$

Bu yerda u_1^μ va u_2^ν mos ravishda birinchi va ikkinchi zarrachalarning 4-tezliklari. Ekvator tekisligida aylanuvchi kvintessensial qora tuynuk atrofida harakatlanayotgan zarrachaning 4-tezligi $\dot{t} = \frac{g_{\phi\phi}E + g_{t\phi}L}{g_{t\phi}^2 - g_{tt}g_{\phi\phi}}$ va $\dot{\phi} = \frac{g_{t\phi}E + g_{tt}L}{g_{t\phi}^2 - g_{tt}g_{\phi\phi}}$ ifodalar bilan ifodalanadi. Soddalashtirish uchun, $E_1 = E_2 = 1$ deb faraz qilib va (3) ga 4-tezlik uchun ifodalarni kiritsak, quyidagi massa markazi energiyasini olish mumkin

$$\frac{E_{CM}^2}{2m_0^2} = \{C(a - L_1)(a - L_2) - Cr^2$$
$$+ r^{3\omega_q}[-2a(L_1 + L_2)M + L_1L_2(2M - r)$$
$$+ 2r^2(-M + r) + 2a^2(M + r)] - [C(a - L_1)^2$$
$$+ Cr^2 + r^{3\omega_q}[2(a - L_1)^2M - L_1^2r + 2Mr^2]]^{\frac{1}{2}} \times [C[(a - L_2)^2 + r^2]$$
$$r^{3\omega_q}[2(a - L_2)^2M - L_2^2r + 2Mr^2]]^{\frac{1}{2}}\} \times [-Cr^2 + r^{3\omega_q+1}(a^2 - 2Mr + r^2)]^{-1} \ .$$

Endi biz $\frac{E_{CM}^2}{2m_0^2}$ ning kvintessensiya materiya parametri C, kvintessensiya maydoni parametri ω_q va nisbiy impuls momenti a ga bog'liqligini tekshiramiz.

1-rasmda a aylanish parametri, ω_q holat parametrining kvintessensial tenglamasi va C kvintessensial maydon parametrining turli qiymatlari uchun massa

energiyasi markazining (xususan $\frac{E_{CM}^2}{2m_0^2}$) radial bog'liqligi ko'rsatilgan. Bu yerda zarrachalarning burchak momenti $L_1 = \sqrt{2}$, $L_2 = -\sqrt{2}$ sifatida tanlanadi, 1-rasmdan ko'rinib turibdiki, C kvintessensial maydon parametrining mavjudligi massa energiyasi markazining pasayishiga olib keladi.
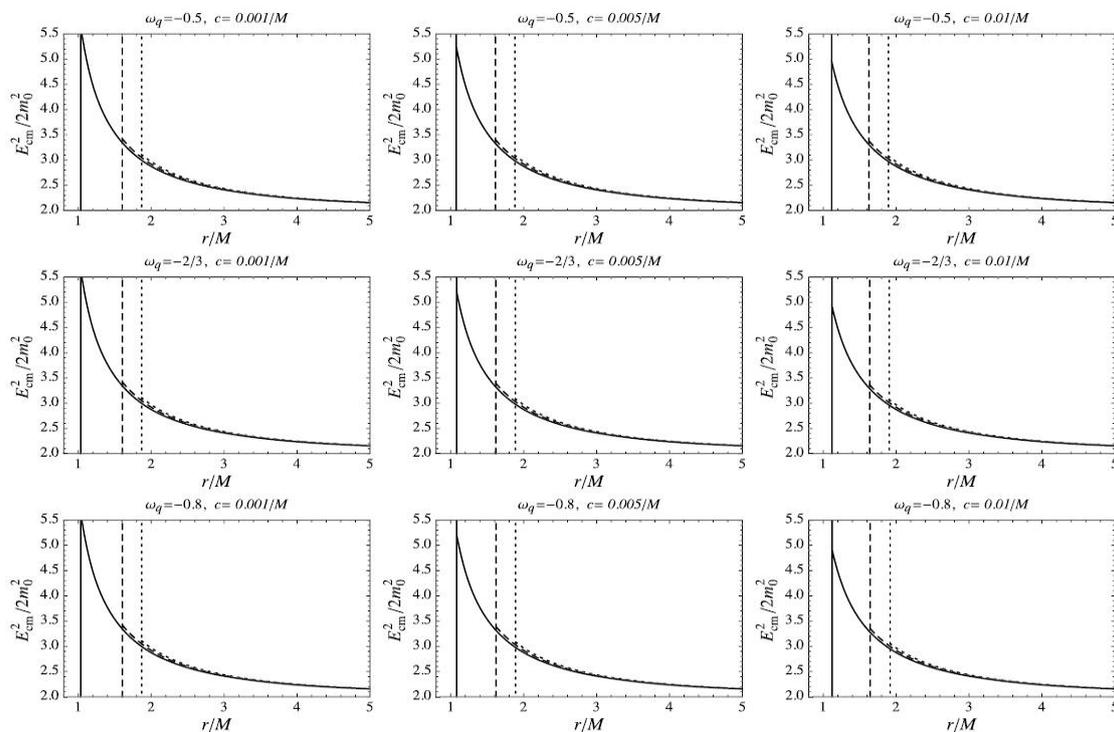
1-rasm. Ikki to'qnashuvchi zarrachalar massa markazi energiyasining aylanish parametri a ning, holat parametrining kvintessensial tenglamasi ω_q va kvintessensial maydon parametri C ning turli qiymatlariga radial bog'liqlik grafiklari. Tutash, punktirli va nuqtali chiziqlar aylanish parametrining quyidagi qiymatlariga mos ravishda mos keladi $a = 1$; 0.8 va 0.5.

"**Kerr-Kiselev qora tuynuklari atrofida spinli sinov zarralarining doiraviy harakati va to'qnashuvlari**" deb nomlangan **ikkinchi bo'limda** biz hisob-kitoblarimizni aylanuvchi qora tuynuk atrofida spinli sinov zarralari harakati uchun kengaytiramiz. Asosan biz neytral zarrachalarning spini ularning dinamikasiga ta'sirini o'rganishni maqsad qildik. Avval biz zarrachalar dinamikasini boshqaruvchi, hal qiluvchi miqdor bo'lgan effektiv potentsialni tekshiramiz. Samarali potentsialning analitik ifodasi juda murakkab shaklda topilgan.

U quyidagicha aniqlanadi

$$V_{eff} = \frac{-B + \sqrt{B^2 - 4AD}}{2A}$$

bu yerda

$A = 4r^{12-6\omega_q}(4a^3 s r^{3\omega_q+1}(3C\omega_q + C + 2r^{3\omega_q}) + a^2(C^2(3s\omega_q + s)^2 +$

$$4Cr^{3\omega_q}(r^3 + 3(r + 1)s^2\omega_q + rs^2 + s^2) + 4((r + 2)r^3 + (2r + 1)s^2)r^{6\omega_q} +$$

$$12asr^{3\omega_q+3}(C\omega_q + C + 2r^{3\omega_q}) + 4r^{3\omega_q+3}(Cs^2 + (r^3 - (r - 2)s^2)r^{3\omega_q}),$$

$$B = -8jr^{12-6\omega_q}(4a^2sr^{3\omega_q+1}(C\omega_q + C + 2r^{3\omega_q}) + aC^2(3s\omega_q + s)^2 +$$

$$2aCr^{3\omega_q}(2r^3 + 3(r + 2)s^2\omega_q + rs^2 + 2s^2) + 4a(2r^3 + (r + 1)s^2)r^{6\omega_q} +$$

$$6Cs(\omega_q + 1)r^{3\omega_q+3} - 4(r - 3)sr^{6\omega_q+3} \ ,$$

$$D = -4r^{10-9\omega_q}(C^2s^2(3\omega_q + 1)r^{3\omega_q}(3s^2\omega_q(a^2 + (r - 2)r) + a^2s^2 -$$

$$j^2r^2(3\omega_q + 1) + 4r^4 + (r - 6)rs^2 - 4Cr^{6\omega_q}((r^3 - s^2)(3s^2\omega_q(a^2 + (r - 2)r)$$

$$+a^2s^2 + r^4 + (r - 3)rs^2 + j^2r^2(3s\omega_q(ar + s) + ars + r^3 + s^2))$$

$$+4r^{9\omega_q}((a^2 + (r - 2)r)(r^3 - s^2)^2 + j^2r^2(-2ars + (r - 2)r^3 - s^2))$$

$$-C^3rs^4(3\omega_q + 1)^2 \ . \quad (2.1)$$

2-rasmda test zarrachaning spini turli qiymatlari uchun aylanuvchi qora tuynuk orbitasida aylanuvchi spinli sinov zarrasining effektiv potentsialning radial bog'liqligi ko'rsatilgan. O'ng tomondagi grafik musbat impuls momentiga ega bo'lgan korotatsiya qiluvchi zarrachaning effektiv potentsialining tabiatini ko'rsatadi. Ko'rinib turibdiki, tez aylanadigan zarralar uchun $s = 1$, sekin aylanadigan zarrachalarga qaraganda barqaror bog'langan orbitalar $s = 0.5$ mavjud. Zarrachaning spini kamayishi bilan uni bog'langan orbitada ushlab turuvchi potentsial to'siqning balandligi pasayadi va bu tendentsiya qarama-qarshi aylanadigan zarralar uchun o'sishda davom etadi.
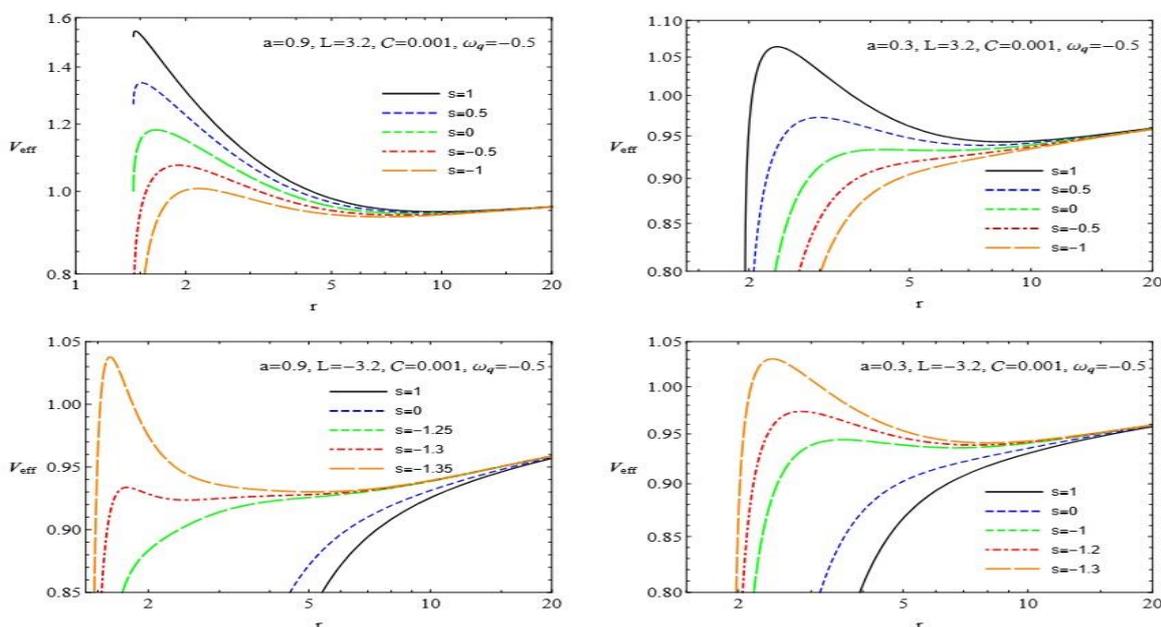

2-rasm Tez aylanadigan (chap ustun) va sekin aylanadigan (o'ng ustun) kvintessensial qora tuynuk holatlari uchun samarali potentsialning radial profillari sinov zarralari spinining turli qiymatlari keltirilgan.

Bundan tashqari, teskari spinli zarralar uchun barqaror doiraviy orbitalar topildi. Pastki chap grafikdan xulosa qilish mumkinki, teskari aylanadigan zarrachalar, agar ular etarlicha tez aylansa, barqaror doiraviy orbitalarga ega bo'lishi mumkin. Zarrachalar teskari aylanayotgan va teskari spinga ega bo'lsa, zarralar barqaror bog'langan orbitalarga ega bo'lolmaydi. O'ng tomonda sekin

aylanadigan qora tuynuklar uchun vaziyat ko'rsatilgan. Ikkita grafik sekin aylanadigan qora tuynuk atrofidagi zarrachalarning barqarorligi tez aylanadigan qora tuynuknikiga juda o'xshashligini ko'rsatadi. Yagona farq shundaki, qarama-qarshi aylanuvchi zarracha bir xil manfiy spin $s = -1$ bo'lsa, barqarorroq bog'langan orbitaga ega bo'lishi mumkin.

