“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

TOSHKENT AMALIY FANLAR UNIVERSITETI

JAVED FAISAL

KOMPAKT OBYEKTLAR YUPQA QOBIG’I ORQALI TERMODINAMIKA VA TURG’UNLIGIGA TA’SIRI

01.03.01-Astronomiya
01.04.02 – Nazariy fizika
(fizika-matematika fanlari)

E’lon qilingan ilmiy ishlar bo’yicha dissertatsiyasiz fan doktori (DSc) ilmiy darajasini olish uchun
TAQDIMNOMA

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Fizika-matematika fanlari doktori (DSc) dissertatsiyasi mavzusi O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligi huzuridagi Oliy attestatsiya komissiyasida B2024.1.DSc/FM257 raqami bilan ro‘yxatga olingan.

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KIRISH (Fan doktori (DSc) taqdimnoma annotatsiyasi)

Mavzuning dolzarbligi va zarurligi. Umumiy nisbiylik nazariyasidagi (GR) so‘nggi yutuqlar kosmik tuzilishdagi bir nechta astrofizik hodisalarga qiyin inqiloblarni olib keldi va shuningdek, tortishish kuchidan foydalangan holda bir nechta qiziqarli tajribalarga olib keldi. Zamonaviy o‘rganish davrida qora o‘ralar (BH) kuchli tortishish maydonlarining eng ajoyib xususiyatlaridan biri hisoblanadi. Qora o‘raning kuchli tortishish zonasi har qanday narsaning hodisalar gorizontidan chiqib ketishiga yo‘l qo‘ymaydi, lekin u atrofdagi hamma narsani ham yutib yuboradi. Qora o‘ra geometriyalarining fizik xususiyatlari bilan bog‘liq kvant tebranishlarining hayratlanarli oqibatlari har doim bo‘lgan. Yagonalik nuqtasi fazoviy vaqtning asosiy mintaqasi bo‘lib, u erda zichlik va fazo-vaqt egriligi farqlanadi va fizik qonunlar bekor qilinadi. Yagonalik nuqtasining mavjudligi qora o‘ra fizikasining asosiy muammolaridan biridir.

Xususan, Xoking bug‘lanish jarayoni, chalkashlik va axborotni yo‘qotish paradoksi boy tarixga va chuqur natijalarga ega bo‘lgan qora o‘radagi kvant tortishish jarayonlarining natijasidir. Qora o‘ra o‘ziga xosliklari halqa kvant tortishish kuchi va renormalizatsiya-guruhni yaxshilash (RGI) texnikasidan kelib chiqadigan kvant tortishish effektlari bilan hal qilinadi, ular so‘nayotgan yulduzning gravitatsion qulashi paytida yagonalikning paydo bo‘lishini oldini oladi yoki yo‘q qiladi. Xoking nurlanish jarayonida qora o‘ra tarqalib ketganda, fazo-vaqt egri chizig‘ining ochiq yagonalik nuqtasi ochiladi.

Statik sharsimon geometriyadagi vaqtga o‘xshash yupqa qobiq kosmologik senariylarning keng doirasini tahlil qilish uchun ishlatilishi mumkin bo‘lgan ajoyib kosmologik konfiguratsiyalardan biridir. Yupqa qobiq – moddaning fazo-vaqt birikmasi vazifasini bajaradigan cheksiz yupqa qatlami deb ataladi. Yupqa qobiq ma’lum bir materiya taqsimotini birlashtirganligi sababli, u tegishli fazo vaqtining haqiqiyligini tasdiqlovchi ma’lum energiya cheklovlarini qondirishi kerak. Ushbu shartlar bosim-energiya tensori orqali geometrik strukturaning tashqi egriligi bilan bog‘liq bo‘lishi mumkin.

Eynshteyn tenglamalarining matematik yechimlari bo‘lgan qora o‘ralar deb nomlanuvchi astrofizik obyektlar keng e’tirof etilgan. Yaqinda koinotimizdagi qora o‘ralar haqida ikkita muhim kuzatuv haqida xabar berildi. Birinchisi, qora o‘ralarning qo‘shqavatlaridan keladigan tortishish to‘lqinlarining kashfiyoti, ikkinchisi - galaktikamizning M87 va Sgr A* markazlaridagi qora o‘ralarning fotografik isbotining topilishi. Ammo uzoqdagi kuzatuvchilar hodisa ufqidan tashqarida yoki hatto ular paydo bo‘lishidan oldin sodir bo‘layotgan hodisalarni kuzatishi kerak. Natijada, astrofizik obyektning hodisa gorizonti bor yoki yo‘qligi hali ham aniq emas. Bir qancha mualliflar katta yulduzning gravitatsion qulashi qora o‘ralardan tashqari eng zich samoviy jismlarni ham yaratishi mumkinligini taxmin qilishgan. Ushbu g‘oyani hal qilish uchun Mazur va Mottola tortishish tizimidagi Bose-Eynshteyn kondensatsiyasining kengaytirilgan kontseptsiyasini o‘z ichiga olgan tortishish vakuum yulduzlari yoki "gravastars" deb nomlanuvchi yulduz jismlarining qulashining yangi nazariyasini taqdim etdilar. Gravastar qora o‘ra o‘rnini bosuvchi vosita sifatida taklif qilingan, u ham kvant effektlarini hisobga oladi. Gravastar modeli an’anaviy qora o‘ralar bilan bog‘liq muammolarni hal qilishni taklif qiladi, shu bilan birga yulduzlar evolyutsiyasining barqaror yakuniy nuqtasi uchun barcha nazariy talablarga javob beradi. Bu nazariya shuni ko‘rsatadiki, kvant vakuum tebranishlari kollaps dinamikasida muhim rol o‘ynaydi, bu fazali o‘tishga olib keladi, bu esa qulab tushadigan jismni muvozanatlashtiradigan va r = 2m chegarasi yaqinida ufq (va o‘ziga xoslik) shakllanishiga to‘sqinlik qiladigan repulsiv de Sitter yadrosiga olib keladi. Biroq, bu hodisa chegaraga juda yaqin sodir bo‘lib, begona odam uchun gravastar va haqiqiy qora o‘ra o‘rtasidagi farqni qiyinlashtiradi.

Mazkur ilmiy tadqiqot ishi quyidagi davlat me’yoriy hujjatlari bilan belgilangan vazifalarga mos keladi: O‘zbekiston Respublikasi Prezidentining 2017-yil 7-fevraldagi “O‘zbekiston Respublikasini yanada rivojlantirish bo‘yicha Harakatlar strategiyasi to‘g‘risida”gi PF-4947-son Farmoni, O‘zbekiston Respublikasi Prezidentining 2017-yil 18-fevraldagi “Fanlar akademiyasi faoliyatini yanada takomillashtirish, ilmiy-tadqiqot faoliyatini tashkil etish, boshqarish va moliyalashtirish chora-tadbirlari to‘g‘risida”gi PQ-2789-son qarori va boshqalar.

Tadqiqotning Respublika fan va texnikasini rivojlantirishning asosiy ustuvor yo‘nalishlariga muvofiqligi. Dissertatsiya tadqiqoti O‘zbekiston Respublikasi fan va texnikasining ustuvor yo‘nalishlariga muvofiq olib borilgan: II. "Energetika, energiya va resurs tejamkorligi".

Muammoni bilish darajasi. Kompakt obyektlar termodinamikasi butun dunoyo olimlari(Z. Stuchlik, J, Schee, A. Abdujabbarov, B Ahmedov, J. Kunz, N. Dadhich, S. Ghosh, P. Joshi, F. Atamurotov) tomonidan o’rganilgan. Biroq, kompakt obyektlar parametrlarining termodinamik kattaliklariga ta’siri tizimli ravishda turli modellar va nazariyalarda tizimli ravishda o‘rganilmagan.

Qora materiyaning muntazam qora o‘ra atrofidagi astrofizik jarayonlarga ta’siri ham o‘rganilmagan. Bunday obyektlar atrofidagi zarralar dinamikasini tavsiflovchi matematik modellarni ishlab chiqish va takomillashtirish tortishishning o‘zgartirilgan va/yoki muqobil nazariyalarining parametrlari uchun chegara qiymatlarini olishga yordam beradi.

Dissertatsiya mavzusi mavzusini dissertatsiya olib borilayotgan oliy o‘quv yurtlari va ilmiy-tadqiqot muassasalarining ilmiy ishlari bilan bog‘lash. Dissertatsiya Innovatsion rivojlanish vazirligi tomonidan moliyalashtirilgan ilmiy loyihalar doirasida bajarilgan. F-FA-2021-510 "Modifikatsiyalangan gravitatsiya nazariyasi doirasida neytron yulduzlardagi yadro moddalarini tadqiq etish".

Tadqiqot maqsadi renormalizatsiya guruhining takomillashtirilgan tortishish nazariyasi va kompakt obyektlar uchun tegishli yechimlar uchun nazariy modellarni ishlab chiqish va takomillashtirishdir.

Tadqiqotning vazifalari:

ichki yassi fazo-vaqt va tashqi RGI Shvartsshild Qora o‘ra bilan yupqa qobiqning geometrik konstruktsiyasini kesish va yopishtirish usuli orqali o‘rganish;

ushbu tuzilgan geometriyalarning dinamik tenglamasini ishlab chiqadigan gipersuratdagi Eynshteyn maydon tenglamalarining qisqartirilgan ko‘rinishidan kuchlanish-energiya tensorini hisoblash;

metrik funktsiyaning grafik harakatini tahlil qilish va KG va saqlanish tenglamalari yordamida massasiz va massiv skalyar maydondan tashkil topgan yupqa qobiqning dinamik konfiguratsiyasini o‘rganish;

muvozanat qobig‘i radiusi bo‘yicha chiziqli radial tebranish bilan kvintessensiya, quyuqenergiya va fantom energiya turi EoSdan keyin materiya taqsimoti bilan to‘ldirilgan ingichka qobiqning barqaror konfiguratsiyasini o‘rganish;

qobiq radiusining muvozanat holatini hisobga olmagan holda, yupqa qobiqning samarali potentsiali va qobiq radiusidan foydalangan holda skalyar maydon kontekstida yupqa qobiq dinamikasini tahlil qilish;

to‘g‘ri vaqt fonida samarali potentsial, qobiq radiusi va skalyar maydonning harakatini o‘rganish uchun saqlanish tenglamasi va KG tenglamasini ko‘rib chiqish; fantomga o‘xshash EoS fonida qobiq radiusi bo‘yicha chiziqli radial tebranishlardan foydalangan holda ishlab chiqilgan strukturaning barqaror konfiguratsiyasini o‘rganish;

modifikatsiyalangan materiya manbai doirasida Eynshteyn maydoni tenglamasini ishlab chiqish va gravastar tuzilishi va ularning fizik xossalarini hisoblash;

chiziqli radial tebranish orqali gravastarlarning barqarorligini o‘rganishda ajoyib rol o‘ynaydigan kuchlanish-energiya tensorining tarkibiy qismlarini aniqlash.

Tadqiqot obyekti - astrofizik kompakt obyektlar, gravastar yulduzlar, tortishishning muqobil nazariyalari, qorong’i materiya.

Tadqiqot predmeti ixcham gravitatsion obyektlar, gravitatsion yulduzlar uchun aniq analitik yechimlarni o‘rganish uchun nazariy modellardir.

Tadqiqot usullari hisoblash matematikasi usullari, nazariy astrofizika usullari, matematik fizikaning zamonaviy usullari, maydon va zarralar harakati uchun differentsial tenglamalarni hisoblashning analitik va raqamli usullaridan iborat.

Tadqiqotning ilmiy yangiligi quyidagilardan iborat:

Birinchi marta kuchlanish-energiya tensorining komponentlari ushbu tuzilgan geometriyalarning dinamik tenglamalarini ishlab chiqadigan gipersuratdagi Eynshteyn maydon tenglamalarining qisqartirilgan shaklidan hisoblab chiqildi. RGI Schwarzschildning hodisa gorizonti pozitsiyasi Schwarzschild qora o‘rasidan kamroq ekanligi kuzatildi. Muvozanat qobig‘i radiusi bo‘yicha chiziqli radial tebranish bilan kvintessensiya, quyuq energiya va fantom energiya turi EoSdan keyin materiya taqsimoti bilan to‘ldirilgan ingichka qobiqning barqaror konfiguratsiyasi o‘rganildi.

Skayar maydon kontekstida yupqa qobiq dinamikasi, qobiq radiusining muvozanat holatini hisobga olmagan holda, nozik qobiqning samarali potentsiali va qobiq radiusidan foydalangan holda muhokama qilinadi. Tegishli vaqt fonida samarali potentsial, qobiq radiusi va skalyar maydonning harakatini oʻrganish uchun saqlanish tenglamasi va KG tenglamasi koʻrib chiqildi.

Birinchi marta fantomga oʻxshash EoS fonida qobiq radiusi boʻyicha chiziqli radial buzilishdan foydalangan holda ishlab chiqilgan strukturaning barqaror konfiguratsiyasi oʻrganildi. Ma’lum boʻlishicha, yupqa qobiqning grafik tahlili ingichka qobiqning asosiy sharti boʻlib, qobiq radiusi hodisa gorizonti radiusidan kattaroq boʻlishi kerak.

Ta’kidlanishicha, yupqa qobiq ham kvintessensiya, ham quyuqe nergiya tipidagi moddalar tarkibi uchun barqaror harakatni ifodalaydi. Yupqa qobiq EoS fantom energiya turi uchun jismoniy parametrlarning har bir tanlovi uchun beqaror konfiguratsiyani ifodalaydi. Aniqlanishicha, quyuq energiya tipidagi moddalar tarkibi kvintessensiya tipidagi moddalar taqsimotiga qaraganda ancha barqaror konfiguratsiyaga ega. RGI Shvartsshild qora oʻrasini tanlashda Shvartsshild qora oʻrasiga nisbatan yupqa qobiqning barqarorligi pasaygan degan xulosaga keldi.

Birinchi marta modifikatsiyalangan materiya manbai doirasida Eynshteyn maydon tenglamasi ishlab chiqildi. Bundan tashqari, gravastar tuzilishi va ularning fizik xususiyatlari hisoblab chiqilgan. EoS ni ichki mintaqaga qoʻllash va harakat tenglamalari va saqlanish tenglamalarini tahlil qilish orqali yechimning yagonaligi yoʻqligi aniqlandi. Bundan tashqari, tizimning energiya zichligi va bosimi doimiy boʻlib qoladi, bu quyuq energiya bilan bogʻliq xususiyatlarga mos keladi.

Tadqiqotning amaliy natijalari quyidagilardir:

Bu oraliq qobiq holatiga mos keladigan va tegishli metrik potentsialni aniqlaydigan EoS deb hisoblanadi. U tashqi manifold sifatida qatorli bulut va kvintessensiya bilan oʻralgan aniq qora oʻra yechimi bilan foydalanilgan. Gravastar tuzilishi Darmois-Isroil rasmiyatchiligini hisobga olgan holda ishlab chiqilgan. Chiziqli radial tebranish orqali gravastarlarning barqarorligini oʻrganishda ajoyib rol oʻynaydigan kuchlanish-energiya tensorining tarkibiy qismlari olindi. Kvintessensiya maydoni parametri ortishi bilan barqaror mintaqaning kamayishi koʻrsatilgan.