3-rasmda C parametr (chap panel) va kvintessensial parametr ω_q (o'ng panel) ning turli qiymatlari uchun effektiv potentsialning radial bog'liqligini ko'rsatilgan. Birgalikda aylanadigan zarralar (ko'k chiziqlar) grafikasidan ko'rinib turibdiki, kvintessensial maydon parametri C oshgani sayin, barqaror orbitalar uchun ruxsat etilgan interval ham ortadi. Astrofizik nuqtai nazardan, bu kvintessensial maydonning kuchi uchun mas'ul bo'lgan C kvintessensial maydon parametrini oshirish bilan birga, tez aylanadigan va sekin aylanadigan qora tuynuklar akretsiya diskining radiusi ham ortadi. Qarama-qarshi aylanadigan qora tuynuklar (qizil chiziqlar) bo'lsa-da, birgalikda aylanadigan zarralar uchun barqaror bog'langan orbitalar mavjud va ular tez aylanadigan va sekin aylanadigan qora tuynuklar uchun qora tuynuk ichiga tushadi. Keyinchalik, 3-rasmning o'ng panelida biz ω_q kvintessensial parametrining turli qiymatlari uchun effektiv potentsialning radial o'zgarishini tahlil ko'rsatamiz. Ikkala grafikdan ham barqaror bog'langan orbitalar faqat ω_q ning kichik qiymatlari uchun mavjud. Kvintessensial parametr ω_q ortganda, bog'langan orbitalarning barqarorligi yo'qoladi. Astrofizika nuqtai nazaridan, oldingi holatga o'xshab, ω_q ortishi bilan 3-rasmda, akretsiya diskining radiusi kattalashib boradi va bundan keyin zarrachalarni qora tuynuk ichiga tushishidan saqlaydigan faqat potentsial to'siq qoldiradi. Bu shuni anglatadiki, zarralar bog'langan orbitalarga ega bo'lolmaydi va ma'lum bir masofada qora tuynuk gorizontiga yaqinlashib, cheksizlikka qaytishi mumkin. 3-rasm,
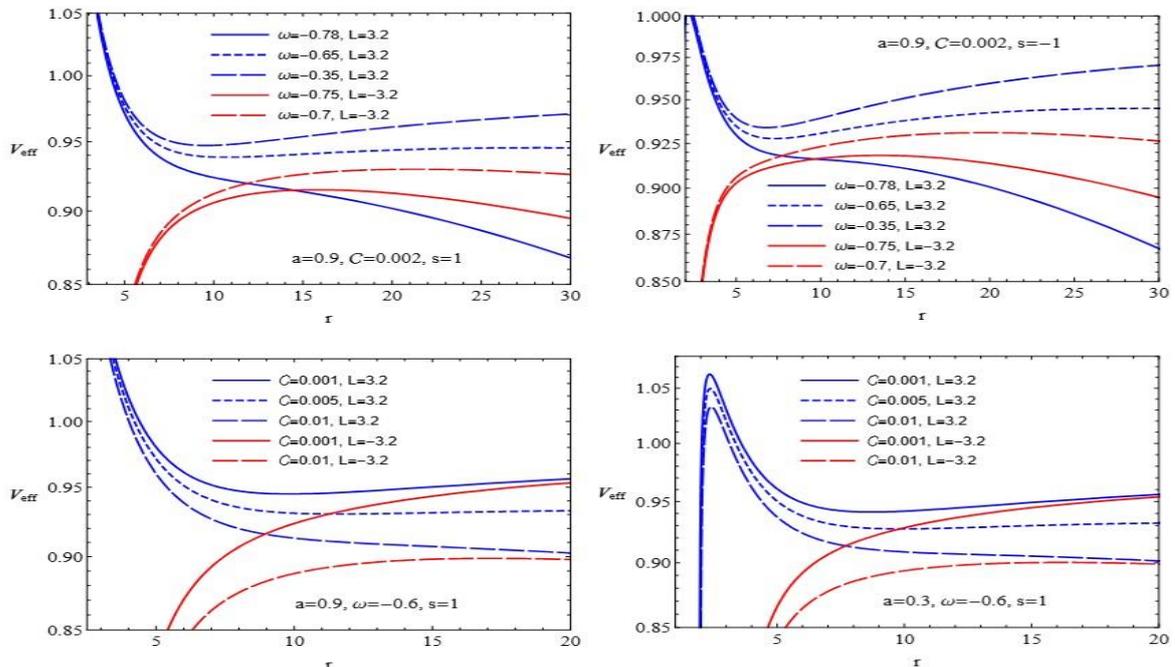
3-rasm. 2-rasmdagi grafiklarga o'xshash, lekin kvintessensial maydon parametri C (pastki panellar) va kvintessensial parametr ω_q (yuqori panellar) ning turli qiymatlari uchun keltirilgan.

14

"Reissner-Nordstrom qora tuynukda zaryadlangan tor halqalar" deb nomlangan **uchinchi bo'limda** tortishish va elektromagnit maydonni birlashtirgan Reissner-Nordström qora tuynukda tok o'tkazuvchi zaryadlangan tor halqalarning harakatini o'rganilgan. Markaziy zaryad va zaryadlangan tor halqa o'rtasida yangi elektromagnit o'zaro ta'sirni joriy qilish, tor halqa harakat tenglamalarini hatto tekis fazo-vaqt chegarasida ham integrallanmaydigan qilib qo'yadi, lekin u hatto qora tuynuk fonida ham effektiv potentsial bilan boshqarilishi mumkin. Effektiv potentsial yondashuvdan foydalangan holda tor halqasi traektoriyalarining har xil turlarini tasniflangan va eng ichki turg'un halqa aylana o'rinlarini zaryadlangan zarrachaning eng ichki barqaror orbitalarining joylashuvi bilan solishtirilgan. Tor halqasining effektiv potentsialining minimali atrofidagi tor halqasining kichik tebranishlarini tekshirilgan va radial va vertikal tebranish chastotalarining rejimlari profillarini tuzilgan. Zaryadlangan tor halqali kvazi davriy tebranishlar modeli tuzilgan va uni GRO 1655-40, XTE 1550-564 va GRS 1915+105 mikrokvazarlaridan kuzatilgan ma'lumotlar bilan solishtirilgan. Shuningdek, elektromagnit o'zaro ta'sirni hisobga olgan holda, vertikal o'q bo'ylab tok o'tkazuvchi tor halqalarining tezlashishini va RN qora tuynuk atrofidan tor halqasining chiqarilib yuborilishi o'rganilgan.

Tor halqasining markaziy elektr zaryadlangan qora tuynuk bilan o'zaro tortishishi geometrik birliklarda ifodalangan

$$f(r) = 1 - \frac{2M}{r} + \frac{Q^2}{r^2} \quad (3.1)$$

chiziqli elementli sferik simmetriyali Reissner-Nordstrom (RN) metrikasi orqali o'qiladi.

$f(r)$ metrik funksiyasida M parametri qora tuynuk massasini, Q esa qora tuynuk zaryadini bildiradi.

$0 \le Q < M$ uchun metrikada ikkita hodisa gorizonti joylashgan qora tuynuk tasvirlangan.

$$r_{h\pm} = M \pm \sqrt{M^2 - Q^2} \quad (3.2)$$

$Q = M$ uchun faqat bitta degeneratsiyalangan hodisa gorizonti yechimi mavjud, $Q > M$ uchun gorizontsiz yalang singulyarlik mavjud. Keyinchalik, bu bobda soddalashtirish uchun qora tuynukning massasi $M = 1$ bo'lgan birliklar tizimidan foydalanilgan, ya'ni tegishli miqdorlar qora tuynuk massasi birliklarida ifodalangan.

Reissner Nordstrom fonida tor aylana harakati uchun Gamiltonianning umumiy shakli quyidagicha qisqaradi.

$$H = \frac{1}{2} f(r) P_r^2 + \frac{1}{2r^2} P_\theta^2 + \frac{1}{2} \left(\frac{J^2}{r \sin\theta} + r \sin\theta \right)^2 - \frac{1}{2f(r)} \left(E - \frac{\Omega Q}{r} \right)^2 .$$

Butun aksi-simmetrik tor halqasi $y = 0$ koordinatasi bilan ifodalanadigan bitta nuqta sifatida tasvirlanishi mumkin bo'lganligi sababli, zaryadlangan sim halqasi uchun effektiv potensialni quyidagi ko'rinishda kiritish mumkin:

$$V_{eff}(x, r, Q, J, \omega) = \sqrt{1 - \frac{2M}{r} + \frac{Q^2}{r^2}} \left(\mu x + \frac{J^2}{x} \right) + \frac{\sqrt{2}\omega J Q}{r}$$

Bu yerda r - radial masofa, $r^2 = x^2 + z^2$ va μ – torning tarrangligi, J – impuls parametri, ω – zaryad parametrlari.

4(a)-rasmda biz chegara energiya profillari bilan bir qatorda tor halqasining harakat kesmasi traektoriyalarini ko'rsatamiz - harakatning yopiq hududda tutib qolganligini kuzatamiz. Ushbu holat uchun torli halqaning traektoriyasi 4(b)-rasmda keltirilgan; z - yo'nalishi bo'yicha harakat chekli, energiya chegarasi profili qora tuynuk uchun ochiq, va tor halqa nihoyat qora tuynukga tushadi, degan xulosaga kelishimiz mumkin. Oxirgi holatda $Q = 0.3$, $\omega = -1$ konfiguratsiyada $J = 4$ qiymatini olamiz. Bunday holda, hech qanday tuzoqqa tushishi mumkin bo'lgan harakat yo'q va torli halqa vertikal yo'nalishda cheksizlikka qochishi kerak (4-rasm (c)). Qora tuynuk atrofida mumkin bo'lgan yana bir tor halqa traektoriyasi $Q = 0.3$, $\omega = 1$, $J = 10$ (b) rasmda berilgan, bunda tor cheksizlikka qochib ketadi. 4-rasmda (a) biz chegara energiya profillari bilan bir qatorda tor halqasining harakat kesmasi traektoriyalarini ko'rsatamiz - harakatning hududda tutib qolganligini kuzatamiz. Ushbu holat uchun torli halqaning traektoriyasi 4(b)-rasmda joy; z - yo'nalishi bo'yicha harakat chekli, energiya chegarasi profili qora tuynuk uchun ochiq, va tor halqa nihoyat qora tuynukga tushadi, buning uchun kelishimiz mumkin. Oxirgi holatda Q=0,3 , $\omega = -1$ konfiguratsiyada J=4 aniqlashni olamiz. Bunday holda, hech qanday tuzoqqa tushishi mumkin bo'lgan harakat yo'q va torli halqa vertikal yo'nalishda cheksizlikka qo'yishi kerak (4-rasm)). Qora tuynuk atrofida mumkin bo'lgan yana bir ipli halqa traektoriyasi (d)-rasmda berilgan, bunda tor halqa cheksizlikka qochib ketadi.
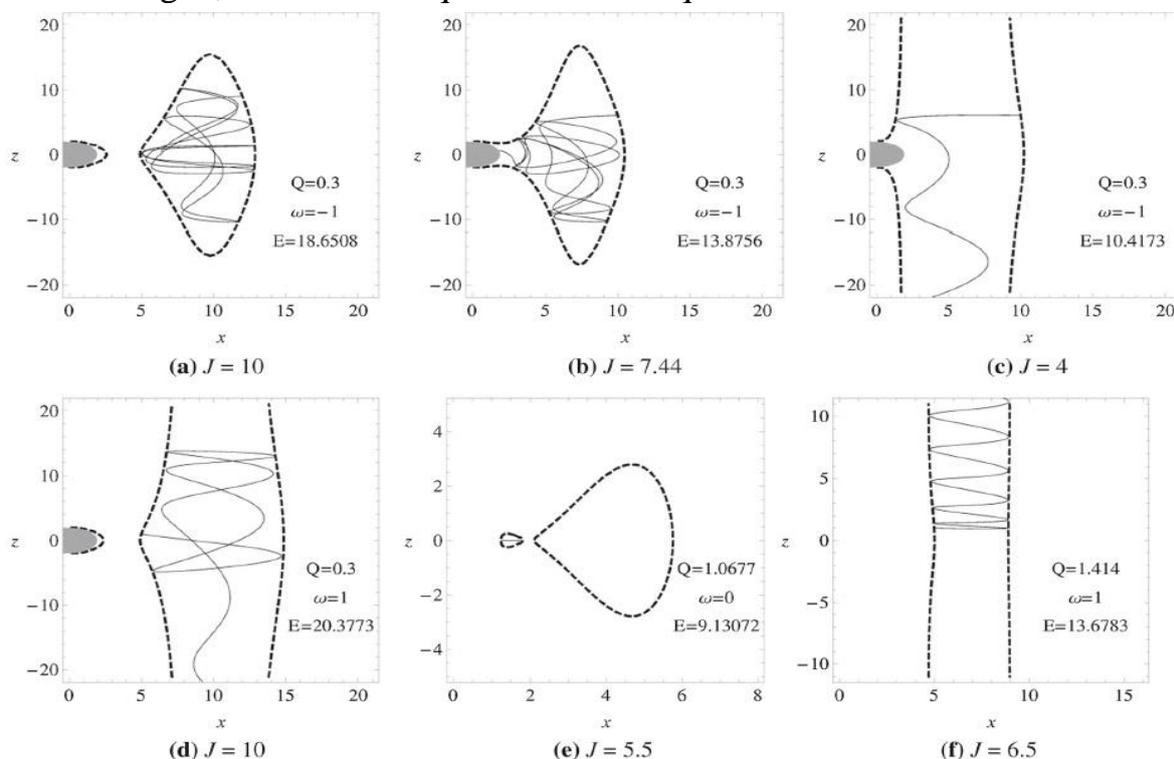
4-rasm Ip halqasining traektoriyalari va ular harakatining energiya chegaralari. Har xil turdagi harakat mumkin: ba'zi "ko'l"ga o'xshash sohada ((a), (e)), qora tuynuk tomonidan tutilgan (b), qulash yoki cheksizlikka qochish (c), cheksizlikka qochish ((d), (f)).

16

O'rta qatordagi elementlar $Q = 1.0677$, $\omega = 0$ holati uchun yalang singulyarliklarini ifodalaydi. Effektiv potensialning eng o'ziga xos ko'rinishi $J = 5.5$ bo'lgan holatda ikki minimumning mavjudligi bilan tavsiflanadi. Bu shuni anglatadiki, tor halqasi x yo'nalishida yalang singulyarlik atrofida ikki barqaror holatga ega bo'ladi va tor halqasi energiyasi yetarlicha past bo'lsa, vertikal yo'nalishda qochish mumkin emas. Bunday harakat turi uchun tor halqasining trayektoriyasi 4(e)-rasmda keltirilgan. Ushbu turdagi energiya chegarasi profili tuzoqqa tushgan harakatga mos keladi — bu harakat RN yalang singulyarlik atrofida ikkita mumkin bo'lgan yopiq toroidal sohalardan birida sodir bo'lishi mumkin. Quyi qatorda $Q = 1.414$, $\omega = 1$ holati ko'rib chiqiladi. Potensial qudug'ining bir minimumi barqaror muvozanat holatiga mos keladi. Tor halqasining x yo'nalishidagi harakati cheklangan. Kichik potensial to'siq ham mavjud bo'lib, tor halqasining $z = 0$ ekvatorial tekislikni kesib o'tishiga qarshilik ko'rsatadi. Tor halqasi x yo'nalishidagi tebranish energiyasini yo'qotib, cheksizlikka qochadi (4(f)-rasm).

Ruxsat etilgan qora tuynuk zaryadi Q va tor halqa zaryadi parametri ω uchun egizak yuqori chastotali KDTning yuqori chastotasi qora tuynuk massasi M ga bog'liq bo'lishi mumkin. Agar qora tuynuk massasi odatda bo'lgani kabi, alohida kuzatishlar bilan cheklangan bo'lsa, 5-rasmda ko'rsatilganidek, biz tor halqa rezonansli tebranishlar modeli bo'yicha ba'zi cheklovlarni olamiz. Bu erda vaziyat qora tuynuk zaryadining Q va qora tuynuk massasi chegaralarining bir necha qiymatlari uchun 1-jadvalda keltirilganidek ko'rsatilgan. Biz Shvartsshild qora tuynugiga ($Q = 0$) torli halqa modeli GRS 1915+105 da faqat yuqori chastotali KDT larni tushuntira olishini ko'rishimiz mumkin. Qora tuynuk zaryadi Q va ω parametrini kiritgan holda, ipli halqa rezonansli tebranishlari modeli uning qo'llanilishi sohasini kengaytiradi. $\omega = 1$ va $Q = 0.5, 0.8$ holatlar uchun model GRO 1655-40 manbasidan kuzatilgan qiymatlarni to'liq tavsiflaydi. U 1-jadvaldan kutilgan massa diapazonini o'z ichiga oladi. Shunga qaramay, Reissner-Nordstrom fonida tor halqa rezonansli tebranish modeli XTE 1550-564 manbasidan kuzatilgan qiymatlarni tushuntirib bera olmaydi. ω parametrining har qanday qiymati va qora tuynuk zaryadining Q har qanday past qiymatlari uchun tor halqa modeli XTE 1550-564 manbasi uchun kuzatilgan massa diapazoniga mos kelmaydi va qora tuynuk aylanishining qo'shimcha ta'sirini kutish kerak.

1-jadval

Uchta mikrokvazar uchun kuzatilgan egizak yuqori chastotali KDT ma'lumotlari va ulardagi qora tuynuklarning massasiga qo'yilgan cheklovlar, yuqori chastotali KDT o'lchovlariga asoslangan mustaqil o'lchovlar orqali aniqlangan.

Source	GRO 1655-40	XTE 1550-564	GRS 1915+105
ν_U (Hz)	447–453	273–279	165–171
ν_L (Hz)	295–305	179–189	108–118
$M/M_\odot$	6.03–6.57	8.5–9.7	9.6–18.4

Bundan tashqari, 5-rasmda biz qora tuynuk massasining taxmin qilingan qiymati qora tuynuk zaryadining Q ortishi bilan ortib borayotganini aniq ko'rishimiz mumkin. Q parametri ortib borishi bilan kuzatilgan yuqori chastotali KDT larini moslashtirish tobora qiyinlashadi, shuning uchun yangi Q parametrini yuqori chastotali KDT zanjiri modeliga kiritish mikrokvazarlarda kuzatilgan yuqori chastotali KDT larni tushuntirishda samarali emas degan xulosaga kelish mumkin.
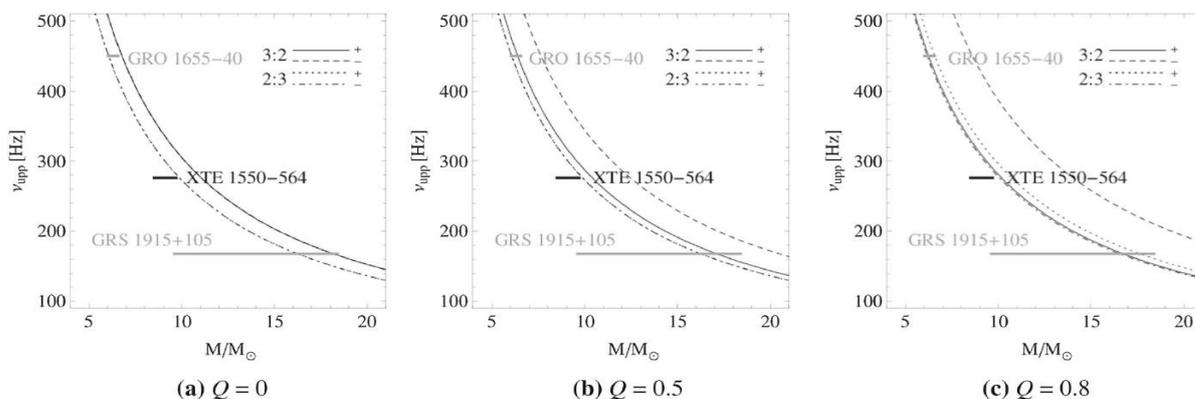
5-rasm 3:2 yoki 2:3 rezonansli radiuslardagi ipli halqa tebranishlarining yuqori chastotasi ω, ipli halqaning makipal diapazoni ν_U parametriga ega bo'lgan tor halqa modeli doirasida bir nechta qiymatlar uchun qora tuynuk massasining funksiyasi sifatida hisoblangan. qora tuynuk zaryadi $Q = 0$ chap, 0,5 o'rta, 0,8 o'ng panel.

XULOSA

Tadqiqot natijalarining ilmiy ahamiyati ularning Kerr-Kiselev qora tuynuklari atrofidagi umumiy nisbiylik nazariyasi doirasida spinli va spinsiz sinov zarralarining energetik jarayonlari va zarrachalar dinamikasini tushunishga qo'shgan hissasidir. Bundan tashqari, olingan natijalar Kerr-Kiselev qora tuynuklari atrofidagi sinov zarralarining eng kichik va eng katta doiraviy orbitalarining energiyasi va impuls momentining kvintessensiya, qora tuynuk va zarracha spiniga bog'liqligi mohiyatini tushunishga yordam beradi. Bundan tashqari, qora tuynuk parametrlari uchun olingan cheklovlar qora tuynukni o'rab turgan fazo-vaqtning tortishish xususiyatlari haqida tushuncha beradi, bu esa qaysi tortishish effekti dominant rol o'ynashini aniqlash imkonini beradi. Topilmalar, shuningdek, qora tuynuk ikkiliklaridan olingan yuqori chastotali kvazi-davriy tebranishlar kuzatuv ma'lumotlari asosida yulduz massasidagi qora tuynuklarning parametrlarini va ular atrofidagi fazo-vaqt xususiyatlarini aniqlash imkonini beradi.

OTEEV TURSINBAY POLATBAEVICH

PARTICLE AND STRING DYNAMICS IN AXIALLY SYMMETRIC SPACETIMES

01.04.02 - Theoretical physics
01.03.01 - Astronomy

DISSERTATION ABSTRACT
of the doctor of philosophy (PhD) on physical and mathematical sciences

Tashkent – 2024

The theme of the dissertation of the doctor of philosophy (PhD) on physical and mathematical sciences was registered by the Supreme Attestation Commission of the Cabinet of Ministers of the Republic of Uzbekistan under No. B2024.2.PhD/FM1093.

The PhD dissertation was carried out at Institute of Fundamental and Applied Research under the National Research University "TIIAME" .

The abstract of the dissertation was posted in three (Uzbek, English, Russian (resume)) languages on the website of the Scientific Council at the address of www.ifar.uz and on the website of "Ziyonet" information and educational portal at www.ziyonet.uz.

Scientific consultants:	**Ahmedov Bobomurat Juraevich,** Doctor of Sciences in Physics and Mathematics, Professor **Djavlanbek Rayimbaev Radjapbaevich,** Doctor of Sciences in Physics and Mathematics
Official opponents:	**Narzilloev Bakhtiyor Murot ugli,** Doctor of Sciences in Physics and Mathematics **Tajimuratov Pulat Sadullaevich** Doctor of Philosophy in Physical and Mathematical Sciences
Leading organization:	**Al-Farabi Kazakh National University**

The defense of the dissertation will be held on "_____" _____ 2025 at _____ in the meeting of the Scientific Council No. DSc.03/31.03.2022.T/FM.10.04 at the Institute of Fundamental and Applied Research under the National Research University "TIIAME" (Address: 100000, Tashkent city, Qori Niyazov Street 39, Institute of Fundamental and Applied Research, Hall 108; tel.: 71 237-09-62.; e-mail: info@ifar.uz

The doctoral (PhD) dissertation can be looked through at the Information Resource Center of the Institute of Fundamental and Applied Research under the National Research University "TIIAME" (registered under № _____). (Address: 100000, Tashkent city, 39 Qori Niyazov str., Institute of Fundamental and Applied Research, hall 108; ph.: 71 237-09-62.

The Abstract of the dissertation was distributed on " 26 " December, 2024.
(Registry record № 17 dated " 5 " December, 2024)

B.A.Toshmatov
Deputy Chairman of the Scientific Council on Award of Scientific Degrees, D.Ph.-M.S.

Sh.N.Mardonov
Scientific Secretary of Scientific Council on Award of Scientific Degrees, D. Ph.-M.S.

B.M. Narzilloev
Chairman of the Scientific Seminar of the Scientific Council on Award of Scientific Degrees, D. Ph.-M.S.

Topicality and demand of the theme of dissertation. Currently, there is an increased interest in the world in the problems of studying energetic processes around black holes, quasi-periodic oscillations (QPOs) in intensity of receiving signals coming from the region of compact objects in space and they provide not only serious fundamental scientific research, but also important practical aspects. In this regard, the study of particle acceleration, energy extraction due to Banados-Silk-West and Penrose mechanisms around Kerr black holes (BHs) in quintessence, QPOs and acceleration of current-carrying string loops around Reissner-Nordstrom (RN) BH are very important.

In particular, the work is broadly inspired by the challenge of understanding the energy extraction mechanisms and the formation of collimated astrophysical jets. These jets are observed in a variety of systems, including accreting young stars, neutron stars, black holes, and supermassive black holes in quasars and active galactic nuclei. Magnetized plasmas interacting with accretion disks are thought to play a fundamental role in the production of these jets. However, despite significant progress and numerous proposed mechanisms, the exact process remains unclear. The behavior of these plasmas is governed by magnetohydrodynamics (MHD), a complex and nonlinear field theory. Under specific conditions, plasmas can exhibit string-like properties. This behavior may arise from the dynamics of magnetic field lines embedded within the plasma or from the motion of relatively thin, isolated flux tubes of plasma, which can be approximately modeled as one-dimensional strings. In such scenarios, these strings are characterized by energy density and tension and may carry currents of mass and/or charge. The aim is to capture key aspects of the underlying physics using string dynamics. This approach offers a significantly simpler framework compared to the complexity of MHD, making it a promising tool for exploring the fundamental mechanisms behind jet formation.