Tahlil shuni koʻrsatadiki, qobiq mintaqasining entropiyasi qobiq qalinligi bilan toʻgʻridan-toʻgʻri proportsionaldir. Xuddi shunday, biz qobiqning entropiyasini tekshiramiz, chunki biz uning qalinligini qatorli bulutning turli qiymatlari uchun oʻzgartiramiz. Shuni ta’kidlash kerakki, entropiya ham qalinligi, ham qatorli buluti parametri ortishi bilan ortadi.

Birinchi marta jismonan maqbul boʻlgan yagonaliksiz yechim ishlab chiqildi. Shuni ta’kidlash joizki, ishlab chiqilgan aniq yangi yechimlar qatorli bulut va kvintessensiya maydonlari yoʻqligida aniq Mazur va Mottola modeliga qisqartiriladi.

Tadqiqot natijalarining ishonchliligi matematik fizika, hisoblash matematikasi va relyativistik astrofizikaning zamonaviy tasdiqlangan usullarini qo‘llash orqali ta’minlanadi. Natijalar qat’iy ravishda umumiy nisbiylik va nazariy fizikaning matematik apparati doirasida olingan. Hisoblashning zamonaviy raqamli va analitik usullari ham qo‘llaniladi va natijalar mavjud kuzatuv ma’lumotlari va boshqa mualliflarning natijalari bilan taqqoslanadi. Tezisning tuzilgan xulosalari ixcham ob’ektlar astrofizikasining asosiy qoidalariga mos keladi.

Tadqiqot natijalarining ilmiy va amaliy ahamiyati. Tadqiqot natijalarining ilmiy ahamiyati shundan dalolat beradiki, gravastarlarning yechimlarini tahlil qilish tortishishning yangi nazariyalarini ishlab chiqishda yordam berishi mumkin.

Tadqiqot natijalarining amaliy ahamiyati shundaki, ular tortishish nazariyalarining model parametrlari bo‘yicha yuqori chegara va cheklovlarni olishda rol o‘ynashi mumkin.

Tadqiqot natijalarini amalga oshirish. Kompakt obyektlar uchun ishlab chiqilgan nazariy modellar asosida: Zarralar harakati bo‘yicha olingan ilmiy natijalar Shanxaydagi Fudan universiteti (FU) olimlari tomonidan qo‘llanildi (FU, Xitoy, 2024 yil 30 aprel ma’lumotnomasi).

Tadqiqot natijalarini nashr etish. DSc tadqiqoti natijalari O‘zbekiston Respublikasi Oliy ta’lim, fan va innovatsiyalar vazirligi huzuridagi Oliy attestatsiya komissiyasi tomonidan tavsiya etilgan nufuzli 1/2 chorak to‘rtlik ilmiy jurnallarida chop etilgan 31 ta ilmiy maqolalarda taqdim etilgan.

ISHNING ASOSIY MAZMUNI

I qism

Taqdimotning ushbu qismida bizning asosiy e’tiborimiz taniqli kesish va yopishtirish usuli orqali yaxshilangan Shvartsshild qora o’rasining ichki tekis va tashqi moslashuvi orqali yupqa qobiqning geometrik tuzilishini olishdir. Keyin biz harakat tenglamasi va Klein-Gordon tenglamasi orqali skalyar maydondan (massiv va massasiz) tashkil topgan yupqa qobiqning dinamik konfiguratsiyasini muhokama qilishga qiziqamiz. Nihoyat, yupqa qobiqning barqaror konfiguratsiyasi xayoliy holat tenglamasi, ya’ni kvintessensiya, quyuq energiya va fantom energiyasi bilan muvozanat qobiq radiusi bo‘yicha chiziqli radial tebranish yondashuvi orqali kuzatiladi. Ta’kidlanishicha, yupqa qobiqning barqaror/beqaror xatti-harakati tashqi manifoldning hodisa gorizontining kutilgan pozitsiyasidan keyin topiladi. Takomillashtirilgan Shvartsshild qora o‘ralarining renormallashtirilgan guruhiga nisbatan Shvartsshild qora o‘ralarini tanlashda yupqa qobiqning barqarorligi kattaroq degan xulosaga kelindi. Biz $r = w(\tau)$ radiusli Σ bilan ifodalangan $(2+1)-D$ yupqa qobiqni yaratamiz, bu yerda τ to‘g‘ri vaqt. Bu qobiq ikki xil manifoldni bog'laydi, ya’ni tashqi mintaqa (r>w) Qora o‘ra fazo vaqti sifatida tanlanadi, ichki mintaqa (r<w) esa tekis geometriya bilan belgilanadi. Ushbu geometriyalar uchun chiziq elementi quyidagicha yozilishi mumkin:

$$ds_{\pm}^2 = -f_n(r)dt^2 + (f_n(r))^{-1}dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2),$$

bu yerda $n = i, e$ mos ravishda ichki va tashqi rayonlarga mos keladi.

Yupqa qobiqda h_{ij} metrik funktsiyasi $y^i = (\tau, \theta, \phi)$ koordinatalari bo'lgan vaqtga o'xshash 2-sferani ifodalaydi, uni quyidagicha ifodalash mumkin:

$$ds^2 = h_{ij} dy^i dy^j = - d\tau^2 + w^2 d\theta^2 + w^2 \sin^2 \theta d\phi^2.$$

Yupqa qobiq ichki fazo vaqtini tashqi qismdan ajratib turuvchi chegarani bildiradi. Yupqa qobiqning fizik hayotiyligi uchun yupqa qobiqdagi induksiyalangan metrikaning uzluksizligi va tashqi egrilik uzluksizligi kabi ulanish sharoitlari talab qilinadi [?]. Shuningdek, biz ushbu geometriyalar uchun sirt kuchlanishlarini Lanczos deb nomlangan nozik qobiqli maydon tenglamalari orqali olamiz. Biz qobiqdagi jismoniy xususiyatlarni (tashqi egrilik uzilishlarini keltirib chiqaradigan) bosim-energiya tensori S^i_j yordamida hisoblashimiz mumkin. Yupqa qobiqdagi materiya komponentlarini quyidagicha yozish mumkin:

$$S^\tau_\tau \equiv \rho(w) = - \frac{1}{4\pi w} (\chi_e(w) - \chi_i(w))$$

$$S^\theta_\theta = S^\phi_\phi \equiv \mathfrak{P}(w) = \frac{-\chi_i(w) + \chi_e(w)}{8\pi w} + \frac{2\ddot{w} + f'_e(w)}{16\pi \chi_e(w)} - \frac{2\ddot{w} + f'_i(w)}{16\pi \chi_i(w)}$$

Bu yerda

$$\chi_i(w) = \sqrt{f_i(w) + \dot{w}^2},\ \chi_e(w) = \sqrt{f_e(w) + \dot{w}^2}$$

$\rho(w)$ va $\mathfrak{P}(w)$ energiya zichligi va tangensial bosimni ifodalaydi, ortiqcha nuqta va chiziq esa mos ravishda vaqt va radial koordinata w.r.t hosilalariga mos keladi. Demak, bizda quyidagicha kelib chiqadi:

$$\rho = - \frac{\sqrt{\dot{w}^2 + f_e(w)} - \sqrt{\dot{w}^2 + f_i(w)}}{4\pi w}$$

$$\mathfrak{P} = \frac{1}{8\pi} \left(\frac{2\ddot{w} + f'_e(w)}{2\sqrt{\dot{w}^2 + f_e(w)}} - \frac{2\ddot{w} + f'_i(w)}{2\sqrt{\dot{w}^2 + f_i(w)}} + \frac{\sqrt{\dot{w}^2 + f_e(w)} - \sqrt{\dot{w}^2 + f_i(w)}}{w} \right),$$

Muvozanatli qobiq radiusida $\dot{w}_0 = \ddot{w}_0 = 0$. Shunday qilib, biz quyidagilarni olamiz:

$$\rho_0 = \rho(w_0) = -\frac{\sqrt{f_e(w_0)} - \sqrt{f_i(w_0)}}{4\pi w_0}$$

$$\mathfrak{P}_0 = \mathfrak{P}(w_0) = \frac{1}{8\pi}\left(\frac{\sqrt{f_e(w_0)} - \sqrt{f_i(w_0)}}{w_0} + \frac{f_e'(w_0)}{2\sqrt{f_e(w_0)}} - \frac{f_i'(w_0)}{2\sqrt{f_i(w_0)}}\right).$$

Minkovskiy fazoviy vaqt uchun ichki geometriyada materiya tarkibi yo‘qligi sababli qobiq ichida tortishish mavjud emas. Tashqi qismi ham vakuum sifatida olinadi, lekin tortishish maydoni Qora o‘ra tomonidan belgilanganidek mavjud. Ushbu ko‘rsatkichdagi massa parametri m gravitatsiyaviy potentsial energiyani, kinetik energiyani va fazoviy vaqtning dam massa energiyasini boshqaradigan qobiqning tortishish massasi bilan bog‘liq bo‘lishi mumkin. Biz qobiqning massasini $M = 4\pi w^2 \rho$ deb belgilashimiz mumkin. Bundan tashqari, saqlash tenglamasi quyidagicha hosil bo‘ladi:

$$\mathfrak{P}\frac{d}{d\tau}(w^2) + \frac{d}{d\tau}(\rho w^2) = 0$$

bu esa quyidagini hosil qiladi

$$\rho' = -\frac{2}{w}(\mathfrak{P}(\rho, w) + \rho).$$

Sirt energiyasi zichligi (6) quyidagi kabi harakat tenglamasini aniq beradi:

$$\dot{w}^2 + \Pi(\rho(w), w) = 0$$

Buyerda $\Pi(\rho(w), w)$ quyidagi tarzda berilgan qobiqning samarali potentsialini ko‘rsatadi:

$$\Pi(\rho(w), w) = \frac{f_e f_i}{32\pi^2 w^2 \rho^2} - \frac{f_i^2}{64\pi^2 w^2 \rho^2} + \frac{f_i}{2} - \frac{f_e^2}{64\pi^2 w^2 \rho^2} + \frac{f_e}{2} - 4\pi^2 w^2 \rho^2$$

Renormalizatsiya guruhi usullari kvant effektlarini Shvartsshild qora o‘ra geometriyasiga kiritish uchun ishlatiladi. Ushbu modifikatsiya natijasida fazoviy vaqtning o‘ziga xosligi yo‘q qilinganligi sababli, tegishli manifold nol, bir yoki ikkita ufqga ega bo‘lishi mumkin. Buyerda biz ichki tekis va tashqi RGI Shvartsshild qora tuynugini kesish va yopishtirish usuli yordamida yupqa qobiqni ishlab chiqishdan manfaatdormiz. Shvartsshild qora o‘raining ichki tekisligi va tashqi ko‘rinishidagi mos metrik funktsiyalari quyidagicha ifodalanadi:

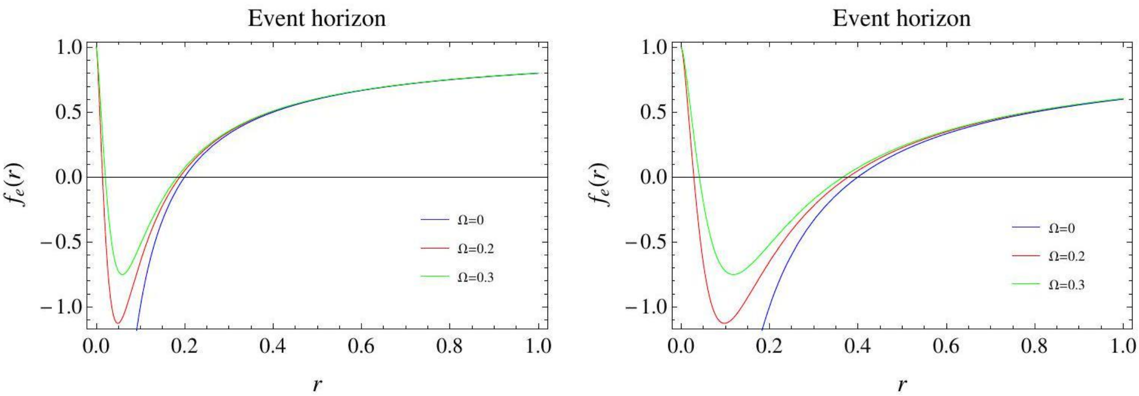
$$f_i(r) = 1,\ f_e(r) = 1 - \frac{2m}{r}\left(\frac{\gamma m^3\Omega}{r^3} + \frac{m^2\Omega}{r^2} + 1\right)^{-1},$$

bu yerda m - Shvartsshild qora o‘rasining haqiqiy konstantalari Ω va γ bo‘lgan massasi. $\Omega = 0$ uchun u GRda Shvartsshild eritmasiga qaytariladi. Qora o‘ra hodisa gorizontining pozitsiyasi metrik funktsiya nolga aylanadigan radial pozitsiyaga to‘g‘ri keladi. Demak, $f_e(r) = 0$ yordamida hodisa gorizonti o‘rnini quyidagicha aniqlashimiz mumkin:

$$r_h = \frac{1}{6}\left(\frac{8\sqrt[3]{2}m^2}{\sqrt[3]{h(r)}} + 2^{2/3}\sqrt[3]{h(r)} + 4m\right)$$

bu yerda

$$h(r) = m^3(16 - 9(3\gamma + 2)\Omega) + 3\sqrt{3}\sqrt{\Omega m^6((9\gamma(3\gamma + 4) - 4)\Omega - 32\gamma + 4\Omega^2)}$$



1-rasm: $m = 0.1$ (chapda) va $m = 0.2$ (o‘ngda) r bo‘lgan $\gamma = 0.05$ bo‘lgan metrik funksiya grafigi.

9-shaklda biz fizik parametrlarning mos qiymatlari uchun metrik funktsiyaning harakatini muhokama qilamiz. RGI Schwarzschild qora o‘ra uchun hodisa gorizontining pozitsiyasi kamayadi ($(r_h$ kamayishi bilan Ω ortadi). Natijada, r_h Shvartsshild va yaxshilangan Shvartsshild qora o‘ralari uchun massaning yuqori qiymatlari uchun katta bo‘lishi aniqlandi.