Energy extraction mechanisms from the ergosphere and the dynamics of current-carrying strings within the framework of both alternative and general theories of relativity have been extensively studied. However, these studies have not focused on particle acceleration and energy extraction processes around Kerr-Kiselev black holes. Additionally, the dynamics of spinning test particles near Kerr-Kiselev black holes have not been widely explored. Moreover, research on testing gravity theories and constraining parameters of charged black holes using current-carrying string loops based on observational data from QPOs has not been conducted. Studies involving electromagnetic interactions, such as the acceleration of current-carrying string loops along the vertical axis and their ejection from the neighborhood of Reissner-Nordström black holes, are also limited.

In our country, significant emphasis is placed on practical research in astronomy and theoretical astrophysics, as well as on the international collaboration in fundamental research. The Strategy of Actions for the Further Development of the Republic of Uzbekistan (2017–2021) highlights the advancement of science within the nation, identifies key areas of fundamental research, and outlines methods for applying the outcomes of such research within Uzbekistan. The results obtained in this dissertation helps to understand the nature

of quintessence, which is one of the models explaining the expanding universe at an accelerating rate, the dynamics of the spinning particles around Kerr-Kiselev BHs, the QPOs coming from the GRO 1655-40 source. Additionally, the oscillatory energy of the charged rings, through its translational motion, explains the acceleration of plasma flows along the vertical axis of the black hole, and quantitatively determines their Lorentz factor.

This research aligns with the objectives outlined in the Decrees of the President of the Republic of Uzbekistan, including Decree No. UP-6097 "On the Approval of the Concept for the Development of Science Until 2030" dated October 29, 2020, as well as other relevant legal and regulatory documents in this field.

Relevance of the research to the priority areas of science and technology development of the Republic of Uzbekistan. The dissertation research has been carried out in accordance with the priority areas of science and technology in the Republic of Uzbekistan: Decree of the President of the Republic of Uzbekistan No. UP-4947 "On the Strategy of Actions for the Further Development of the Republic of Uzbekistan" dated February 07, 2017.

Degree of study of the problem. The processes of energy extraction around black holes (BHs) have been extensively studied within the framework of various gravity theories. Significant contribution has been made by researchers from different regions. In Europe, scholars such as Oleg Zaslavskii, Gregor Ovcharenko, Luc Blanchet, Alexei Deriglazov, Eva Heckmann, Valeria Kagramanova, Zdeněk Stuchlík, and Jan Schee have conducted notable researches. Similarly, in Asia, important studies have been carried out by Sushant Ghosh, Mubasher Jamil, Yaghoub Haydarzade, and Suzuki Shingo.

Radiation mechanisms in the accretion disks of black holes, particularly the generation and analysis of QPOs within the framework of general and alternative gravity theories, have also been widely investigated. European researchers such as Lucianno Rezzolla, Marek Abramowicz, Gabriel Torok, Pavel Bakala, Zdeněk Stuchlík, and Martin Kolos have contributed significantly to this area. In the USA, scientists including Sara Motta, Luigi Stella, Mario Vietri, and Robert Wagoner have made substantial progress. Additionally, notable work have been conducted by researchers from Japan, such as Shoji Kato and Jun Fukue, as well as from China, including Zhongxiang Wang, Xiang-Dong Li, and Shuang-Nan Zhang.

In our country, theoretical studies on the dynamics and energetic processes around black holes in various gravity theories have been carried out by Bobomurat Ahmedov, Ahmadjon Abdujabbarov, Javlon Rayimbaev, Farrukh Atamuratov, Bobir Toshmatov, Sanjar Shaymatov, and Bakhtiyor Narzilloev etc,.

Connection of the topic of dissertation with the scientific researches of the higher educational institutions, where the dissertation is completed. This dissertation work was carried out within the framework of the scientific project No. F2-FA-F113 and No. F2-FA-F029 of the Academy of Sciences of the Republic of Uzbekistan.

The aim of the research of the dissertation is exploring the dynamics of (non)spinning particles and energy extraction processes around black holes in axially symmetric spacetime in the presence of quintessential field.

The tasks of the research. Study the motion and collisions of spinning and non-spinning neutral test particles around a rotating BH immersed in quintessential dark energy; Investigate the motion of the current carrying charged string loops in the RN BH background combining the gravitational and electromagnetic field; Constraining the BH charge and mass using QPO data;

The objects of the research are relativistic compact gravitating objects immersed in quintessence, charged BHs, spinning neutral particles and current-carrying string loops.

The subjects of the research acceleration of particles and current-carrying strings, energy extraction processes around Kerr-Kiselev BHs through Penrose and BSW mechanisms, HF QPOs in BH binaries.

The methods of the research are mathematical techniques for analyzing experimental data, mathematical apparatus of General Relativity and numerical methods of statistics.

The scientific novelty of the research is as follows:

for the first time, it is shown that the center-of-mass energy of the colliding particles decreases as quintessential field parameter increases;

for the first time, it is shown that the spinning particles with the biggest spins can stay closest to the stable orbits around the KK black hole;

for the first time, demonstrated the decrease of the ISCO energy due to an increase in black hole spin and the independence of OSCO energy on the black hole and particle spin;

for the first time, in the field of RN naked singularities, found two closed toroidal regions for charged string loop motion;

for the first time, found the compatibility of string loop harmonic oscillations around stable equilibrium in the field of RN BH with HF QPOs observed data from the GRO1655-40 source;

for the first time, it is demonstrated that the RN black hole charge Q does not contribute to the acceleration speeds of the string loop due to electrostatic repulsion.

Practical results of the research are as follows:

for the first time, constraints for the mass of the BH in the microquasar GRO 1655-40, XTE 1550-564, GRS 1915-105 are obtained using observational data from twin peak QPOs;

for the first time, demonstrated the effect of BH and string loop charges interaction on the string loop acceleration in the RN BH neighborhood, which is one of the possible explanations of relativistic jets coming from AGN;

for the first time, it is found that the quintessence field decreases the energy extraction efficiency through the Penrose process.

Reliability of the research results is provided with the following: modern methods of general relativity and theoretical physics and highly effective numerical methods and algorithms are used; careful check of consistency of the received theoretical results with observational data and results of other authors is

performed; conclusions are well consistent with the main provisions of the field theory of gravitational compact objects.

Scientific and practical significance of the research results.

The obtained results can help comprehend the energetic processes and particle dynamics of spinning and non-spinning test particles around Kerr-Kiselev BHs in the general theory of relativity;

the obtained constraints for the parameters of BHs may allow getting information about the gravitational feature of the spacetime around the BHs, giving the possibility of determining which gravitational effect plays a dominant role;

the obtained results may help to determine the parameters of stellar mass BHs together with the space-time features around them based on observational data from HF QPOs from BH binaries, and the results made it possible to explain the physical mechanisms in the oscillations of accretion discs.

Implementation of the research results. The results of the study of the particle dynamics around a rotating BH in quintessence BH and charged string dynamics around RN BH in various gravity theories have been applied as follows:

The approach of determining the particle dynamics around various BHs in quintessence based on observational data has been used by several authors in the investigations of spacetime properties around BHs as well as gravitational models (Physics Letters B, 771, 365-373, (2017), International Journal of Modern Physics D, Volume 26, Issue 6, id. 1750051-23, (2017), The European Physical Journal C, Volume 78, Issue 9, article id. 750, 13 pp, (2018), Physical Review D, Volume 95, Issue 6, id.064015,(2017), The European Physical Journal C, Volume 78, Issue 6, article id. 513, 12 pp, (2018), Physical Review D, Volume 102, Issue 10, article id.104062, (2020). The results have been provided to make possible analyses in numerous dark matter models around BHs based on observational data of BHs.

Several authors have used the approach of analyzing the charged string dynamics around RN BHs in the investigations of spacetime properties around numerous BHs as well as gravitational models (Classical and Quantum Gravity, Volume 37, Issue 24, id.245007, 21 pp, (2020), Physics of the Dark Universe, Volume 44, id.101483, (2024), The European Physical Journal C, Volume 82, Issue 5, article id.494, (2022), Physics of the Dark Universe, Volume 26, article id. 100331, (2019), Chinese Journal of Physics, vol. 70, pp. 55-68, (2021). The results have been provided to make possible analyses in various models of perfect fluids encircling BHs based on observational data of BHs.

We have investigated the ISCOs and OSCOs of spinning test particles and their energy and angular momentum at the orbits. One can explain that OSCOs exist due to the cosmological-like horizon caused by the quintessential field. This shows that the ISCO and OSCO coincide at critical values of the quintessential field and EoS parameters, which also depend on the particle and black hole spin. Finally, we consider collisions of spinning particles and analyze the center-of-mass energies and critical angular momentum, which allows the collisions of the particles near the black hole. It is shown that the spinning particles with the biggest spins can stay closest to the stable orbits around the KK black hole. Also, there is a decrease in the ISCO energy due to an increase in black hole spin, which decreases rapidly for highly spinning particles. However, the OSCO energy does not depend

24

on the black hole and particle spin. The OSCO and ISCO energies also decrease as the quintessential field parameter increases. The quintessential field parameter has an upper value where the OSCO and ISCO coincide, and the upper limit increases with the increase in the particle spin due to an additional interaction between the quintessential field and particle spin. Moreover, one can also observe an increase in the spin of the particles, which causes decreasing energy values. The OSCO and ISCO energies increase with increasing ω_q and sensitivity for the OSCO energy compared to the ISCO. Similarly, an upper limit in the value of the ω_q parameter also decreases due to an increase in s. In the first row, we can observe thin vertical lines that imply the maximum value of s, called superluminal bounds. Similar behaviors of ISCO and OSCO angular momentum can be observed as it is in the energy.

Finally, in the last section, we studied spinning particle collisions near the KK black holes. First, we analyzed critical values of the angular momentum with which the particles can collide near the horizon. We found that the angular momentum decreases with the increase of the black hole spin. Inversely, it increases due to the increase of the quintessential field parameter. The effect of the EoS parameter on the angular momentum is almost negligible for the particles with the positive spin. Moreover, we have analyzed the center of mass energy in the collisions of the spinning particle with positive and negative spin parameters (orientation). It is obtained that the energy increases as $\omega_q \rightarrow -1$; in particular, the energy decreases radially, but at some distance, it increases again due to the presence of the exotic matter with negative pressure similar to the dark energy. The energy also increases due to the increase of the quintessential field parameter. However, the effects of the quintessential field and EoS parameter on the energy are negligible near the black hole horizon. However, the black hole spin causes a decrease in the energy. The center of mass energy is bigger in the configuration of $L < 0 \ \& \ s > 0$ compared to the cases $L > 0 \ \& \ s < 0$ L>0. It is shown that the energy is essentially bigger in the cases $L_1 > 0 \ \& \ s_1 > 0$ and $L_2 < 0 \ \ \& \ s_2 < 0$ from all other combinations.

Approbation of the research results. The dissertation results have been discussed in 1 international and 1 local conference.

Publication of the research results more than 6 scientific publications have been made on research results, and 3 of them are research papers in refereed journals.

Volume and structure of the dissertation. The dissertation consists of an introduction, three chapters, a conclusion, and a list of references. The size of the dissertation is 88 pages.

THE MAIN CONTENTS OF THE DISSERTATION

In the introduction the topicality and demand of the dissertation theme, the main aims set out on the dissertation and the scientific novelty and the practical results were emphasized, the reliability of the results and their theoretical and practical significance were stated, the application of the research results and the dissertation structure were given. Throughout the abstract we use geometric units

such that the gravitational constant and the speed of light are both equal to unity $G = c = 1$.

The first chapter of the dissertation entitled **"Energy extraction and particle acceleration around a rotating black hole in quintessence"** is devoted to the study of energy extraction processes from rotating black holes in quintessence through Banados-Silk-West(BSW) and Penrose mechanisms.