Shunisi qiziqki, "Qora o‘ra massasi" Qora o‘raning hodisa gorizontida joylashgan haqiqiy massani anglatadi, bu yerda tortishish shunchalik kuchliki, hech narsa, hatto yorug‘lik ham qochib qutula olmaydi. Boshqa tomondan, qobiqning "tortishish massasi" hodisa gorizontidan tashqaridagi jismlar tomonidan seziladigan tortishish kuchiga hissa qo‘shadigan massani anglatadi. 5- va 14-tenglamalardan foydalanib, qobiqning tortishish massasi va massasi o‘rtasidagi munosabatlarni quyidagicha topamiz.

$$\chi_e(w) - \chi_i(w) = -M/w,\ \chi_e(w) + \chi_i(w) = \frac{2w^3 m}{M(w^3 + m^2\Omega(w + \gamma m))}$$

Skayar maydondan tashkil topgan qobiq dinamikasini uning harakat tenglamalarini tahlil qilish orqali o‘rganamiz. Harakat tenglamalarini ($\dot{w}^2 + \Pi(w) = 0$) integrallashning ikkita usuli borligi ko‘rsatilgan. Birinchisi, qobiq bosimini uning radiusining aniq funktsiyasi sifatida hisobga olishni, ikkinchisi esa qobiq bosimi va energiya zichligini bog‘laydigan holat tenglamasining mavjudligini taxmin qilishni o‘z ichiga oladi. Yuqorida aytib o'tganimizdek, $\dot{w}^2 + \Pi(w) = 0$ tenglamasi har qanday vaqtda "kinetik komponent" $\dot{w}^2$ va "potentsial komponent" $\Pi(w)$ yig'indisi nolga teng ekanligini bildiruvchi energiyani tejash qonuniga mos keladi. Bu dinamik tenglamadan ko‘ra ko‘proq cheklovdir, chunki tizimni rivojlantirish uchun o‘zboshimchalik bilan boshlang'ich shartlarni berish mumkin emas, lekin faqat shu shartlar saqlanish tenglamasini qanoatlantiradi.

Bundan kelib chiqadiki, ruxsat etilgan yechimlar faqat samarali potentsial manfiy yoki nolga teng bo‘ladi, ya’ni $\Pi(w) < 0$ yoki $\Pi(w) = 0$. Ikkinchi holat ($\Pi(w) = 0$) statik konfiguratsiyaga yoki $\dot{w}^2 = 0$ ga olib keladigan burilish nuqtalariga, ya’ni ekstremal radiusi $\dot{w}^2 = 0$ orbitalariga mos keladi. $\Pi(w) > 0$ tenglamasi qobiqning tarqalishiga ruxsat bermaydi. Birinchidan, biz massasiz va massiv skalyar maydonlar uchun birinchi holatni ($\dot{w} \neq 0$) ko‘rib chiqamiz va skalyar qobiqning dinamikasini kuzatamiz. Saqlash tenglamasi va Klein-Gordon (KG) tenglamasi kabi birlashtirilgan differentsial tenglamalar tizimining raqamli integratsiyasi, masalan, boshlang‘ich radiusi $w(\tau)$ va $\dot{\Upsilon}(\tau)$ va $\Upsilon(\tau)$ ning boshlang‘ich qiymatlarini belgilash orqali amalga oshiriladi.

$V(\Upsilon) = 0$ ni hisobga olsak, kuchlanish-energiya tensorining komponentlari EoS ($P = \rho$) orqali bog‘lanadi. Tegishli KG tenglamasini quyidagicha yozish mumkin

$$w\ddot{\Upsilon} + 2\dot{w}\dot{\Upsilon} = 0$$

bu esa quyidagini hosil qiladi

$$\xi = w^2\dot{\Upsilon}$$

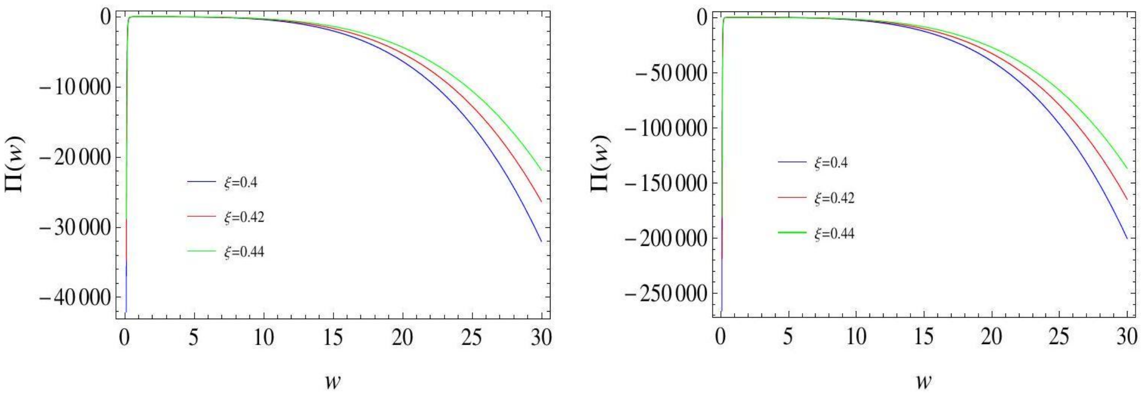
bu yerda integrallashtiruvchi konstanta ξ bilan ifodalanadi. $V(\Upsilon) = 0$ dan foydalanib, biz massasiz skalyar qobiqning quyidagicha yuqori samarali potentsialini olamiz:

$$\Pi(w) = -\frac{m^2 w^{10}}{4\pi^2\xi^4(m^2\Omega(\gamma m + w) + w^3)^2} - \frac{m w^2}{m^2\Omega(\gamma m + w) + w^3} - \frac{\pi^2\xi^4}{w^6} + 1$$

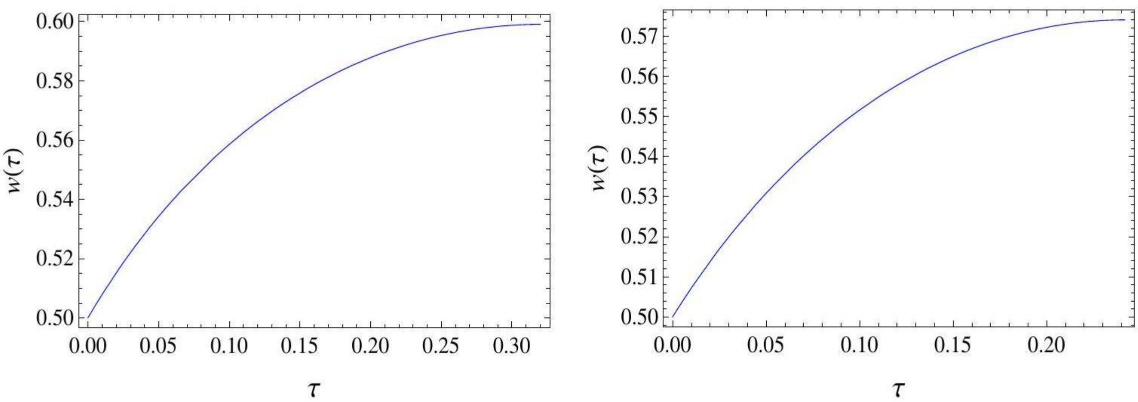
Massasiz skalyar maydon uchun biz 10 va 3-rasmlarda ko'rsatilgan ($\dot{w} \neq 0$) kabi boshlang'ich shartdan foydalanib, samarali potentsial va qobiq radiusini tahlil qilamiz. Massasiz skaler maydonning samarali potentsialining harakati monotonik kengayuvchi qobiqqa (10 va 3-rasmlarga qarang), ya'ni markazdan uzoqda musbat boshlang'ich tezlik bilan ma'lum bir radiusdan boshlab $w = 0$ ravishda abadiy kengayadigan qobiqga mos keladi (3-rasmga qarang).

Endi biz $V(\Upsilon) = m^2\Upsilon^2$ tenglamasi bilan belgilangan massiv skalyar maydon ishtirokida evolyutsiya jarayonida skalyar qobiqning harakatini tekshiramiz:

$$2m^2\Upsilon^2 = \sigma - P, \; \dot{\Upsilon}^2 = \sigma + P.$$



2-rasm: $m = 0.2$ (chapdagi chizma) va $m = 0.5$ (o‘ngdagi chizma) satrlarning massasiz skalyar maydonning samarali potentsiali bo‘yicha qobiqning dinamikasi w turli xil qiymatlari bo‘lgan ξ va $\gamma = 0.5, \Omega = 0.5$.



3-rasm: $\Omega = 0.1$ (chap chizma) va $\Omega = 0.5$ (o‘ng chizma) uchun massasiz skalyar qobiq radiusi to‘g‘ri vaqtga nisbatan $w[0] = 0.5$ va 1 $\lambda = 0.2, m = 0.3, \gamma = 0.5$ uchun $\dot{w} > 0$.

Statik kuzatuvchiga tegishli dinamik tenglamalarni qurish uchun biz yupqa qobiqdagi sirt materiyaning massasi va σ o‘rtasida bog‘lanish hosil qilamiz. Buning uchun biz qobiqdagi sirt moddasi sirt energiyasi zichligi va bosim o‘rtasidagi chiziqli munosabatga mos kelishini taklif qilamiz, ya’ni $P = B_0e^{-zw}$, bu yerda z va B_0 doimiylardir. 11-tenglamadan foydalanib, P ning maxsus tanlovi bilan biz quyidagi tenglamaga ega bo‘lamiz

$$\sigma = \frac{\chi}{w^2} + \frac{2B_0}{(wz)^2}\Gamma(2, wz)$$

bu yerda χ integrallashtiruvchi konstantani va $\Gamma(2, wz) = \int_{wz}^{\infty} \nu^3 e^{-\nu} d\nu$ ni ifodalaydi. 20-tenglamada σ va P ning ifodasini hisobga olgan holda, biz quyidagini olamiz:

$$\dot{\Upsilon}^2 = \frac{\chi}{w^2} + B_0\{e^{-zw} + \frac{2}{(wz)^2}\Gamma(2, wz)\}$$

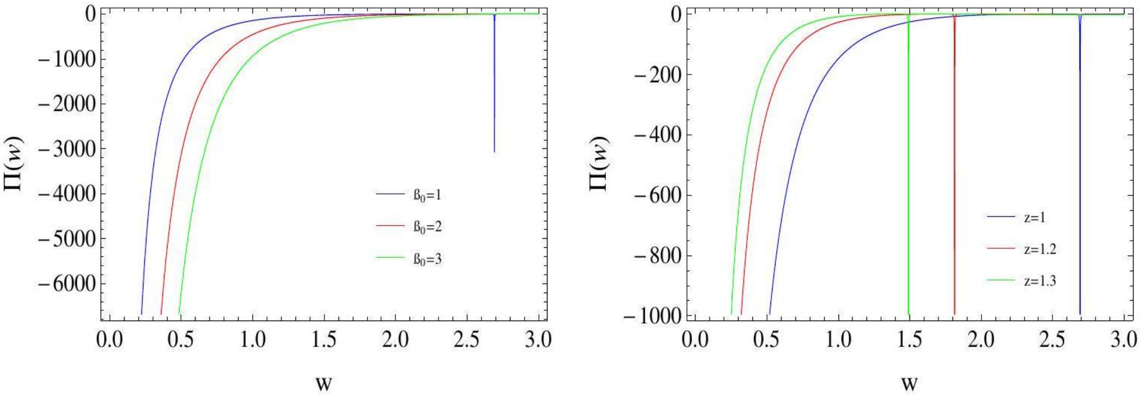
$$\Upsilon^2 = \frac{\chi}{2m^2w^2} + \frac{B_0}{2m^2}\{\frac{2}{(wz)^2}\Gamma(2, wz) - e^{-zw}\},$$

bu esa KG tenglamasiga ergashadi. Bundan tashqari bizda quyidagi yuzaga keladi:

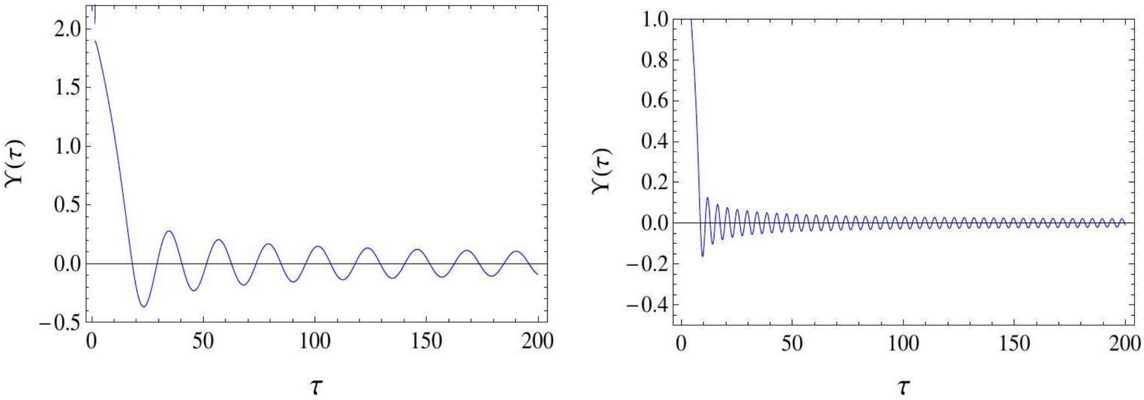
$$\mathcal{M} = 4\pi w^2\sigma = 4\pi\chi + \frac{8\pi B_0}{\gamma^2}\Gamma(2, wz)$$

Massiv skalyar maydonlar uchun integratsiyaning ushbu tartibi 4 va 5-rasmlarda ko‘rsatilgan bo‘lib, ular samarali potentsialni va kvadratik skalyar potentsialga ega bo‘lgan kengayuvchi qobiqni tavsiflovchi tenglamalar (saqlanish va KG tenglamalari) yechimlari uchun mos ravishda skalyar maydonni tasvirlaydi. 4-rasmda biz samarali potentsial $\Pi(w)$ ning xatti-harakati skalyar maydonga aniq bog‘liqligi tufayli skalyar maydonga bog‘liqligini ko‘ramiz. Shuni ham ta’kidlaymizki, qobiq kengayishi bilan $\Pi(w)$ nolga intiladi va shuning uchun kengayish sekinlashadi. Bu Υ ning xulq-atvoriga ta’sir qiladi, ya’ni $\dot{w}$ katta bo‘lganda amplituda harakatning boshida yuqori darajada so‘ndiriladi, lekin keyin 5-rasmda ko‘rsatilganidek, $\dot{w}$ kichikroq bo‘lganda u oddiy garmonik tebranishga o‘xshaydi.

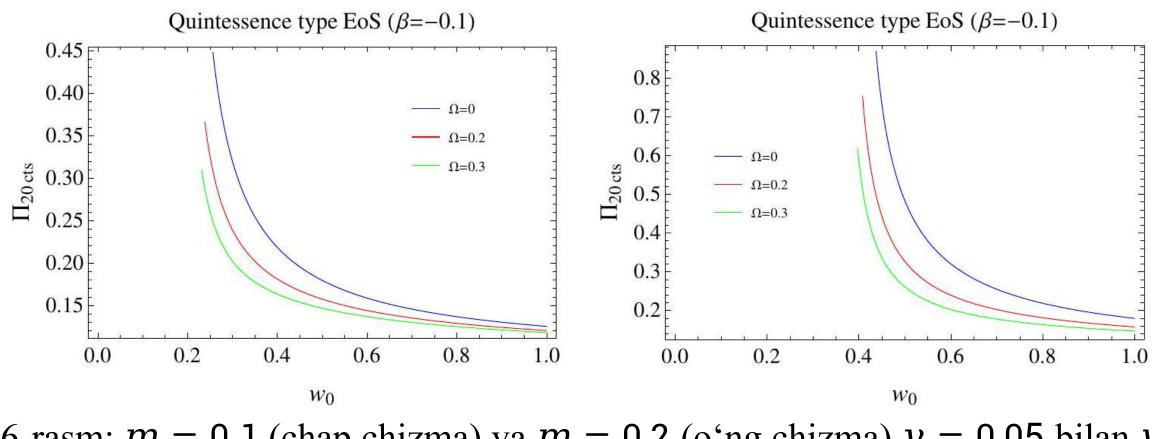
Holat tenglamasi yuqori sirtda joylashgan har xil turdagi moddalar tarkibining yupqa qobiqli tuzilmalarning barqaror/beqaror xususiyatlariga ta’sirini tushuntirish uchun juda muhim tushunchadir. Buyerda biz EoS holatining o‘ziga xos turini ko‘rib chiqamiz



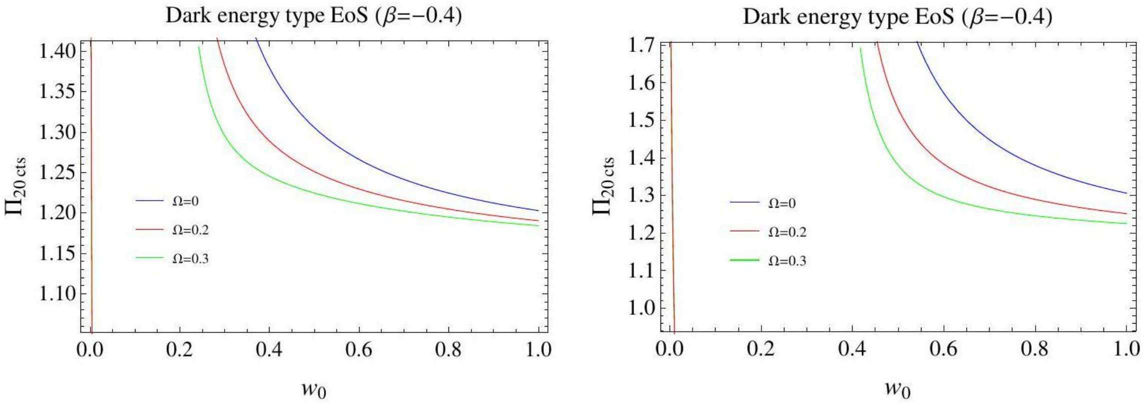
4-rasm: $\gamma = 0.5, \chi = 1, m = 0.2, \Omega = 0.5$ bo‘lgan B_0 (chap chizma) va z (o‘ng chizma) oyatlarining turli qiymatlari uchun massiv skalyar maydonning samarali potentsiali orqali qobiq dinamikasi.



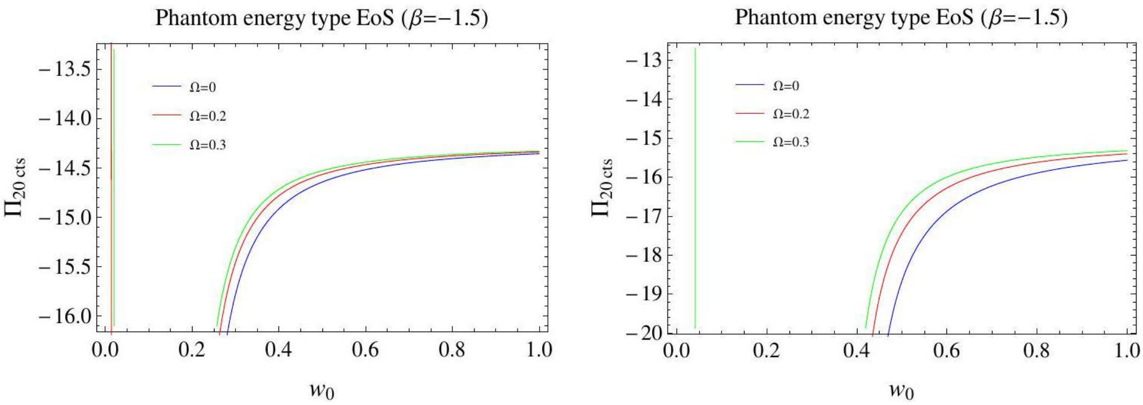
5-rasm: $m = 0.2$ (chap chizma) va $m = 1$ (o‘ng chizma) uchun mos vaqtga nisbatan massiv skalyar maydon $\gamma = 0.5, \Omega = 0.5$ uchun $\dot{w}(0) = 0.5, \dot{\Upsilon}[0] = 1.5, \Upsilon[0] = 1.5$. Tebranishlar qobiqning kengayishi hisobiga $\dot{w} > 0$ katta bo‘lganda, boshida yuqori darajada susayadi.



6-rasm: $m = 0.1$ (chap chizma) va $m = 0.2$ (o‘ng chizma) $\gamma = 0.05$ bilan w_0 versiyalari uchun kvintessensiya tipidagi moddalar tarkibi bilan to‘ldirilgan yupqa qobiqning barqarorlik tahlili.



7-rasm: $m = 0.1$ (chapdagi chizma) va $m = 0.2$ (o‘ngdagi chizma) $\gamma = 0.05$ bilan w_0 versiyalari uchun qorong‘u energiya turidagi moddalar tarkibi bilan to‘ldirilgan yupqa qobiqning barqarorlik tahlili.



8-rasm: $m = 0.1$ (chap chizma) va $m = 0.2$ (o‘ng chizma) $\gamma = 0.05$ bilan w_0 versiyalari uchun fantom energiya turidagi moddalar tarkibi bilan to‘ldirilgan yupqa qobiqning barqarorlik tahlili.

fantomga o‘xshash EoS quyidagicha ifodalangan:

$$\mathfrak{P}(w) = \beta\rho(w),$$

bu yerda $\beta < 0$ EoS parametrini bildiradi. Tenglama holati parametrining turli diapazonlari materiya tarkibining har xil turlarini quyidagicha ifodalaydi:

- If $\beta < -1$ bu fantom energiya holatini ifodalaydi.
- If $0 > \beta > -1/3$ keyin bu kvintessensiya tipidagi materiya tarkibini ifodalaydi.
- If $\beta < -1/3$ keyin bu qorong'u energiya holatini ifodalaydi.

Endi biz takomillashtirilgan Shvartsshild qora o‘ra fonida yupqa qobiqning barqaror va beqaror xususiyatlarini 6-8-rasmlarda ko‘rsatilganidek, fantomga o‘xshash EoS uchun Π_{20cts} yordamida grafik tarzda o‘rganamiz. Shuni ta’kidlash juda qiziqki, yupqa qobiqning barqaror/beqaror harakati yupqa qobiqning asosiy shartiga mos keladi, bu qobiq radiusi hodisa gorizonti radiusidan kattaroq bo‘lishi kerak (hodisalar gorizonti uchun 9-rasmga qarang va nozik qobiq konfiguratsiyasi uchun 6-8-rasmlarga qarang). Demak, yupqa qobiqning barqarorligi bilan bog‘liq biz xohlagan natijalar hodisa gorizonti pozitsiyasidan keyin hosil bo‘ladi.

Aniqlanishicha, yupqa qobiq Shvartsshild uchun ham, yaxshilangan Shvartsshild qora o‘ralari uchun ham kvintessensiya tipidagi moddalar tarkibiga to‘la barqaror harakatni ko‘rsatadi (6-rasm). Ta’kidlanishicha, Shvartsshild qora tuynugiga nisbatan takomillashtirilgan Shvartsshild qora tuynugini tanlashda yupqa qobiq barqarorligi pasaygan. Yupqa qobiqning barqarorligi massaning yuqori qiymatlari uchun ortadi. Xuddi shunday, biz quyuq energiya turidagi moddalar tarkibini tanlash uchun bir xil natijalarga erishamiz (7-rasm). Qorong‘i energiya turidagi moddalar tarkibi kvintessensiya tipidagi moddalar taqsimotiga qaraganda ancha barqaror konfiguratsiyani ko‘rsatadi. Fantom energiya turi EoS uchun nozik qobiq har bir jismoniy parametr tanlash uchun beqaror harakatni ko‘rsatadi (8-rasm). Shunday qilib, yupqa qobiq kvintessensiya va EoS quyuq energiya turini tanlash uchun barqaror konfiguratsiyani ifoda etdi.

2 qism

Qora o‘ralarga nazariy muqobil bo‘lgan gravastarlar o‘zining noyob xususiyatlari tufayli olimlarning astrofizikaga qiziqishini uyg‘otdi. Taqdimotning ikkinchi qismi umumiy nisbiylik doirasida Mazur-Mottola usuliga asoslangan yangi gravastar modelining aniq yechimini, xususan, qatorlar buluti va kvintessensiyani o‘z ichiga olgan holda yanada tadqiq qilishga bag‘ishlangan. Gravastar tortishish maydoni va energiya zichligini tahlil qilish orqali koinotdagi ixcham jismlarning tabiati haqida qimmatli tushunchalarga ega bo‘lish mumkin. Gravastarlarning barqarorligini tushunish qora o‘ralar va muqobil kompakt ob’ektlarni tushunishimiz uchun ham juda muhimdir. Buning uchun biz Eynshteyn maydon tenglamalarini modifikatsiyalangan modda manbai bilan taqdim etamiz va gravastarlarning ichki va oraliq mintaqalari uchun aniq echimlarni hisoblaymiz. Tashqi mintaqa torlar va kvintessensiya buluti bilan o‘ralgan qora o‘ra sifatida ko‘rib chiqiladi va fazoviy vaqtlar Darmoise-Isroil formalizmi yordamida mos keladi. Chiziqli radial tebranish yordamida gravastarlarning barqarorligi bo‘yicha tadqiqot o‘tkaziladi.

Bundan tashqari, qobiqning to‘g‘ri uzunligi, energiya tarkibi va entropiyasi hisoblab chiqiladi. Gravastarlarning barqarorligi satrlar buluti parametrining kuchayishi bilan ijobiy bog‘liq bo‘lsa, kvintessensiya maydoni parametrining o‘sishi bilan salbiy bog‘liqdir. Biz topilmalarning qisqacha mazmuni va ularning astrofizika va kosmologiya sohasidagi oqibatlari bilan yakunlaymiz.

Biz sferik simmetrik va statik bo‘lgan va sferik sirt bilan chegaralangan 4 o‘lchovli fazoga e’tibor qaratishdan boshlaymiz. Shvartsshild koordinatalaridan foydalanib, tegishli ko‘rsatkich quyidagicha taqdim etiladi:

$$ds^2 = e^{\epsilon(r)}dt^2 - e^{\varepsilon(r)}dr^2 - r^2\sin^2\theta d\phi^2 - r^2 d\theta^2$$

bu yerda vaqtinchalik va radial koordinatalarning tortishish funksiyalari mos ravishda $\epsilon(r)$ va $\varepsilon(r)$ bilan belgilanadi. Moddaning o‘zgartirilgan shaklidan foydalangan holda, 26-metrik uchun tegishli Eynshteyn maydon tenglamalari quyidagicha bo‘ladi.

$$G_{ij} = R_{ij} - \frac{1}{2}g_{ij}R = T_{ij}^{\text{eff}},\ i,j = 0,1,2,3$$

bu yerda

$$T_{ij}^{\text{eff}} = \Theta_{ij} + \hat{T}_{ij} + \hat{\Theta}_{ij}$$

bu yerda Θ_{ij} qatorli bulut tufayli yuzaga kelgan materiyani, Θ_{ij} esa kvintessensiya maydonlari ta’sirida bo‘lgan materiyani tasvirlaydi. Binobarin, bulutlar qatorlari fonida tegishli Lagranj zichligi quyidagicha yozilishi mumkin:

$$L_s = -\frac{k}{2}\Sigma^{ij}\Sigma_{ij},$$

bu yerda ip va bivektorning tarangligi doimiy k bilan belgilanadi. Shu munosabat bilan biz quyidagi munosabatni olamiz

$$\Sigma^{ij} = \epsilon^{a\beta}\frac{\partial x^i}{\partial\lambda^a}\frac{\partial x^j}{\partial\lambda^\beta},$$

bu yerda dunyo varag‘ini parametrlash munosabati $\lambda^a\ (\lambda^a = \lambda^0, \lambda^1)$ deb ataladi va Levi-Civita tenzori $\epsilon^{a\beta}$ bilan ifodalanadi. Induktsiyalangan metrikani qo‘llash orqali uni satr uchun quyidagicha tavsiflash mumkin

$$h_{a\beta} = g_{ij}\frac{\partial x^i}{\partial\lambda^a}\frac{\partial x^j}{\partial\lambda^\beta}$$

Binobarin, ba’zi muhim identifikatsiyalar sifatida berilgan Σ^{ij} dan olinadi

$$\Sigma^{i[a}\Sigma^{\beta\sigma]} = 0,\ \Sigma^{ia}\Sigma_{a\sigma}\Sigma^{\sigma j} = \mathbf{h}\Sigma^{ji},\ \nabla_i\Sigma^{i[a}\Sigma^{\beta\sigma]} = 0$$

bu yerda $h_{\alpha\beta}$ ning determinanti $\mathbf{h}$ bilan belgilanadi.