Distant Ia-type supernova explosions confirm that a very small relict repulsive cosmological constant $\Lambda > 0$, in other words, a dark energy demonstrating repulsive gravitational effect is necessary to explain the accelerated expansion of the Universe at the current epoch of evolution. These results are supported through observation of the cosmic microwave background thermal anisotropies by the space observatory PLANCK. The dark energy represents more than 73% of the total energy content of the observable universe, and the equation of the state of the dark energy is similar to that of the vacuum energy. However, dark energy is related to the so-called quintessence and is not excluded. The quintessence is defined as a scalar field coupled to gravity with the potential which decreases as the gravitational field increases. The cosmological and astrophysical phenomena of cosmic repulsion provide a recent value of the cosmological constant to be $\Lambda \approx 1.3 \times 10^{-56} \, cm^{-2}$

The solution for a quintessential static black hole can be generalized to the rotational one using the standard methods developed by Newman and Janis. The line element of the quintessential rotating spacetime in the standard Boyer-Lindquist coordinates takes the form

$$ds^2 = g_{tt}dt^2 + g_{rr}dr^2 + 2g_{t\phi}drd\phi + g_{\theta\theta}d\theta^2 + g_{\phi\phi}d\phi^2 \qquad (1.1)$$

with

$$g_{tt} = -1 + \frac{2Mr + Cr^{1-3\omega_q}}{r^2 + a^2cos^2\theta},$$

$$g_{rr} = \frac{r^2 + a^2cos^2\theta}{a^2 - 2Mr + r^2 - Cr^{1-3\omega_q}},$$

$$g_{t\phi} = -a\frac{2Mr + Cr^{1-3\omega_q}}{r^2 + a^2cos^2\theta}sin^2\theta,$$

$$g_{\theta\theta} = r^2 + a^2cos^2\theta,$$

$$g_{\phi\phi} = (r^2 + a^2 + a^2sin^2\theta\frac{2Mr + Cr^{1-3\omega_q}}{r^2 + a^2cos^2\theta})sin^2\theta . \quad (1.2)$$

Here, M and a are the black hole's gravitational mass and the specific angular momentum, respectively. $\omega_q \in (-1. -1/3)$ is the dimensionless quintessential equation of state parameter, and it governs the quintessential field's equation of state as $p = \omega_q\rho$, where p and ρ are the pressure and energy density of the quintessential field, respectively. The presence of the quintessential field leads to the geometry being Ricci non-flat. When the quintessential field parameter $C = 0$, the rotating quintessential geometry reduces to the known Kerr geometry; further, taking $a = 0$ and $C = 0$ limits, one can also arrive at the Schwarzschild metric.

Now, based on the BSW mechanism of the energy extraction from the rotating black hole, we calculate the center-of-mass energy E_{CM} for a collision of two particles with mass $m_1 = m_2 = m_0$ in the vicinity of a rotating black hole in

quintessence. We assume that particles are coming from infinity with $\frac{E_1}{m_1} = \frac{E_2}{m_2} = 1$ and approaching the black hole with the different angular momenta L_1 and L_2 as well as the particles' motion and their collision occur in the equatorial plane $\theta = \frac{\pi}{2}$.

The center of mass energy can be found by using the following well-known formula:

$$\frac{E_{CM}^2}{2m_0^2} = 1 - g_{\mu\nu}u_1^\mu \ u_2^\nu \quad (3)$$

where u_1^μ and u_2^ν are four velocities of the first and second particles, respectively. The four velocities of the particle that is moving around the rotating quintessential black hole in the equatorial plane are given by the expressions $\dot{t} = \frac{g_{\phi\phi}E + g_{t\phi}L}{g_{t\phi}^2 - g_{tt}g_{\phi\phi}}$ and $\dot{\phi} = \frac{g_{t\phi}E + g_{tt}L}{g_{t\phi}^2 - g_{tt}g_{\phi\phi}}$. For simplicity, assuming $E_1 = E_2 = 1$ and inserting the expressions for four velocities into (3), one can obtain the center-of-mass energy as

$$\frac{E_{CM}^2}{2m_0^2} = \{C(a - L_1)(a - L_2) - Cr^2$$
$$+ r^{3\omega_q}[-2a(L_1 + L_2)M + L_1L_2(2M - r)$$
$$+ 2r^2(-M + r) + 2a^2(M + r)] - [C(a - L_1)^2$$
$$+ Cr^2 + r^{3\omega_q}[2(a - L_1)^2M - L_1^2r + 2Mr^2]]^{\frac{1}{2}} \times [C[(a - L_2)^2 + r^2]$$
$$r^{3\omega_q}[2(a - L_2)^2M - L_2^2r + 2Mr^2]]^{\frac{1}{2}}\} \times [-Cr^2 + r^{3\omega_q+1}(a^2 - 2Mr + r^2)]^{-1}$$

Now we investigate the dependence of $\frac{E_{CM}^2}{2m_0^2}$ on the quintessence matter parameter C, the quintessence field parameter ω_q and the specific angular momentum a.
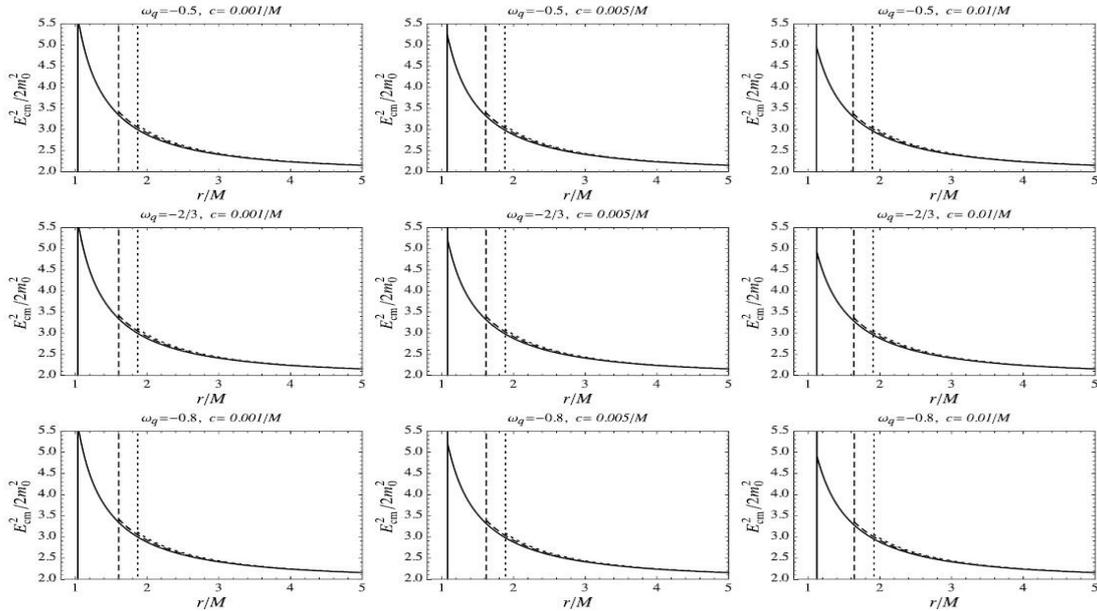

Fig.1 The radial dependence of the center of mass energy of two colliding particles for the different values of the rotation parameter a, quintessential equation of state parameter ω_q and the quintessential field parameter C.

The solid, dashed and dotted lines correspond to the values of the rotation parameter $a = 1$; 0.8 and 0.5, respectively.

Fig.1 represents the radial dependence of the center of mass energy (particularly $\frac{E_{CM}^2}{2m_0^2}$) for the different values of the rotation parameter a, the quintessential equation of state parameter ω_q and the quintessential field parameter C, where the angular momentum of the particles is chosen as $L_1 = \sqrt{2}, L_2 = -\sqrt{2}$, for simplicity. From Fig.1 one can easily see that the existence of the quintessential field parameter C leads to the decrease of the center of mass energy.

In the second section, named "**Circular motion and collisions of spinning test particles around Kerr-Kiselev black holes**" we plan to extend our calculations to spinning test particles motion around a rotating black hole in quintessence. Basically we aimed to investigate the influence of the neutral particles spin on the dynamics of the particle. First we investigate the effective potential which is a crucial quantity governing the particle dynamics. Analytical expression for the effective potential is found in a quite complicated form.

It is defined as following

$$V_{eff} = \frac{-B + \sqrt{B^2 - 4AD}}{2A}$$

where

$A = 4r^{12-6\omega_q}(4a^3 sr^{3\omega_q+1}(3C\omega_q + C + 2r^{3\omega_q}) + a^2(C^2(3s\omega_q + s)^2 + 4Cr^{3\omega_q}(r^3 + 3(r+1)s^2\omega_q + rs^2 + s^2) + 4((r+2)r^3 + (2r+1)s^2)r^{6\omega_q} + 12asr^{3\omega_q+3}(C\omega_q + C + 2r^{3\omega_q}) + 4r^{3\omega_q+3}(Cs^2 + (r^3 - (r-2)s^2)r^{3\omega_q})$,

$B = -8jr^{12-6\omega_q}(4a^2sr^{3\omega_q+1}(C\omega_q + C + 2r^{3\omega_q}) + aC^2(3s\omega_q + s)^2 + 2aCr^{3\omega_q}(2r^3 + 3(r+2)s^2\omega_q + rs^2 + 2s^2) + 4a(2r^3 + (r+1)s^2)r^{6\omega_q} + 6Cs(\omega_q + 1)r^{3\omega_q+3} - 4(r-3)sr^{6\omega_q+3}$,

$D = -4r^{10-9\omega_q}(C^2s^2(3\omega_q + 1)r^{3\omega_q}(3s^2\omega_q(a^2 + (r-2)r) + a^2s^2 - j^2r^2(3\omega_q + 1) + 4r^4 + (r-6)rs^2 - 4Cr^{6\omega_q}((r^3 - s^2)(3s^2\omega_q(a^2 + (r-2)r) + a^2s^2 + r^4 + (r-3)rs^2 + j^2r^2(3s\omega_q(ar+s) + ars + r^3 + s^2)) + 4r^{9\omega_q}((a^2 + (r-2)r)(r^3 - s^2)^2 + j^2r^2(-2ars + (r-2)r^3 - s^2)) - C^3rs^4(3\omega_q + 1)^2$. (2.1)

Fig.2 shows the radial dependence of the effective potential of the spin test particle orbiting a rotating black hole for the different spin values of the test particle. The graphic on the right-hand side presents the behavior of the effective potential for the case of a corotating particle with positive angular momentum. It is seen that for fast-spinning particles, $s = 1$, there are more stable bound orbits than slow-spinning particles $s = 0.5$. As a particle's spin decreases, the height of the potential barrier holding it in a bound orbit decreases, and this tendency keeps growing for counter-spinning particles. Furthermore, stable circular orbits are found for counter-rotating particles. From the left bottom graphic, it can be concluded that contour-rotating particles can have stable circular orbits only if they are counter-spinning fast enough. Particles can't have stable bound orbits if the particle is counter-rotating and counter-spinning. On the right is presented the situation for slow-rotating black holes. The two graphics show that the stability of

the particles in the slow-rotating black hole case is very similar to that of the fast-rotating black hole. The only difference is that the counter-rotating particle can have a more stable bound orbit if it carries the same negative spin $s = -1$.
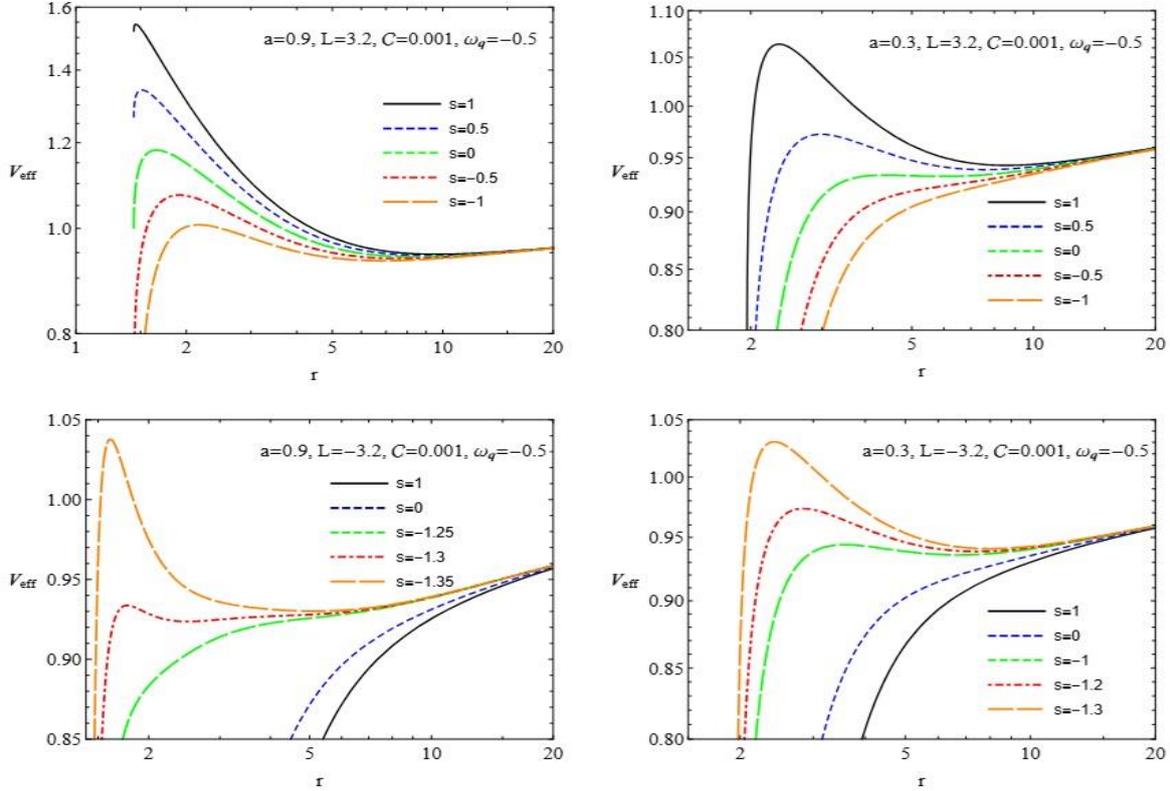

Fig.2 Radial profiles of the effective potential for rapidly rotating (left column) and slow rotating (right column) quintessential black hole cases for different values of the test particle's spin s.