Bundan tashqari, g_{ij} metrik tensoriga nisbatan Lagranj zichligini o'zgartirib, biz quyidagi hosilani olamiz:

$$\Theta_{ij} = \rho_s \frac{\Sigma^{ia}\Sigma_a^j}{\sqrt{-\mathbf{h}}}$$

bu yerda ρ_s qatorli bulutning zichligini bildiradi. Quyidagi $\partial_i(\sqrt{-g}\Sigma^{ia}) = 0$ ifodani 32-tenglamada keltirilgan o'ziga xosliklarni hisobga olgan holda olamiz. Qatorli bulutlar fonida kuchlanish-energiya tensorining tegishli komponentlari bo'ladi

$$\Theta_{tt} = \Theta_{rr} =- \frac{a}{r^2}\ \Theta_{\theta\theta} = \Theta_{\phi\phi} = 0$$

bu yerda a parametri qatorli bulutini bildiradi. Shuningdek, kvintessensiya moddalarining taqsimlanishi uchun quyidagi munosabatni quyidagicha olamiz

$$L_q =- \frac{1}{2} g^{ij}\partial_i\Psi\partial_j\Psi - V(\Psi).$$

Kvintessensiya maydoni (Ψ) ta'sirida jismoniy yashovchan bo'lgan stress-energiya-momentum tensor komponentlari kvintessensiya maydonining potentsial terminini bildiruvchi $V(\Psi)$ bilan belgilanadi.

$$\hat{\Theta}_{tt} = \hat{\Theta}_{rr} = \rho_q\ \hat{\Theta}_{\theta\theta} = \hat{\Theta}_{\phi\phi} =- \frac{\rho_q}{2}(3\omega_q + 1)$$

Bu yerda ω_q va ρ_q mos ravishda kvintessensiya maydoni parametrini va kvintessensiya zichligini bildiradi va materiya manbai $\hat{T}_{ij}$ ishtirokida tizimning ichki tuzilishini tavsiflash uchun ishlatiladi. Kosmik vaqtning fizik tarkibini tahlil qilish uchun biz hududni qamrab oluvchi izotrop moddalar taqsimotining energiya zichligini tekshiramiz. Bu yerda radial bosim p bilan ifodalanadi va energiya zichligi ρ bilan tasvirlangan. Keyinchalik, kuchlanish-energiya tensorining tegishli komponentlari $\hat{T}_{ij}$ bo'ladi

$$\hat{T}_{tt} = \rho,\ \hat{T}_{rr} =- p_r,\ \hat{T}_{\theta\theta} = \hat{T}_{\phi\phi} =- p_t$$

Bundan tashqari, biz modifikatsiyalangan materiya manbasi bilan aniq maydon tenglamalaridan foydalangan holda gravastar strukturasini qatorli bulut va kvintessensiya fonida ishlab chiqishdan manfaatdormiz. Umuman olganda, qatorli bulut va kvintessensiyaga ega gravastar konfiguratsiyasi quyuq energiya tabiati va koinotning kelib chiqishiga oydinlik kiritishi mumkin bo‘lgan ajoyib modeldir. Gravastar - bu kvintessensiya maydoni bilan yaxshiroq tushuntirilishi mumkin bo‘lgan salbiy bosim manbai mavjudligida materiyaning qulashi natijasida hosil bo‘lgan faraziy modeldir.

Kvintessensiya - bu koinotning kengayishini tezlashtirish uchun javobgar bo‘lgan quyuq energiya shakli. Ushbu modelda gravastar ultra-relativistik kosmik torlar qalin qobig‘i bilan o‘ralgan teskari bosimning yupqa qobig‘idan iborat. Kosmik tor - konsentrlangan massa mavjudligi sababli fazo-vaqtning cho‘zilishidan hosil bo‘lgan faraziy bir o‘lchovli obyekt. Gravastar strukturasida kvintessensiya qobig‘i zarur bo‘lgan o‘z-o‘zini tortishish kuchini hosil qiluvchi kosmik tor bilan quvvatlanadi. Tizimning o‘z tortishish kuchi kvintessensiyaning salbiy bosimi bilan kuchayadi, bu barqaror muvozanatga olib keladi. Obyekt ichida barqaror orbitalarning paydo bo‘lish qobiliyati gravastar tuzilishining qiziqarli xususiyatidir. Buning sababi shundaki, kosmik torli qobiq itaruvchi kuch hosil qiladi, kvintessensiya qobig‘i esa qo‘shni massalarni tortishish bilan tortadi. Ushbu kuchlarning kombinatsiyasi gravastar ichida orbitalar saqlanishi mumkin bo‘lgan barqaror mintaqani yaratishga olib kelishi mumkin.

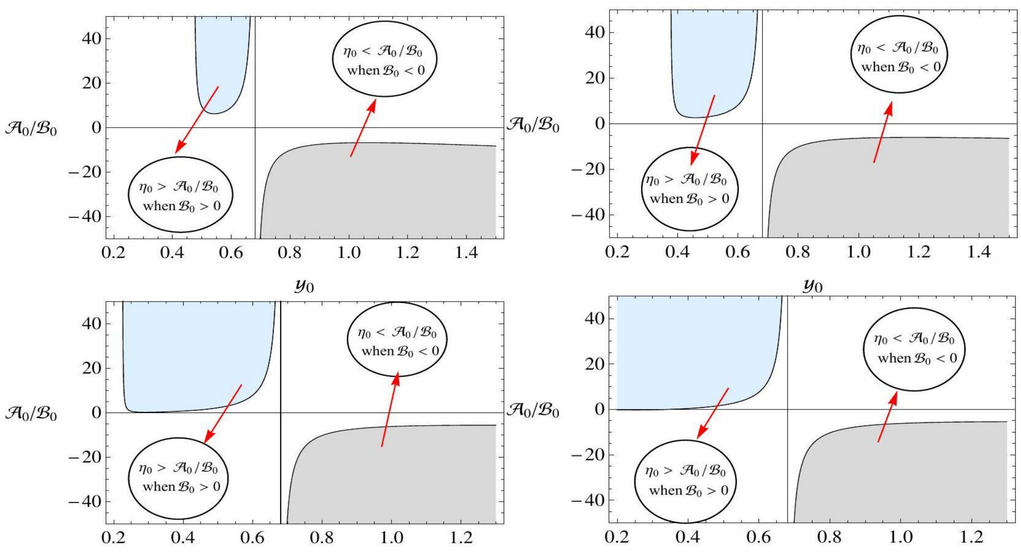
Biz o‘zgartirilgan modda manbai doirasida maydon tenglamasidan foydalangan holda gravastar strukturasini ishlab chiqdik. Shu maqsadda biz gravastarni uch xil hududga bo‘lish mumkin bo‘lgan geometrik tuzilishini tushunish orqali rivojlantiramiz. Ushbu hududlarning materiya tarkibining xatti-harakati EoS ning ma’lum bir turi orqali tavsiflanishi mumkin. Bunday geometrik struktura ichki $(0 \leq r < r_1)$, oraliq yoki yupqa qobiqli $(r_1 < r < r_2)$ va tashqi mintaqaga $(r_2 < r)$ bo‘linadi. Bu yerda r_1 va r_2 ichki va tashqi hududlar radiusini bildiradi. Shuningdek, oraliq mintaqaning qalinligi $r_2 - r_1$ deb ataladi. Ushbu hududlar uchun maxsus EoS quyidagicha ifodalanadi

- $p = -\sigma$ ichki hudud uchun;
- $p = \sigma$ o‘rtadagi hudud uchun;
- $p = 0 = \sigma$ tashqaridagi hudud uchun.

Endi biz gravastarning turli jismoniy xususiyatlariga qatorli bulut va kvintessensiya maydonining ta’sirini o‘rganishni maqsad qilganmiz. Shu nuqtai nazardan, biz chiziqli tebranish orqali barqarorlikni hisoblaymiz. Keyin biz gravastarlarning to‘g‘ri uzunligini, qobiq energiyasini va entropiyasini kuzatamiz.

9 va 10-rasmlarda biz gravastarlarning barqaror konfiguratsiyasini kvintessensiya va qatorli buluti doirasida o‘rganishdan manfaatdormiz. Shuni

ta’kidlash juda qiziqki, gravastarlarning barqaror hududlari qatorli bulut va kvintessensiya maydon parametrlarining mavjudligi katta ta’sir ko‘rsatadi. 9-rasmda qatorli buluti parametrining gravastarlarning barqarorligiga ta’sirini o‘rganish uchun ishlatiladi. Qatorli bulut parametri ortishi bilan barqaror hududlar ortib borishi aniqlandi. Bu ishlab chiqilgan strukturaning qatorli bulutning ta’siri tufayli barqarorroq ekanligini ko‘rsatadi (9-rasm). 10-rasmda biz kvintessensiya maydoni parametrining turli qiymatlarini hisobga olgan holda ishlab chiqilgan strukturaning barqarorligini muhokama qilishdan manfaatdormiz. Aniqlanishicha, barqarorlik hududlari kvintessensiya maydoni parametri ortib borishi bilan kamayadi (10-rasm). Shunday qilib, kvintessensiya ham,qatorli bulut ham Gravatarlarning barqarorligini saqlashda ajoyib rol o‘ynaydi.



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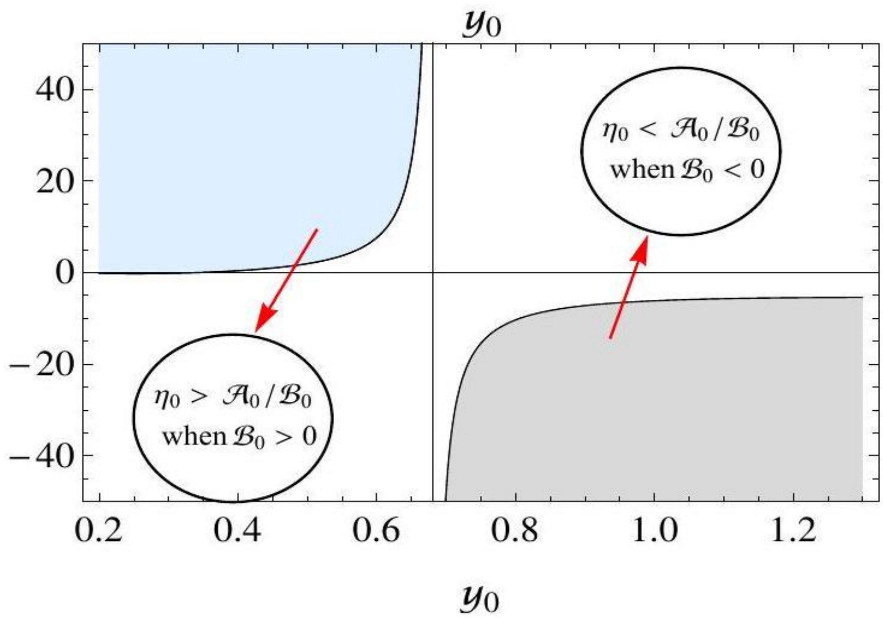
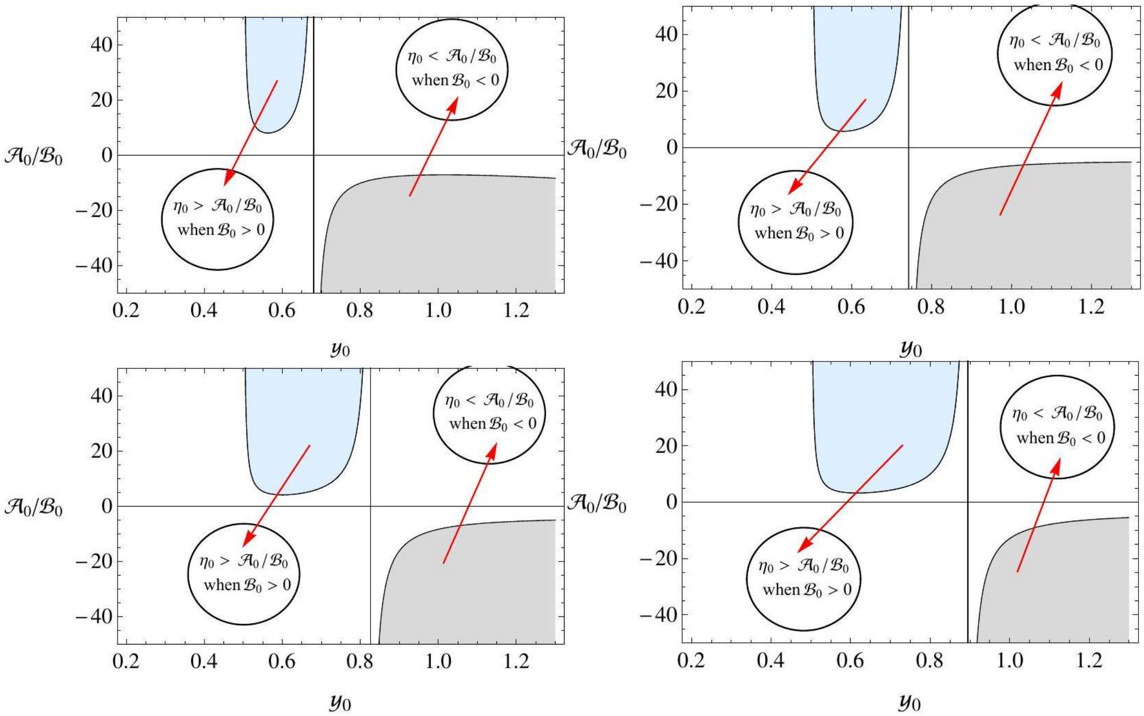


9-rasm: Bulut parametrining $a = 0.3$ (birinchi chizma), $a = 0.6$ (ikkinchi chizma), $a = 0.9$ (uchinchi chizma), $a = 1.2$ (to‘rtinchi chizma) $\omega_q =-\frac{2}{3}$, $\rho_c = 0.5$, $C_2 = 1$, $\gamma = 0.2$, $m =$

0.5 bo‘lgan turli qiymatlari uchun $\mathcal{A}_0/\mathcal{B}_0$ va y_0 ning chizmalari.Bu yerda soyali hududlar gravastarlarning barqarorligini, agar $\mathcal{B}_0 > 0$ (ochiq ko‘k mintaqa) va $\mathcal{B}_0 > 0$ (ochiq kulrang mintaqa) bo‘lsa, $\eta_0$harakati orqali tasvirlaydi.



10-rasm: $\gamma = 0.2$ (birinchi chizma), $\gamma = 0.8$ (ikkinchi chizma), $\gamma = 1.5$ (uchinchi chizma), $\gamma = 2$ (to‘rtinchi chizma) kvintessensiya parametrining turli qiymatlari uchun $\omega_q = -2/3, \rho_c = 0.5, C_2 = 1, a = 0.2, m = 0.5$.bilan $\mathcal{A}_0/\mathcal{B}_0$ va y_0 ga nisbatan chizmalar.

Kvintessensiya bulutining turli qiymatlari uchun to‘g‘ri uzunlik va qobiq qalinligining harakati 11-rasmning chap chizmasida ko‘rsatilgan. To‘g‘ri uzunlik qalinlik bilan birga qatorli bulut parametri ortishi bilan ham ortadi. Quintessensiyaning turli qiymatlari uchun qobiq qalinligiga nisbatan energiya tarkibining grafik tahlili 11-rasmning o‘rta chizig‘ida ko‘rsatilgan. Qalinligi bilan bir qatorda qatorlar buluti parametri oshishi bilan u ortadi.

Geometrik tuzilishdagi tartibsizlik yoki buzilish darajasi entropiya o‘lchovi bilan bog‘liq. Gravastar geometriyasining tasodifiyligini tushunish uchun biz yupqa qobiqli gravastarlarning entropiyasiga qaraymiz. Mazur va Mottola g‘oyasi yupqa qobiqli gravastarning entropiyasi uchun tenglamani hisoblash uchun ishlatiladi.

$$S = \int_{y}^{y+\delta} 4\pi r^2 h(r) \sqrt{e^{\varepsilon(r)}} dr$$

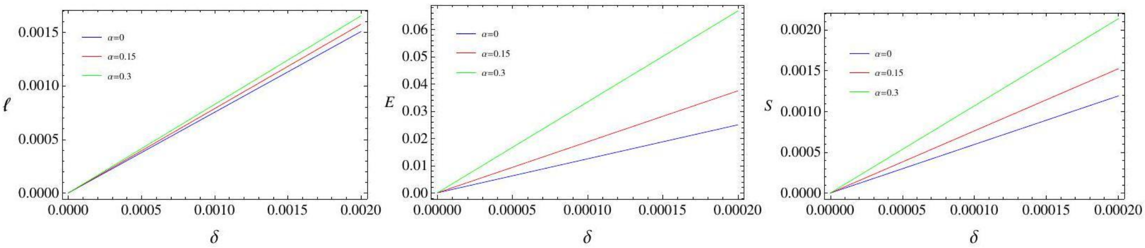
Mahalliy harorat uchun entropiya zichligi quyidagicha hisoblanadi

$$h(r) = \frac{\eta K_B}{\hbar} \sqrt{\frac{p(r)}{2\pi}}$$

bu yerda η o‘lchamsiz parametr sifatida ifodalanadi. Buyerda biz Plank birliklarini ($K_B = 1 = \hbar$ olamiz, shunda qobiq entropiyasiga aylanadi.

$$S = 2\sqrt{2\pi}\delta\eta y^2\sqrt{\frac{1}{-a + 3^{2/3}e^{-C_4 y^{2/3}} + 1}}\sqrt{C_6 e^{-\frac{3 3^{2/3}e^{-C_3 y^{2/3}}}{a-1}}}$$

Qayd etilishicha, qobiq entropiyasi ham δ ga proportsionaldir. Xuddi shunday, biz satrlar bulutining turli qiymatlari uchun qobiqning qalinligi bo‘ylab qobiqning entropiyasini 11-rasmning o‘ngdagi chizmasida o‘rganamiz. Ta’kidlanishicha, entropiya δ ni, shuningdek, qatorli bulut parametrini oshirish orqali ortadi.



11-rasm: Torli bulutining turli qiymatlari uchun $a = 0{,}0.15{,}0.3$ parametri uchun to‘g‘ri uzunlik (chap chizma), energiya tarkibi (o‘rta chizma) va qobiq entropiyasi (o‘ng chizma) harakati.

XULOSA

“Kompakt obyektlar yupqa qobig’i orqali termodinamika va turg’unligiga ta’siri ” mavzusida olib borilgan tadqiqotlar asosida quyidagi xulosalar kelindi:

1. Ta’kidlanganidek, massiv skalyar qobiq strukturasiga olib keladigan ma’lum parametrlarni tanlash tebranish konfiguratsiyasini ko‘rsatdi. Ushbu konfiguratsiya potentsial va kinetik energiyaning uzluksiz almashinuvini o‘z ichiga olgan, bu qobiqning o‘zgaruvchan sirt bosimi va tortishish kuchi tufayli mumkin bo‘lgan. Metrik funksiyaning grafik harakatidan RGI Shvartsshildning hodisa gorizontining holati Shvartsshild qora tuynugidan kamroq ekanligi aniqlandi.

2. Yupqa qobiqni grafik tahlil qilishda qobiq radiusi hodisa gorizonti radiusidan kattaroq bo‘lishi kerak bo‘lgan yupqa qobiqning asosiy shartiga amal qilish ko‘rsatilgan. Ta’kidlanishicha, yupqa qobiq ham kvintessensiya, ham qorong‘u energiya tipidagi moddalar tarkibi uchun barqaror harakatni ifodalaydi. Aniqlanishicha, qorong’u energiya tipidagi moddalar tarkibi kvintessensiya tipidagi moddalar taqsimotiga qaraganda ancha barqaror konfiguratsiyaga ega. RGI Schwarzschild qora tuynukni tanlashda Shvartschild qora o‘rasi bilan solishtirganda yupqa qobiqning barqarorligi pasaygan degan xulosaga keldi.

3. Eynshteyn maydon tenglamasi birinchi marta modifikatsiyalangan materiya manbai doirasida ishlab chiqildi. Bundan tashqari, gravastar strukturasi uchun yechim olindi va eritmaning o‘ziga xos xususiyati yo‘qligi aniqlandi. Bundan tashqari, tizimning energiya zichligi va bosimi doimiy bo‘lib qoladi, bu quyuq energiya bilan bog‘liq xususiyatlarga mos keladi.

4. Birinchi marta gravastar strukturasi Darmois-Isroil formalizmini hisobga olgan holda ishlab chiqilgan. Qayd etilishicha, qatorli buluti parametri gravastarlarning barqaror hududlarini kuchaytiradi va chiziql parametri kamayishi bilan barqarorlik pasayadi. Kvintessensiya maydoni parametri ortishi bilan barqaror mintaqaning kamayishi ko‘rsatilgan.

5. Qobiq qalinligi va uning to‘g‘ri uzunligi o‘rtasidagi bog‘liqlik tahlili shuni ko‘rsatdiki, qatorlarning qalinligi ham, buluti ham parametri ortishi bilan to‘g‘ri uzunlik ham ortadi. Tahlil shuni ko‘rsatadiki, qobiq mintaqasining entropiyasi qobiq qalinligi bilan to‘g‘ridan-to‘g‘ri proportsionaldir.

6. Birinchi marta jismonan maqbul bo‘lgan yagonaliksiz yechim olindi. Ushbu yechimlar qatorlar buluti va kvintessensiya maydonlari yo‘qligida aniq Mazur va Mottola modeliga qisqartirilganligi ko‘rsatilgan.

SCIENTIFIC COUNCIL DSc.03/31.03.2022.T/FM.10.04 ON AWARD OF SCIENTIFIC DEGREE AT INSTITUTE OF FUNDAMENTAL AND APPLIED RESEARCH “TIIAME” NATIONAL RESEARCH UNIVERSITY

UNIVERSITY OF TASHKENT FOR APPLIED SCIENCES

JAVED FAISAL

IMPACT ON THERMODYNAMICS AND STABILITY VIA THIN-SHELL OF COMPACT OBJECTS

01.03.01 – Astronomy
01.04.02 – Theoretical Physics
(physical and mathematical sciences)

PRESENTATION
on awarding the scientific degree of Doctor of Science (DSc) on the basis of published papers without a dissertation

Tashkent – 2024

The theme of the doctor of science (DSc) researche is registered by Supreme Attestation Commission of Higher Education, Science and Innovations of Republic of Uzbekistan under B2024.1.DSc/FM257.

The esearch work has been carried out at the University of Tashkent for Applied Sciences.

The presentation was posted in three (Uzbek, English, Russian (resume)) languages on the website of the Scientific Council (www.ifar.uz) and on the information and education portal at "Zionet" (www.ziyonet.uz).

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Doctor of physical and mathematical sciences, professor

Presentation of the research will be held on " ___" _______ 2024 at ____ in the meeting of the Scientific Council No. DSc.03/31.03.2022 T/FM.10.4 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.: 71 237-09-61.; e-mail: info@ifar.uz

The presentation 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 205; ph.: 71 237-09-61

The presentation was distributed on "___" __________, 2024.

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D. Ph.-M.S.

D.R. Rayimbayev
Scientific Secretary of Scientific Council
on Award of Scientific Degrees
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INTRODUCTION (presentation abstract)

Relevance and necessity of the topic. Recent advancements in general relativity (GR) have brought challenging revolutions to several astrophysical phenomena in the cosmic setup, and have also led to several fascinating experiments using gravity. In the modern era of study, black holes (BHs) are considered to be one of the most remarkable features of powerful gravitational fields. A BH's powerful gravitational zone prevents anything from escaping its event horizon, but it also swallows anything that becomes entangled in its surroundings. There have always been astonishing consequences of quantum fluctuations related to the physical characteristics of BH geometries. Singularity is a core region of spacetime where density and spacetime curvature diverges and physical laws are rendered invalid. The presence of singularity is one of the fundamental problems in BH physics.

Particularly, the Hawking evaporation process, entanglement, and the information loss paradox are all results of the quantum gravitational processes in BHs, which have a rich history and deep results. The BH singularities are solved by the quantum gravity effects that stem from loop quantum gravity and the renormalization-group-improvement (RGI) technique, which either prevent or eliminate the emergence of a singularity during the gravitational collapse of a dying star. As the BH dissipates during the Hawking evaporation process, the naked singularity of the spacetime curve is revealed.

A timelike thin-shell in a static spherical geometry is one of the fascinating cosmological configurations that can be used to analyze a wide range of cosmological scenarios. A thin-shell is referred to as an infinitesimally thin layer of a substance that serves as a spacetime junction. Since thin-shell integrates a certain matter distribution, it must satisfy certain energy constraints that validate the validity of the respective spacetime. These conditions can be related to the extrinsic curvature of the geometrical structure through stress-energy tensor.

Astrophysical objects known as black holes, which are the mathematical solutions to the Einstein equations, are widely acknowledged. Two significant observations about black holes in our universe were recently reported. The first is the discovery of gravitational waves coming from black hole binaries, and the second is the discovery of photographic proof of black holes at the centers of our galaxy's M87 and Sgr A*. But distant observers should be able to observe phenomena that happen outside the event horizon or even before they form. As a result, it is still unclear whether an astrophysical object has an event horizon. Several authors have suggested that the gravitational collapse of a massive star could make the densest celestial objects other than black holes. To address this idea, Mazur and Mottola introduced a new theory of collapsing stellar objects known as gravitational vacuum stars, or “gravastars”, which incorporates the expanded concept of Bose-Einstein condensation in the gravitational system. Gravastar has been proposed as a black hole substitute that also considers quantum effects. The gravastar model is believed to offer a solution to issues associated with traditional black holes, while also meeting all theoretical requirements for a stable endpoint of stellar evolution. This theory suggests that quantum vacuum fluctuations play a significant role in collapse dynamics, leading to a phase transition that results in a repulsive de Sitter core that balances the collapsing body and prevents the formation of a horizon (and singularity) near the bound of r=2m. However, this phenomenon occurs very close to the limit, making it challenging for an outsider to differentiate between a gravastar and a true black hole.

This research work corresponds to the tasks by the following state regulatory documents: Decree of the President of the Republic of Uzbekistan No. PD-4947 "On the Strategy of Actions for the Further Development of the Republic of Uzbekistan" dated February 07, 2017, Resolution of the President of the Republic of Uzbekistan No. PR-2789 "On measures for further improvement of the activities of the Academy of Sciences, organization, management and financing of research activities" dated February 18, 2017 and others.

Conformity of the research to the main priorities of science and technology development of the Republic. The dissertation research has been carried out in accordance with the priority areas of science and technology in the Republic of Uzbekistan: II. “Power, energy and resource-saving”.

The degree of knowledge of the problem. Thermodynamics around compact gravitating object have been investigated by the different researcher worldwide (Z. Stuchlik, J, Schee, A. Abdujabbarov, B Ahmedov, J. Kunz, N. Dadhich, S. Ghosh, P. Joshi, F. Atamurotov). However, the effect of black hole parameters on thermodynamical quantities have not been systematically studied in different models and theories

The influence of dark matter on the astrophysical processes around a regular black hole also remains unexplored. The development and improvement of mathematical models describing the dynamics of particles around such objects contribute to obtaining limit values for the parameters of modified and/or alternative theories of gravity.

Connection of the topic of the dissertation topic to the scientific works of higher education and research institutions, where the dissertation is carried out. The dissertation was done in the framework of the scientific projects funded by the Ministry of Innovative Development. F-FA-2021-510 "Investigations of nuclear matter of neutron stars in modified gravity".

The aim of the research is the development and improvement of theoretical models for the renormalization group improved gravity theory and corresponding solutions for the compact objects.

The tasks of the research:

to study the geometrical construction of thin-shell with inner flat spacetime and outer RGI Schwarzschild BH through a cut and paste approach;

to calculate the stress-energy tensor from the reduced form of Einstein field equations at the hypersurface which develop the dynamical equation of these constructed geometries;

to analyze the graphical behavior of the metric function and to explore the dynamical configuration of thin-shell composed of the massless and massive scalar field by using KG and conservation equations;

to explore the stable configuration of thin-shell filled with matter distribution which follows quintessence, dark energy, and phantom energy type EoS with linearized radial perturbation about equilibrium shell radius;

to analyze the thin-shell dynamics in the context of scalar field by using the effective potential and shell radius of thin-shell without considering the equilibrium position of shell radius;

to consider conservation equation and KG equation to explore the behavior of effective potential, shell radius, and scalar field in the background of proper time; to explore the stable configuration of developed structure by using linearized radial perturbation about equilibrium shell radius in the background of phantomlike EoS;

to develop the Einstein field equation in the framework of a modified matter source and to calculate the gravastar structure and their physical properties;

to determine the components of the stress-energy tensor that play remarkable role in exploring the stability of the gravastars through linearized radial perturbation.

The object of the research are astrophysical compact objects, gravastars, alternative theories of gravity, drak matter.

The subject of the research are theoretical models for studying exact analytical solutions for compact gravitational objects, gravstars.

The methods of the research are methods of computational mathematics, methods of theoretical astrophysics, modern methods of mathematical physics, analytical and numerical methods of calculating differential equations for field and particle motion.

The scientific novelty of the research is the following:

For the first time the components of the stress-energy tensor are calculated from the reduced form of Einstein field equations at the hypersurface which develop the dynamical equations of these constructed geometries. It has been observed that the position of the event horizon of RGI Schwarzschild is less than the Schwarzschild BH. It has been explored the stable configuration of thin-shell filled with matter distribution which follows quintessence, dark energy, and phantom energy type EoS with linearized radial perturbation about equilibrium shell radius.

The thin-shell dynamics in the context of scalar field are discussed by using the effective potential and shell radius of thin-shell without considering the equilibrium position of shell radius. It has been considered conservation equation and KG equation to explore the behavior of effective potential, shell radius, and scalar field in the background of proper time.

For the first time, the stable configuration of developed structure explored by using linearized radial perturbation about equilibrium shell radius in the background of phantomlike EoS. It has been obtained that the graphical analysis of thin-shell follows the basic condition of thin-shell that the shell radius must be greater than the radius of event horizon.

It is noted that thin-shell expressed stable behavior for both quintessence and dark energy type matter contents. Thin-shell represented unstable configuration for every choice of physical parameters for phantom energy type EoS. It is found that the dark energy type matter contents show a more stable configuration than the quintessence type matter distribution. It is concluded that the stability of thin-shell is decreased for the choice of RGI Schwarzschild BH as compared to Schwarzschild BH.

For the first time it has been developed the Einstein field equation in the framework of a modified matter source. Further, it has been calculated the gravastar structure and their physical properties. By applying the EoS to the interior region and analyzing the equations of motion and conservation equation, it has been established that the solution does not have a singularity. Additionally, the energy density and pressure of the system remain constant, which is consistent with the characteristics associated with dark energy.**The practical results of the research** are the following:

It has been considered the EoS that follows the intermediate shell condition and also determined the respective metric potential. It has been used the exact black hole solution surrounded by a cloud of strings and quintessence as an outer manifold. The gravastar structure has been developed by considering Darmois-Israel formalism. The components of the stress-energy tensor have been obtained that play remarkable role in exploring the stability of the gravastars through linearized radial perturbation. It has been shown that the stable region decreases as the quintessence field parameter increases.