Fig.3, shows the radial dependence of the effective potential for different values of the C parameter (left panel) and the quintessential parameter ω_q (right panel). As observed from the graphics for the co-rotating particles (blue lines), as the quintessential field parameter C increases, the interval allowed for stable orbits also increases. From an astrophysical point of view, it means that, with increasing the quintessential field parameter C, which is considered to be responsible for the strength of the quintessential field, the radius of the accretion disc also increases for both fast-rotating and slow-rotating black holes. While counter-rotating black holes (red lines), there are stable bound orbits for the co-spinning particles, and they fall into a black hole for both fast-rotating and slow-rotating black holes. Next, in the right panel of Fig.3, we demonstrate the radial behavior of the effective potential for different values of the quintessential parameter ω_q. From both graphics, stable bound orbits are possible only for small values of ω_q. When quintessential parameter ω_q increases, the stability of bound orbits is lost. From an astrophysical point of view, similar to the previous case, Fig.3 as ω_q increases, the radius of the accretion disc becomes bigger and bigger and further leaves only a potential barrier keeping particles from falling into a black hole. This means

particles cannot have bound orbits and may come close to the black hole horizon at a particular distance and return to infinity.
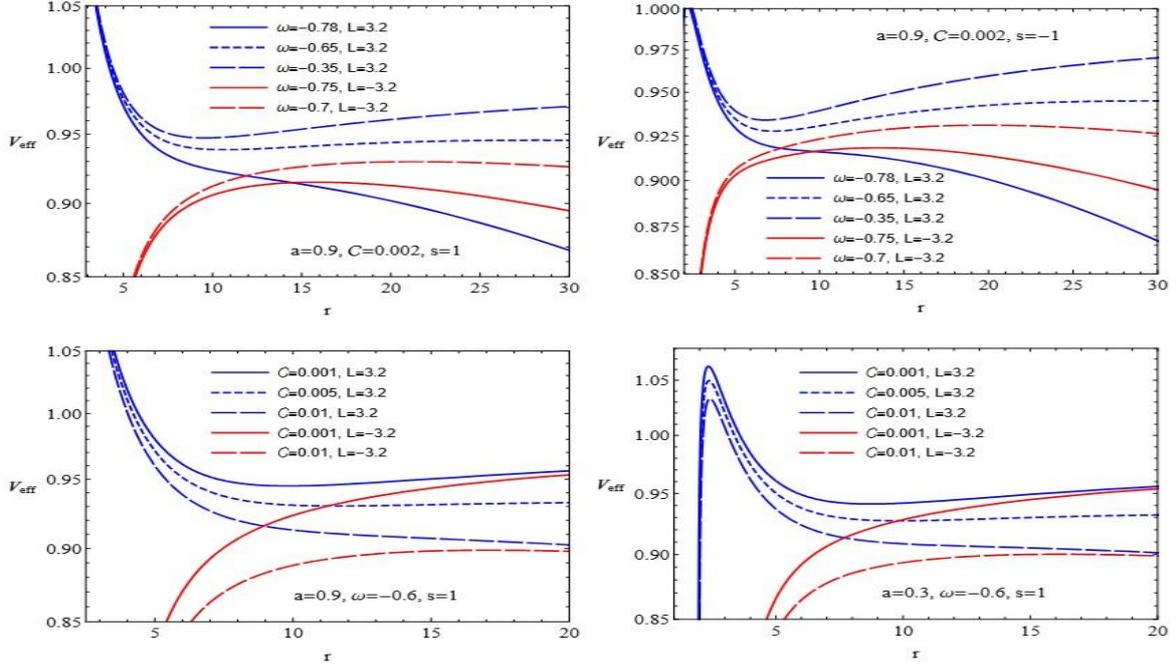

Fig.3 The same figure with Fig.2 but for different values of the quintessential field parameter C (bottom panels) and the quintessential parameter ω_q(top panels).

In the third section, titled "**Charged string loops in Reissner–Nordstrom black hole background**", we study the motion of current carrying charged string loops in the Reissner–Nordström black hole background combining the gravitational and electromagnetic field. Introducing new electromagnetic interaction between central charge and charged string loop makes the string loop equations of motion to be non-integrable even in the flat spacetime limit, but it can be governed by an effective potential even in the black hole background. We classify different types of the string loop trajectories using effective potential approach, and we compare the innermost stable string loop positions with loci of the charged particle innermost stable orbits.We examine string loop small oscillations around minima of the string loop effective potential, and we plot radial profiles of the string loop oscillation frequencies for both the radial and vertical modes. We construct a charged string loop quasi-periodic oscillations model and we compare it with observed data from microquasars GRO 1655-40, XTE 1550-564, and GRS 1915+105. We also study the acceleration of current carrying string loops along the vertical axis and the string loop ejection from RN black hole neighbourhood, taking also into account the electromagnetic interaction.

The gravitational interaction of the string loop with the central electrically charged black hole occurs through the spherically symmetric Reissner-Nordstrom (RN) metric given by the line element expressed in geometric units with the metric function reads

$$f(r) = 1 - \frac{2M}{r} + \frac{Q^2}{r^2} \quad (3.1)$$

30

In the metric function $f(r)$, the parameter M stands for the black hole mass, while Q stands for the black hole charge.

For $0 \leq Q < M$, the metric describes a black hole with two event horizons located at

$$r_{h\pm} = M \pm \sqrt{M^2 - Q^2} \quad (3.2)$$

for $Q = M$ there is just one degenerate event horizon solution, for $Q > M$ we have naked singularity without horizons. Hereafter, in this chapter, we will use, for simplicity, the system of units in which the mass of the black hole is $M = 1$, i.e., we express the related quantities in units of the black hole mass.

For string loop motion in the Reissner Nordstrom background, the general form of the Hamiltonian reduces to

$$H = \frac{1}{2} f(r) P_r^2 + \frac{1}{2r^2} P_\theta^2 + \frac{1}{2} \left(\frac{J}{r \sin\theta} + r \sin\theta \right)^2 - \frac{1}{2f(r)} \left(E - \frac{\Omega Q}{r} \right)^2.$$

As the whole axisymmetric string loop can be represented by a single point that a coordinate $y = 0$ can characterize, we can introduce the effective potential for charged string loop in the form

$$V_{eff}(x, r, Q, J, \omega) = \sqrt{1 - \frac{2M}{r} + \frac{Q^2}{r^2} \left(\mu x + \frac{J^2}{x} \right) + \frac{\sqrt{2}\omega J Q}{r}}$$

where r is radial distance $r^2 = x^2 + z^2$ and μ - string tension, J - angular parameter, ω - charge parameters.

In Fig.4(a), we show trajectories of the string loop's motion cross-section along with the boundary energy profiles - we observe that the motion is trapped in the closed region. String loop's trajectory for this case is given in Fig.4(b); we can conclude that the motion is finite in the z-direction, the energy boundary profile is open to the black hole, and the string finally falls to the black hole. In the last case of $= 0.3$, $\omega = -1$ configuration, we take $J = 4$ value. In this case, there is no possible-trapped motion, and the string loop has to escape to infinity in the vertical direction (Fig.4(c)). Another possible string loop trajectory around the black hole is given for $Q = 0.3$, $\omega = 1$, $J = 10$ case in Fig(d), with string escaping to infinity.

Medium line elements of represent the naked singularity $Q = 1.0677$, $\omega = 0$ case. The most distinctive behavior of the effective potential is given by the presence of two minima for $J = 5.5$. This indicates that the string loop has in the x-direction two stable positions around the naked singularity, and escape along the vertical direction is impossible for sufficiently low string loop energy. The trajectory of the string loop for this type of motion is given in Fig.4(e). This type of energy boundary profile corresponds to trapped motion - the trapped motion can occur in one of two possible closed toroidal spaces around the RN naked singularity. At the bottom line we consider $Q = 1.414$, $\omega = 1$ situation. One minimum of the potential well corresponds to the stable equilibrium position. The string loop's motion in x-direction is limited. A small potential barrier also exists, resisting the string loop to cross the $z = 0$ equatorial plane. String loop escapes to infinity, loosing oscillatory energy in the x direction (Fig.4(f)).
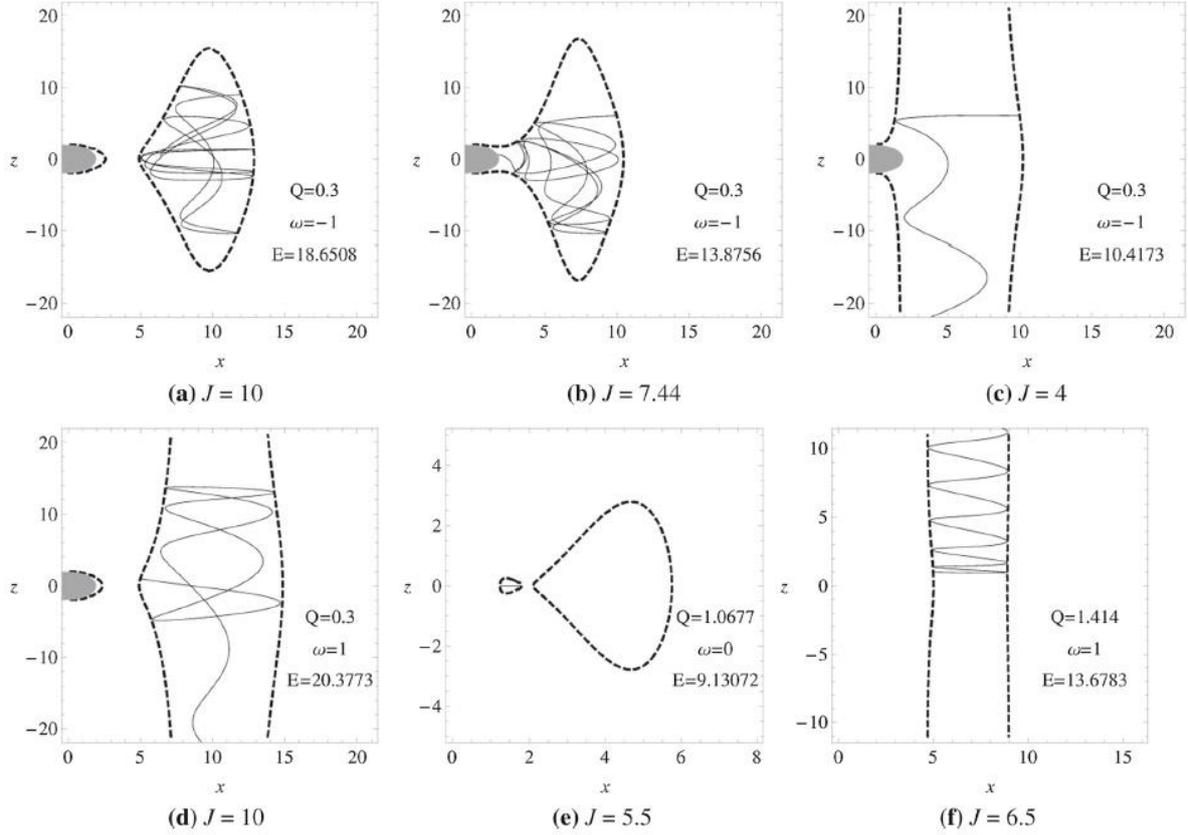
Fig.4 Trajectories of the string loop and energy boundaries of their motion. Various types of motion are possible: trapped in some "lake"-like region ((a), (e)), captured by a black hole (b), collapse or escape to infinity (c), escape to infinity ((d), (f)).