The analysis reveals that the entropy of the shell's region is directly proportional to the thickness of the shell. Likewise, we examine the entropy of the shell as we vary its thickness for different values of the cloud of strings. It is worth noting that the entropy increases as both the thickness and the cloud of strings parameter increase.

For the first time a singularity-free solution has been developed that is physically acceptable. It is interesting to mention that the developed exact novel solutions are reduced to the exact Mazur and Mottola model in the absence of the cloud of strings and quintessence fields.

The reliability of the research results provided by applying modern proven methods of mathematical physics, computational mathematics, and relativistic astrophysics. The results were obtained strictly within the mathematical apparatus of general relativity and theoretical physics. Modern numerical and analytical methods of calculation are also used, and the results are compared with available observational data and the results of other authors. The structured conclusions of the thesis correspond to the basic rules of astrophysics of compact objects.

The scientific and practical significance of the research results. The scientific significance of the research results is found that the analysis of the solution of gravastars may be helpful for developing new theories of gravity.

The practical significance of the research results is that they can play a role in the obtaining the upper limits and constraints on the model parameters of gravity theories.

Implementation of the research results. Based on the developed theoretical models for compact objects: scientific results obtained regarding particle motion were used by scientists from Fudan University (FU) in Shanghai (FU Reference, China, April 30, 2024).

Publication of research results. The results of DSc research have been presented in 31 peer-reviewed articles published in prestigious Q1/Q2 quartile scientific journals recommended by Supreme Attestation Commission at the Ministry of higer education, science and innovations of the Republic of Uzbekistan.

MAIN CONTENT OF THE WORK

Part I

In this part of presentation our main concern is to obtain the geometrical structure of a thin-shell through the match of inner flat and outer the renormalization group improved Schwarzschild black hole through a well-known cut and paste approach. Then, we are interested to discuss the dynamical configuration of thin-shell composed of a scalar field (massive and massless) through an equation of motion and Klein-Gordon's equation. Finally, the stable configuration of thin-shell is observed through the linearized radial perturbation approach about equilibrium shell radius with a phantomlike equation of state, i.e., quintessence, dark energy, and phantom energy. It is noted that stable/unstable behavior of thin-shell is found after the expected position of the event horizon of an exterior manifold. It is concluded that the stability of a thin-shell is greater for the choice of Schwarzschild black hole as compared to the renormalized group of improved Schwarzschild black holes.

We develop a $(2+1)-D$ thin-shell represented by Σ with radius $r = w(\tau)$, where τ is the proper time. This shell connects two different manifolds, i.e., the exterior region $(r > w)$ is chosen as a BH spacetime while the interior region $(r < w)$ is defined by a flat geometry. The line element for these geometries can be written as

$$ds_{\pm}^2 = -f_n(r)dt^2 + (f_n(r))^{-1}dr^2 + r^2(d\theta^2 + \sin^2\theta d\phi^2), \quad (1)$$

where $n = i, e$ correspond to the interior and exterior regions, respectively.

At thin-shell, the metric function h_{ij} represents a timelike 2-sphere with coordinates $y^i = (\tau, \theta, \phi)$ which can be expressed as

$$ds^2 = h_{ij}dy^i dy^j = -d\tau^2 + w^2 d\theta^2 + w^2\sin^2\theta d\phi^2. \quad (2)$$

A thin-shell refers to a boundary that separates interior spacetime from the exterior one. For the physical viability of thin-shell, junction conditions like the continuity of the induced metric at thin-shell and extrinsic curvature discontinuity are required. We also derive the surface stresses for these geometries through the field equations of thin-shell named Lanczos equations. We can compute physical features at the shell (causing extrinsic curvature discontinuity) by using stress-energy tensor S^{i}_{j}. The matter components at thin-shell can be written as

$$S^{\tau}_{\tau} \equiv \rho(w) =- \frac{1}{4\pi w}(\chi_e(w) - \chi_i(w)) \tag{3}$$

$$S^{\theta}_{\theta} = S^{\phi}_{\phi} \equiv \mathfrak{P}(w) = \frac{-\chi_i(w) + \chi_e(w)}{8\pi w} + \frac{2\ddot{w} + f'_e(w)}{16\pi \chi_e(w)} - \frac{2\ddot{w} + f'_i(w)}{16\pi \chi_i(w)} \tag{4}$$

where

$$\chi_i(w) = \sqrt{f_i(w) + \dot{w}^2},\ \chi_e(w) = \sqrt{f_e(w) + \dot{w}^2} \tag{5}$$

$\rho(w)$ and $\mathfrak{P}(w)$ represent energy density and tangential pressure while overdot and dash correspond to the derivatives w.r.t proper time and radial coordinate, respectively. Hence, we have

$$\rho =- \frac{\sqrt{\dot{w}^2 + f_e(w)} - \sqrt{\dot{w}^2 + f_i(w)}}{4\pi w} \tag{6}$$

$$\mathfrak{P} = \frac{1}{8\pi}\left(\frac{2\ddot{w} + f'_e(w)}{2\sqrt{\dot{w}^2 + f_e(w)}} - \frac{2\ddot{w} + f'_i(w)}{2\sqrt{\dot{w}^2 + f_i(w)}} + \frac{\sqrt{\dot{w}^2 + f_e(w)} - \sqrt{\dot{w}^2 + f_i(w)}}{w}\right), \tag{7}$$

At equilibrium shell radius $\dot{w}_0 = \ddot{w}_0 = 0$. Hence, we get

$$\rho_0 = \rho(w_0) =- \frac{\sqrt{f_e(w_0)} - \sqrt{f_i(w_0)}}{4\pi w_0} \tag{8}$$

$$\mathfrak{P}_0 = \mathfrak{P}(w_0) = \frac{1}{8\pi}\left(\frac{\sqrt{f_e(w_0)} - \sqrt{f_i(w_0)}}{w_0} + \frac{f'_e(w_0)}{2\sqrt{f_e(w_0)}} - \frac{f'_i(w_0)}{2\sqrt{f_i(w_0)}}\right). \tag{9}$$

For Minkowski spacetime, gravity does not exist inside the shell due to the absence of matter contents in the interior geometry. The exterior part is also taken as a vacuum but the gravitational field exists as it is defined by BH. The mass parameter m in this metric can be related to the gravitational mass of the shell which governs the gravitational potential energy, kinetic energy as well as the rest-mass energy of the spacetime. We can define the mass of the shell as $M = 4\pi w^2 \rho$. Additionally, the conservation equation yields

$$\mathfrak{P} \frac{d}{d\tau}(w^2) + \frac{d}{d\tau}(\rho w^2) = 0 \tag{10}$$

which yields

$$\rho' = -\frac{2}{w}(\mathfrak{P}(\rho, w) + \rho). \tag{11}$$

The surface energy density (6) explicitly yields an equation of motion as

$$\dot{w}^2 + \Pi(\rho(w), w) = 0 \tag{12}$$

where $\Pi(\rho(w), w)$ shows effective potential of the shell given by

$$\Pi(\rho(w), w) = \frac{f_e f_i}{32\pi^2 w^2 \rho^2} - \frac{f_i^2}{64\pi^2 w^2 \rho^2} + \frac{f_i}{2} - \frac{f_e^2}{64\pi^2 w^2 \rho^2} + \frac{f_e}{2} - 4\pi^2 w^2 \rho^2 \tag{13}$$

The renormalization group methods are used to incorporate the quantum effects into the Schwarzschild BH geometry. Since spacetime singularities are eliminated as a result of this modification, the respective manifold can have zero, one, or two horizons. Here, we are interested to develop a thin-shell by using an inner flat and outer RGI Schwarzschild BH through cut and paste technique. The corresponding metric functions interior flat and exterior improved Schwarzschild BH is expressed as

$$f_i(r) = 1,\ f_e(r) = 1 - \frac{2m}{r}\left(\frac{\gamma m^3 \Omega}{r^3} + \frac{m^2 \Omega}{r^2} + 1\right)^{-1}, \tag{14}$$

where m is the mass of Schwarzschild BH with real constants Ω and γ. For $\Omega = 0$, it is reduced to a Schwarzschild solution in GR. The position of the BH event horizon coincides with the radial position at which the metric function become zero. Hence, we can determine the position of the event horizon using $f_e(r) = 0$ as follows

$$r_h = \frac{1}{6}\left(\frac{8\sqrt[3]{2} m^2}{\sqrt[3]{h(r)}} + 2^{2/3}\sqrt[3]{h(r)} + 4m\right)$$

where

$$h(r) = m^3(16 - 9(3\gamma + 2)\Omega) + 3\sqrt{3}\sqrt{\Omega m^6((9\gamma(3\gamma + 4) - 4)\Omega - 32\gamma + 4\Omega^2)}$$

In Fig. 1, we discuss the behavior of the metric function for suitable values of physical parameters. The position of the event horizon decreases for RGI Schwarzschild BH (r_h decreases as Ω increases). It found that r_h becomes large for higher values of mass for both Schwarzschild and improved Schwarzschild BHs.

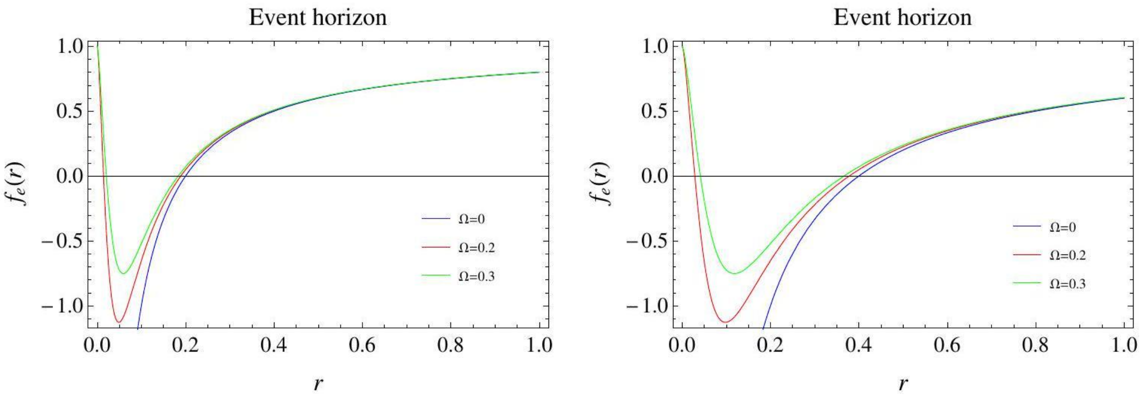

Figure 1. Plots of metric function for $m = 0.1$ (left) and $m = 0.2$ (right) verses r with $\gamma = 0.05$.

It is interesting to mention that the "mass of BH " refers to the actual mass contained within the event horizon of a BH, where gravity is so strong that nothing, not even light, can escape. On the other hand, the "gravitational mass" of the shell refers to the mass that contributes to the gravitational force felt by objects outside of the event horizon. Using Eqs.(5) and (14), we find relations between the gravitational mass and mass of the shell as

$$\chi_e(w) - \chi_i(w) =- M/w, \ \chi_e(w) + \chi_i(w) = \frac{2w^3 m}{M(w^3 + m^2\Omega(w + \gamma m))} \quad (16)$$

We study the dynamics of a shell composed of a scalar field by analyzing its equations of motion. It is demonstrated that there are two ways to integrate the equations of motion $(\dot{w}^2 + \Pi(w) = 0)$. The first involves considering the shell's pressure as an explicit function of its radius, whereas the second involves supposing the existence of an equation of state connecting the shell's pressure and energy density. As we mentioned, the equation $\dot{w}^2 + \Pi(w) = 0$ corresponds to the energy conservation law which states that the sum of the "kinetic component" $\dot{w}^2$ and "potential component" $\Pi(w)$ equals zero at any time. This is more a constraint than a dynamical equation in the sense that one cannot give arbitrary initial conditions to evolve the system, but only those conditions that satisfy the conservation equation. It follows that the solutions allowed are only those for which the effective potential is negative or zero, i.e., $\Pi(w) < 0$ or $\Pi(w) = 0$. The second case $(\Pi(w) = 0)$ will correspond either to a static configuration or to the turning points which lead to

$\dot{w}^2 = 0$, i.e., orbits of extremal radius w. The term $\Pi(w) > 0$ does not permit the propagation of the shell. First, we consider the first case $(\dot{w} \neq 0)$ for both massless and massive scalar fields and observe the dynamics of the scalar shell. The numerical integration of the coupled system of differential equations like conservation equation and Klein-Gordon (KG) equation is carried out by specifying, for example, an initial radius $w(\tau)$, and the initial values of $\dot{\Upsilon}(\tau)$ and $\Upsilon(\tau)$.

By considering $V(\Upsilon) = 0$ the components of the stress-energy tensor are related through EoS $(P = \rho)$. The respective KG equation can be written as

$$w\ddot{\Upsilon} + 2\dot{w}\dot{\Upsilon} = 0 \tag{17}$$

which yields

$$\xi = w^2\dot{\Upsilon} \tag{18}$$

where the integrating constant is represented with ξ. By using $V(\Upsilon) = 0$ we obtain the respected effective potential of the massless scalar shell becomes

$$\Pi(w) = -\frac{m^2 w^{10}}{4\pi^2\xi^4(m^2\Omega(\gamma m + w) + w^3)^2} - \frac{m w^2}{m^2\Omega(\gamma m + w) + w^3} - \frac{\pi^2\xi^4}{w^6} + 1 \tag{19}$$

For a massless scalar field, we analyze the effective potential and shell radius by using the initial condition as $(\dot{w} \neq 0)$ shown in Figs. 2 and 3. The behavior of effective potential of the massless scalar field corresponds to a monotonic expanding shell (Figs. 2 and 3), that is, a shell which, starting from a specific radius with positive initial velocity away from the center $w = 0$, will expand forever see Fig. 3.