For fixed black hole charge Q and fixed string loop charge parameter ω, upper frequency of the twin HF QPOs can be given as a function of black hole's mass M. If the black hole mass is restricted by separated observations, as is commonly the case, we obtain some restrictions on the string loop resonant oscillations model, as illustrated in Fig.5. Here, the situation is demonstrated for several values of black hole's charge Q and limits on the black hole mass as given in Tab.1. We can see that for the Schwarzschild black hole ($Q = 0$), the string loop model can explain only the HF QPOs in GRS 1915+105. Introducing black hole charge Q and parameter ω, the string loop resonant oscillations model widens the area of its applicability. For $\omega = 1$ and $Q = 0.5, 0.8$ case, the model fully describes observed values from GRO 1655-40 source. It contains the whole range of expected mass range from Tab.1. Nevertheless, the string loop resonant oscillation model in Reissner-Nordstrom background can not explain the observed values from XTE 1550-564 source. For any value of ω parameter and for any low values of black hole charge Q, the string loop model can not fit observed mass range for the XTE 1550-564 source and an additional influence of the black hole rotation has to be expected.

Tab.1

Observed twin HF QPOs data for three microquasars, and the restrictions on mass of black holes located in them, based on independent measurements on the HF QPO measurements.

Source	GRO 1655-40	XTE 1550-564	GRS 1915+105
ν_U (Hz)	447–453	273–279	165–171
ν_L (Hz)	295–305	179–189	108–118
$M/M_\odot$	6.03–6.57	8.5–9.7	9.6–18.4

Moreover, in Fig.5 we can clearly see that the predicted value of the black hole mass is increasing with the black hole charge Q increase. It will become harder and harder to fit the observed HF QPOs as the Q parameter increases, hence we can conclude that introducing new parameter Q into the string loop HF QPOs model is not successfully efficient in explaining the observed HF QPOs in microquasars.
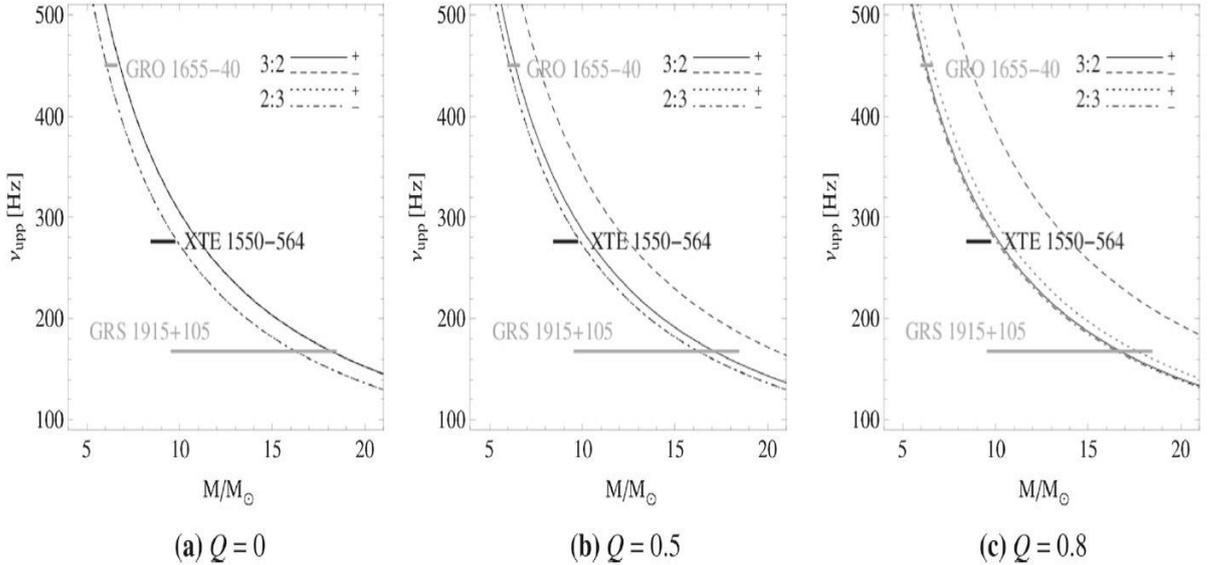

(a) $Q = 0$ (b) $Q = 0.5$ (c) $Q = 0.8$

Fig.5 The upper frequency ν_U of string loop oscillations at 3:2 or 2:3 resonant radii, calculated in the framework of the string loop model with maximal range string loop parameter ω as a function of black hole mass for several values of the black hole charge $Q = 0$ left, 0.5 middle, 0.8 right panels.

CONCLUSION

The scientific significance of the research results lies in their contribution to understanding the energetic processes and particle dynamics of rotating and non-rotating test particles in the framework of general relativity around the Kerr-Kiselev black hole. Additionally, the obtained results help to understand the nature of the dependence of the energy and angular momentum of the smallest and largest circular orbits of test particles around the Kerr-Kiselev black hole on quintessence, the black hole, and particle spin. Furthermore, the constraints derived for the black

hole parameters provide insights into the gravitational properties of spacetime surrounding the black hole, allowing the determination of which gravitational effect plays a dominant role. The findings also enable the determination of the parameters of stellar-mass black holes and the characteristics of the spacetime around them based on observational data from high-frequency quasi-periodic oscillations (HF QPOs) obtained from black hole binaries.

НАУЧНЫЙ СОВЕТ DSc.03/31.03.2022.T/FM.10.04 ПО ПРИСУЖДЕНИЮ УЧЕНЫХ СТЕПЕНЕЙ ПРИ ИНСТИТУТЕ ФУНДАМЕНТАЛЬНЫХ И ПРИКЛАДНЫХ ИССЛЕДОВАНИЙ НАЦИОНАЛЬНОГО ИССЛЕДОВАТЕЛЬСКОГО УНИВЕРСИТЕТА «ТИИИМСХ»

ИНСТИТУТ ФУНДАМЕНТАЛЬНЫХ И ПРИКЛАДНЫХ ИССЛЕДОВАНИЙ НАЦИОНАЛЬНОГО ИССЛЕДОВАТЕЛЬСКОГО УНИВЕРСИТЕТА «ТИИИМСХ»

ОТЕЕВ ТУРСЫНБАЙ ПОЛАТБАЕВИЧ

ДИНАМИКА ЧАСТИЦ И СТРУН В СИММЕТРИЧНЫХ ПРОСТРАНСТВАХ-ВРЕМЕНАХ

01.04.02- Теоретическая физика
01.03.02- Космическая физика и астрофизика

АВТОРЕФЕРАТ
диссертации доктора философии (PhD) по физико-математическим наукам

Ташкент – 2024

Тема диссертации зарегистрирована в Высшей аттестационной комиссии при Министерстве Высшего Образования, Науки и Инноваций Республики Узбекистан за B2024.2.PhD/FM1093.

Диссертация выполнена в Институте фундаментальных и прикладных исследований Национального исследовательского университета "ТИИМСХ". Автореферат диссертации на трех языках (узбекский, английский, русский (резюме)) размещен на веб-странице Научного совета (https://www.ifar.uz) и на Информационно-образовательном портале «ZiyoNet» (www.ziyonet.uz).

Научный руководитель:	**Ахмедов Бобомурат Жураевич** доктор физико-математических наук, профессор
	Райимбаев Джавланбек Раджапбаевич доктор физико-математических наук
Официальные оппоненты:	**Нарзиллоев Бахтиёр Мурот угли** доктор физико-математических наук
	Таджимуратов Пулат Садуллаевич кандидат физико-математических наук
Ведущая организация:	**Казахский национальный университет имени Аль-Фараби**

Защита диссертации состоится «____» _____ 2025 года в _____ часов на заседании Научного совета DSc.03/31.03.2022.T/FM.10.04 при Институте фундаментальных и прикладных исследований Национального исследовательского университета "ТИИМСХ". (Адрес: 100000, г. Ташкент, улица Кори Ниязова 39, Тел.: +998 71 237-09-61; факс: +998 71 234-09-62; e-mail: info@ifar.uz)

С диссертацией можно ознакомиться в Информационно-ресурсном центре Института фундаментальных и прикладных исследований Национального исследовательского университета "ТИИИМСХ" (зарегистрирована за № ____). (Адрес: 100000, г. Ташкент, улица Кори Ниязова 39, Тел.: +998 71 237-09-61).

Автореферат диссертации разослан « 26 » декабря 2024 года.
(протокол рассылки № 17 от « 5 » декабря 2024 года).

Б.А.Тошматов
Заместитель председателя Научного совета по присуждению ученых степеней, доктор физико-математческих наук

Ш.Н. Мардонов
ученый секретарь Научного совета по присуждению ученых степеней, доктор физико-математческих наук

Б.М.Нарзиллоев
председатель научного семинара при Научном совете по присуждению ученых степеней, доктор физико-математических наук

ВВЕДЕНИЕ (Аннотация PhD диссертации)

Актуальность и востребованность темы диссертации. В настоящее время в мире наблюдается повышенный интерес к проблемам изучения энергетических процессов вокруг черных дыр, квазипериодических колебаний (КПК) интенсивности приема сигналов, поступающих из области Заместитель председателякомпактных объектов в космосе, и они дают не только серьезные фундаментальные научные исследования, но и важные практические аспекты. В связи с этим изучение ускорения частиц, извлечения энергии за счет механизмов Banados-Silk-West и Penrose вокруг черных дыр Керра (ЧД) в квинтэссенции, КПК и ускорения струнных петель с током вокруг ЧД Рейсснера-Норстрома (РН) является актуальным.

В частности, работа во многом вдохновлена проблемой понимания механизмов извлечения энергии и формирования коллимированных астрофизических джетов. Эти джеты наблюдаются в различных системах, включая аккрецирующие молодые звезды, нейтронные звезды, черные дыры и сверхмассивные черные дыры в квазарах и активных ядрах галактик. Считается, что намагниченная плазма, взаимодействующая с аккреционными дисками, играет фундаментальную роль в образовании этих джетов. Однако, несмотря на значительный прогресс и многочисленные предложенные механизмы, точный процесс остается неясным. Поведение этой плазмы определяется магнитогидро-динамикой (МГД), сложной нелинейной теорией поля. При определенных условиях плазма может проявлять свойства струны. Такое поведение может возникнуть из-за динамики силовых линий магнитного поля, встроенных в плазму, или из-за движения относительно тонких изолированных трубок потока плазмы, которые можно приближенно смоделировать как одномерные струны. В таких сценариях эти струны характеризуются плотностью энергии и натяжением и могут переносить токи массы и/или заряда. Цель состоит в том, чтобы охватить ключевые аспекты базовой физики с помощью динамики струн. Этот подход предлагает значительно более простую структуру по сравнению со сложностью МГД, что делает его многообещающим инструментом для изучения фундаментальных механизмов формирования джетов.

Механизмы извлечения энергии из эргосферы и динамика струн с током в рамках как альтернативной, так и общей теории относительности широко изучаются. Однако эти исследования не были сосредоточены на процессах ускорения частиц и извлечения энергии вокруг черных дыр Керра-Киселева. Кроме того, динамика вращения пробных частиц вблизи черных дыр Керра-Киселева широко не исследовалась. Более того, исследования по проверке теорий гравитации и ограничению параметров заряженных черных дыр с помощью струнных петель с током на основе данных наблюдений с КПК не проводились. Исследования, связанные с электромагнитными взаимодействиями, такими как ускорение струнных петель с током вдоль вертикальной оси и их выброс из окрестностей черных дыр Рейсснера-Нордстрема, также ограничены.

В нашей стране значительное внимание уделяется практическим исследованиям в области астрономии и теоретической астрофизике, а также международному сотрудничеству в области фундаментальных исследований. Стратегия действий по дальнейшему развитию Республики Узбекистан (2017–2021 годы) освещает развитие науки внутри страны, определяет ключевые направления фундаментальных исследований и определяет методы применения результатов таких исследований на территории Узбекистана. Результаты, полученные в этой диссертации, помогают понять природу квинтэссенции, которая является одной из моделей, объясняющих расширяющуюся Вселенную с ускоряющейся скоростью, динамику вращения частиц вокруг ЧД Керра-Киселева, КПК, исходящие из GRO 1655-40. источник. Кроме того, колебательная энергия заряженных колец посредством своего поступательного движения объясняет ускорение потоков плазмы вдоль вертикальной оси черной дыры и количественно определяет их фактор Лоренца.

Настоящее исследование соответствует целям, обозначенным в Указах Президента Республики Узбекистан, в том числе Указе № УП-6097 «Об утверждении Концепции развития науки до 2030 года» от 29 октября 2020 года, а также другие соответствующие нормативно-правовые документы в этой области.

Актуальность исследования приоритетным направлениям развития науки и технологий Республики Узбекистан. Диссертационное исследование выполнено в соответствии с приоритетными направлениями науки и техники в Республике Узбекистан: Указ Президента Республики Узбекистан №УП-4947 «О Стратегии действий по дальнейшему развитию Республики». Узбекистана» от 07 февраля 2017 года**.**

Степень изученности проблемы. Процессы добычи энергии вокруг черных дыр (ЧД) широко изучаются в рамках различных теорий гравитации. внести свой вклад в исследование исследователей из разных регионов. В Европе такие ученые, как Олег Заславский, Грегор Овчаренко, Люк Бланше, Алексей Дериглазов, Ева Хекманн, Валерия Каграманова, Зденек Стучлик и Ян Ше, провели заметные исследования. Аналогичным образом, в Азии важные исследования провели Сушант Гош, Мубашер Джамиль, Ягуб Хайдарзаде и Сузуки Шинго.

Также широко исследуются механизмы излучения в аккреционных дисках черных дыр, в частности генерация и анализ КПО в рамках общей и альтернативной теории гравитации. Европейские исследователи, такие как Лучано Реццолла, Марек Абрамович, Габриэль Торок, Павел Бакала, Зденек Стучлик и Мартин Колос, внесли значительный вклад в эту область. В США ученые, в том числе Сара Мотта, Луиджи Стелла, Марио Вьетри и Роберт Ваггонер, добились существенного прогресса. Кроме того, заметную работу провели исследователи из Японии, такие как Сёдзи Като и Цзюнь Фукуэ, а также из Китая, в том числе Чжунсян Ван, Сян-Донг Ли и Шуан-Нань Чжан.

В нашей стране теоретические исследования динамики и энергетических процессов вокруг черных дыр в различных теориях гравитации проводили Бобомурат Ахмедов, Ахмаджон Абдуджаббаров, Джавлон Раимбаев, Фаррух Атамуратов, Бобир Тошматов, Санжар Шайматов, Бахтиёр Нарзиллоев и др.

Связь темы диссертации с научными исследованиями высшего учебного заведения, где выполнена диссертация. Данная диссертационная работа выполнена в рамках научного проекта № Ф2-ФА-Ф113 и № Ф2-ФА-Ф029 Академии наук Республики Узбекистан.

Целью исследования диссертации является изучение динамики частиц со спином и без спина и процессов извлечения энергии вокруг черных дыр в аксиально-симметричном пространстве-времени при наличии квинтэссенционного поля.

Задачи исследования. Изучение движение и столкновения вращающихся и невращающихся нейтральных пробных частиц вокруг вращающейся ЧД, погруженной в квинтэссенцию темной энергии; Исследовать движение токонесущих заряженных струнных петель на фоне РН ЧД, сочетающего гравитационное и электромагнитное поля; Ограничение заряда и массы ЧД с использованием данных КПК;

Объектами исследования являются релятивистские компактные гравитирующие объекты, погруженные в квинтэссенцию, заряженные ЧД, вращающиеся нейтральные частицы и струнные петли с током.

Предмет исследования ускорение частиц и струн с током, процессы извлечения энергии вокруг ЧД Керра-Киселева посредством механизмов Пенроуза и BSW, ВЧ КПК в двойных ЧД.

Методами исследования являются математические методы анализа экспериментальных данных, математический аппарат общей теории относительности и численные методы статистики.

Научная новизна исследования заключается в следующем:

впервые показано, что энергия центра масс сталкивающихся частиц уменьшается с увеличением квинтэссенционного параметра поля;

впервые показано, что вращающиеся частицы с наибольшими спинами могут оставаться ближе всего к стабильным орбитам вокруг черной дыры КК;

впервые продемонстрировал уменьшение энергии ISCO за счет увеличения спина черной дыры и независимости энергии OSCO от спина черной дыры и частицы;

впервые в области обнаженных особенностей РН обнаружены две замкнутые тороидальные области движения петли заряженной струны;

впервые показано, что заряд черной дыры РН Q не вносит вклад в ускорение скорости струнной петли из-за электростатического отталкивания.

впервые продемонстрировал влияние взаимодействия зарядов ЧД и струнной петли на ускорение струнной петли в окрестности ЧД РН, что является одним из возможных объяснений релятивистских струй, исходящих от АЯГ;

впервые обнаружено, что поле квинтэссенции снижает эффективность извлечения энергии посредством процесса Пенроуза.

Достоверность результатов исследований обеспечивается следующим: используются современные методы общей теории относительности и теоретической физики, высокоэффективные численные методы и алгоритмы; проводится тщательная проверка соответствия полученных теоретических результатов данным наблюдений и результатам других авторов; Выводы хорошо согласуются с основными положениями теории поля гравитационных компактных объектов.

Научная и практическая значимость результатов исследования.

Полученные результаты могут помочь понять энергетические процессы и динамику пробных частиц со спином и без спина вокруг ЧД Керра-Киселева в общей теории относительности;

полученные ограничения на параметры ЧД могут позволить получить информацию о гравитационной особенности пространства-времени вокруг ЧД, давая возможность определить, какое гравитационное воздействие играет доминирующую роль;

Полученные результаты могут помочь определить параметры ЧД звездных масс вместе с пространственно-временными особенностями вокруг них на основе данных наблюдений высокочачтотных КПК из двойных ЧД, а также позволили объяснить физические механизмы колебаний аккреционных дисков.

Внедрение результатов исследования. Результаты исследования динамики частиц вокруг вращающейся ЧД в квинтэссенции ЧД и динамики заряженных струн вокруг ЧД РН в различных теориях гравитации были применены следующим образом:

Подход определения динамики частиц вокруг различных ЧД в квинтэссенции на основе данных наблюдений использовался рядом авторов при исследовании свойств пространства-времени вокруг ЧД, а также в гравитационных моделях (Physics Letters B, 771, 365-373, (2017), Международный журнал современной физики D, том 26, выпуск 6, ID 1750051-23, (2017), The European. Physical Journal C, том 78, выпуск 9, идентификатор статьи 750, 13 стр., (2018 г.), Physical Review D, том 95, выпуск 6, идентификатор 064015, (2017 г.), The European Physical Journal C, том 78, выпуск 6, номер статьи 513, 12 стр., (2018), Physical Review D, том 102, выпуск 10, статья. id.104062, (2020) Результаты предоставлены для анализа многочисленных моделей темной материи вокруг ЧД на основе данных наблюдений ЧД.

Несколько авторов использовали подход анализа динамики заряженных струн вокруг RN ЧД в исследованиях свойств пространства-времени вокруг многочисленных ЧД, а также в гравитационных моделях (Classical and Quantum Gravity, Volume 37, Issue 24, id.245007, 21 стр, (2020 г.)), Физика темной Вселенной, Том 44, идентификатор 101483, (2024), The European Physical Journal C, Том 82, выпуск 5, номер статьи 494, (2022 г.), Физика темной Вселенной, том 26, идентификатор статьи 100331, (2019 г.), Китайский журнал физики, том 70, стр. 55-68, (2021 г.) Результаты предоставлены для проведения анализа в различных моделях идеальных жидкостей, окружающих ЧД, на основе данных наблюдений ЧД.

Мы исследовали ISCO и OSCO вращающихся пробных частиц, их энергию и угловой момент на орбитах. Существование OSCO можно объяснить космологическим горизонтом, вызванным квинтэссенцией поля. Это показывает, что ISCO и OSCO совпадают при критических значениях параметров квинтэссенционного поля и параметров состояния поля, которые также зависят от спина частицы и черной дыры. Наконец, мы рассматриваем столкновения вращающихся частиц и анализируем энергии центра масс и критический угловой момент, который допускает столкновения частиц вблизи черной дыры. Показано, что вращающиеся частицы с наибольшими спинами могут оставаться ближе всего к стабильным орбитам вокруг черной дыры КК. Также происходит уменьшение энергии ISCO из-за увеличения спина черной дыры, который быстро уменьшается для частиц с большим вращением. Однако энергия OSCO не зависит от спина черной дыры и частицы. Энергии OSCO и ISCO также уменьшаются по мере увеличения параметра квинтэссенции поля. Параметр квинтэссенционного поля имеет верхнее значение там, где OSCO и ISCO совпадают, а верхний предел увеличивается с увеличением спина частицы из-за дополнительного взаимодействия между квинтэссенционным полем и спином частицы. Кроме того, можно также наблюдать увеличение спина частиц, что приводит к уменьшению значений энергии. Энергии OSCO и ISCO увеличиваются с увеличением ω_q и чувствительности энергии OSCO по сравнению с ISCO. Аналогично, верхний предел значения параметра ω_q также уменьшается из-за увеличения s. В первом ряду мы можем наблюдать тонкие вертикальные линии, обозначающие максимальное значение s, называемые сверхсветовыми границами. Аналогичное поведение углового момента ISCO и OSCO можно наблюдать, как и в энергии.

Наконец, в последнем разделе мы изучали столкновения вращающихся частиц вблизи черных дыр КК. Сначала мы проанализировали критические значения момента импульса, с которыми частицы могут столкнуться вблизи горизонта. Мы обнаружили, что момент импульса уменьшается с увеличением спина черной дыры. И наоборот, оно увеличивается за счет увеличения параметра квинтэссенционного поля. Влияние параметра состояниф поля на момент импульса практически незначительно для частиц с положительным спином. Кроме того, мы проанализировали энергию центра

масс при столкновениях вращающейся частицы с положительными и отрицательными параметрами спина (ориентацией). Получается, что энергия возрастает как $\omega_q \to -1$; в частности, энергия уменьшается радиально, но на некотором расстоянии снова увеличивается из-за присутствия экзотической материи с отрицательным давлением, аналогичной темной энергии. Энергия также увеличивается за счет увеличения параметра квинтэссенционного поля. Однако влияние квинтэссенционного поля и параметра состояния поля на энергию вблизи горизонта черной дыры незначительно. Однако вращение черной дыры вызывает уменьшение энергии. Энергия центра масс больше в конфигурации $L < 0 \ \& \ s > 0$ по сравнению со случаями $L > 0 \ \& \ s < 0$ L>0. Из рис. 2 видно, что энергия существенно больше в случаях $L_1 > 0 \ \& \ s_1 > 0$ и $L_2 < 0 \ \& \ s_2 < 0$ от всех остальных комбинаций.

Апробация результатов исследования. Результаты диссертации обсуждались на 1 международных и 1 местной конференции.

Публикация результатов исследований По результатам исследований сделано более 6 научных публикаций, из них 3 – научные статьи в рецензируемых журналах.

Объем и структура диссертации. Диссертация состоит из введения, трёх глав, заключения и списка использованной литературы. Объем диссертации составляет 88 страница.

ЗАКЛЮЧЕНИЕ

Научная значимость результатов исследования заключается в их вкладе в понимание энергетических процессов и динамики тестовых частиц со спином и без спина в рамках общей теории относительности вокруг черной дыры Керра-Киселева. Кроме того, полученные результаты способствуют пониманию зависимости энергии и момента импульса минимальных и максимальных круговых орбит тестовых частиц вокруг черной дыры Керра-Киселева от квинтэссенции, характеристик черной дыры и спина частицы. Также ограничения, полученные для параметров черной дыры, дают представление о гравитационных свойствах пространства-времени вокруг черной дыры, позволяя определить, какой гравитационный эффект играет доминирующую роль. Полученные результаты позволяют определить параметры черных дыр звездной массы и характеристики пространства-времени вокруг них на основе наблюдательных данных о высокочастотных квазипериодических колебаний, полученных от двойных систем с черными дырами.

E'LON QILINGAN ISHLAR RO'YXATI
LIST OF PUBLISHED WORKS
СПИСОК ОПУБЛИКОВАННЫХ РАБОТ

I бўлим (I часть; part I)

1. Tursinbay Oteev, Ahmadjon Abdujabbarov, Zdenek Stuchlik, Bobomurat Ahmedov, Energy extraction and particle acceleration around a rotating black hole in quintessence // Astrophysics and Space Science (2016) 361:269, Springer Netherlands, Netherlands (Q3. Web of Science: IF=1.830) https://DOI 10.1007/s10509-016-2850-9

2. Tursinbay Oteev, Martin Kolos, Zden\v ek Stuchlik, Charged string loops in Reissner–Nordström black hole background// European Physical Journal C (2018) 78:261, Springer New York, Germany (Q1. Web of Science: IF=4.180) https://doi.org/10.1140/epjc/s10052-018-5735-y

3. Tursinbay Oteev, Farukh Abdulkhamidov, Javlon Rayimbaev, Zdenek Stuchlik, Bobomurat Ahmedov, Physics of the Dark Universe, Elsevier BV, Netherlands// Physics of the Dark Universe Volume 46, December 2024, 101588 (Q1. Scopus: IF=5.120) https://doi.org/10.1016/j.dark.2024.101588

II бўлим (II часть; part II)

4. T. Oteev, M. Kološ, A. Tursunov, String loop in electromagnetic field, Fundamental and Applied Problems of Physics, Tashkent, June 13-14 2017, pages 169-174

5. Tursinbay Oteev, Murat Sharibaev, Particle energetics around a rotating black hole in quintessence, Science and Education in Karakalpakstan, volume 3/1 2024, pages 45-50

6. Tursinbay Oteev, Murat Sharibaev, Particle motion around a rotating black hole in quintessence , Science and Education in Karakalpakstan, volume 3/1 2024, pages 33-38

Avtoreferat "IQTISOD-MOLIYA"nashriyotida tahrirdan oʻtkazildi.