Now, we investigate the behavior of the scalar shell as it evolves in the presence of a massive scalar field, denoted by the equation $V(\Upsilon) = m^2\Upsilon^2$:

$$2m^2\Upsilon^2 = \sigma - P, \; \dot{\Upsilon}^2 = \sigma + P. \tag{20}$$

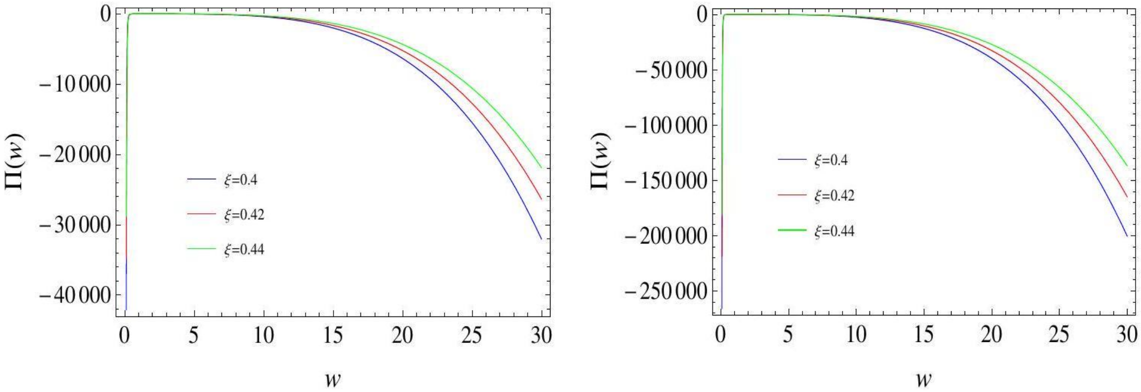

Figure 2. Dynamics of shell via effective potential of massless scalar field $m = 0.2$ (left plot) and $m = 0.5$ (right plot) verses w with different values of ξ and $\gamma = 0.5, \Omega = 0.5$.

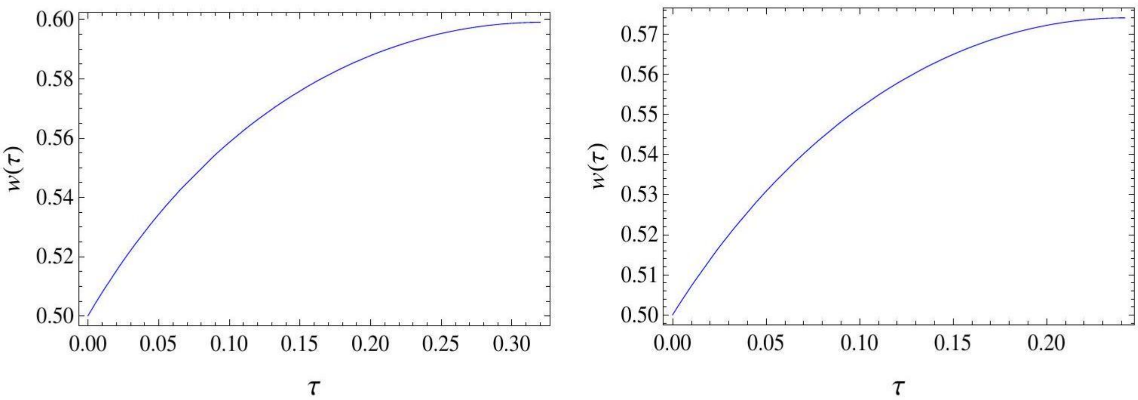

Figure 3. Massless scalar shell radius versus proper time for $\Omega = 0.1$ (left plot) and $\Omega = 0.5$ (right plot) with with initial condition $w[0] = 0.5$ and $\dot{w} > 0$ for $\lambda = 0.2, m = 0.3, \gamma = 0.5$.

We create a link between the mass of the surface matter at thin-shell and σ to build the dynamical equations concerning the static observer. To do this, we propose that the surface matter at the shell complies with the linear relationship among surface energy density and pressure as, i.e., $P = B_0 e^{-zw}$, where z and B_0 are constants. Using Eq. (11) with the particular choice of P, we have

$$\sigma = \frac{\chi}{w^2} + \frac{2B_0}{(wz)^2}\Gamma(2, wz) \tag{21}$$

here χ represents the integrating constant and $\Gamma(2, wz) = \int_{wz}^{\infty} \nu^3 e^{-\nu} d\nu$. By considering the expression of σ and P in Eq. 20), we get

$$\dot{\Upsilon}^2 = \frac{\chi}{w^2} + B_0\{e^{-zw} + \frac{2}{(wz)^2}\Gamma(2, wz)\} \tag{22}$$

$$\Upsilon^2 = \frac{\chi}{2m^2w^2} + \frac{B_0}{2m^2}\{\frac{2}{(wz)^2}\Gamma(2, wz) - e^{-zw}\}, \tag{23}$$

which follows the KG equation. Also, we have

$$\mathcal{M} = 4\pi w^2 \sigma = 4\pi\chi + \frac{8\pi B_0}{\gamma^2}\Gamma(2, wz) \tag{24}$$

For massive scalar fields, this procedure of integration is shown in Figs. 4 and 5 which depict the effective potential, and the scalar field, respectively, for solutions of the equations (conservation and KG equations) describing an expanding shell with a quadratic scalar potential. In Fig. 4, we notice that the behavior of effective potential $\Pi(w)$ depends on the scalar field due to its explicit dependence on the scalar field. We also remark that as the shell expands, $\Pi(w)$ tends to zero, and so the expansion slows down. This affects the behavior of Υ in the sense that the amplitude is highly damped at the beginning of the motion when $\dot{w}$ is large, but then it becomes like an ordinary harmonic oscillator when $\dot{w}$ is smaller as shown in Fig. 5 ,

The equation of state is an extremely important concept to understand to explain the impacts of various kinds of matter contents placed at the hypersurface on the stable/unstable characteristics of thin-shell structures. Here, we consider a specific type of EoS state named phantom-like EoS expressed as

$$\mathfrak{P}(w) = \beta\rho(w), \tag{25}$$

where $\beta < 0$ denotes the EoS parameter.

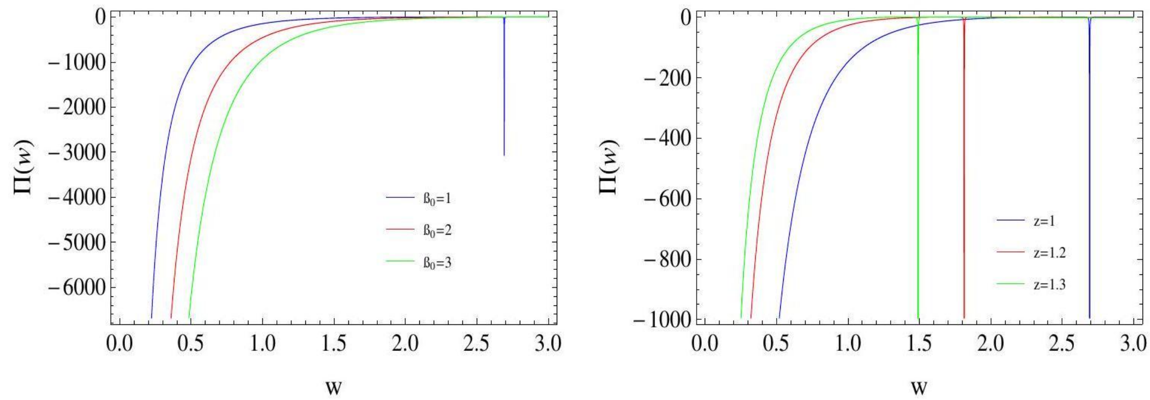

Figure 4. Dynamics of shell via effective potential of massive scalar field for different values of B_0 (left plot) and z (right plot) verses w with $\gamma = 0.5, \chi = 1, m = 0.2, \Omega = 0.5$.

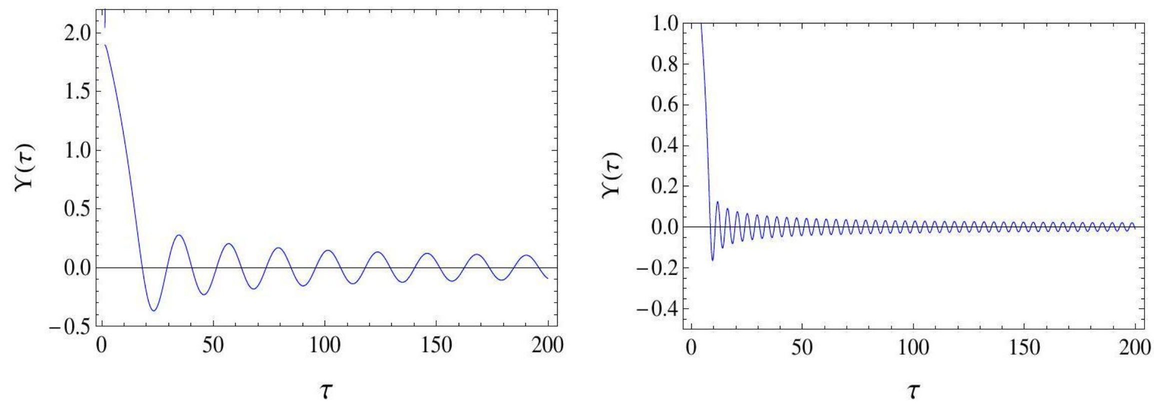

Figure 5. Massive scalar field versus the proper time τ for $m = 0.2$ (left plot) and $m = 1$ (right plot) with initial conditions $\dot{w}(0) = 0.5, \dot{\Upsilon}[0] = 1.5, \Upsilon[0] = 1.5$ for $\gamma = 0.5, \Omega = 0.5$. The oscillations are highly damped at the beginning when $\dot{w} > 0$ is large due to the expansion of the shell.

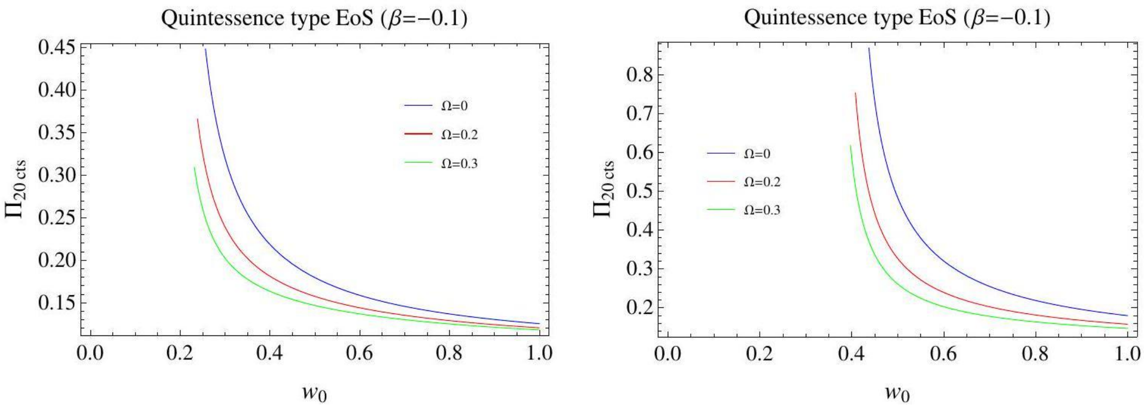

Figure 6. Stability analysis of thin-shell filled with quintessence type matter contents for $m = 0.1$ (left plot) and $m = 0.2$ (right plot) verses w_0 with $\gamma = 0.05$.

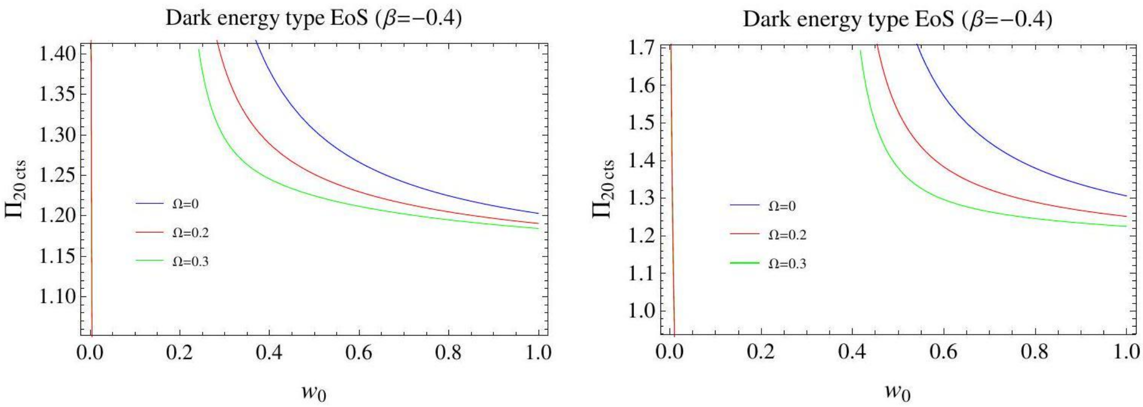

Figure 7. Stability analysis of thin-shell filled with dark energy type matter contents for $m = 0.1$ (left plot) and $m = 0.2$ (right plot) verses w_0 with $\gamma = 0.05$.

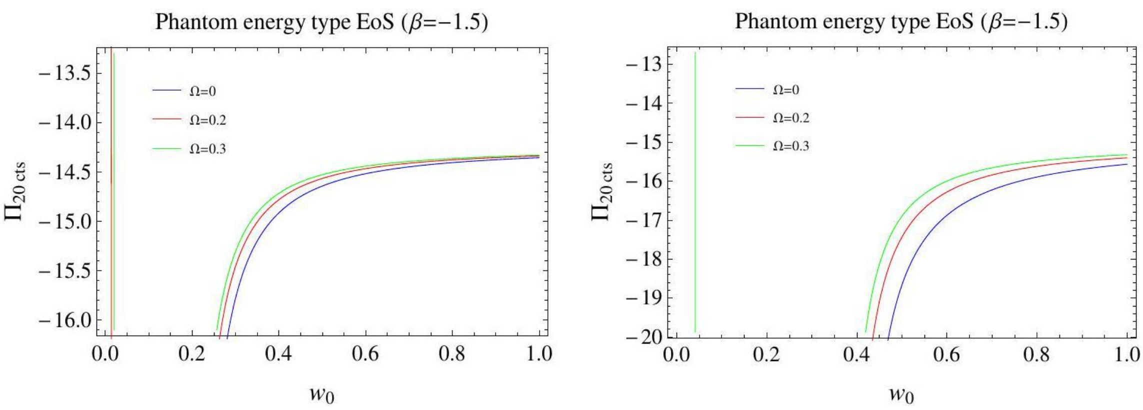

Figure 8. Stability analysis of thin-shell filled with phantom energy type matter contents for $m = 0.1$ (left plot) and $m = 0.2$ (right plot) verses w_0 with $\gamma = 0.05$.

The different ranges of equation state parameter denotes the different types of matter contents expressed as:

If $\beta <- 1$ then it represents phantom energy state.

If $0 > \beta >- 1/3$ then it represents quintessence type matter contents.

If $\beta <- 1/3$ then it represents dark energy state.

Now, we explore the stable and unstable characteristics of thin-shell in the background of improved Schwarzschild BH by using Π_{20cts} for phantomlike EoS graphically as shown in Figs. 648, It is very interesting to mention that the stable/unstable behavior of thin-shell follows the basic condition of thin-shell that shell radius must be greater than the radius of event horizon (see Fig. 1 for event horizon and Figs. $6-8$ for thin-shell configuration). Hence, our desired results related to the stability of thin-shell are formed after the position of the event horizon. It is found that thin-shell shows stable behavior for both Schwarzschild and improved Schwarzschild BHs filled with quintessence type matter contents (Fig. 6). It is noted that thin-shell stability is decreased for the choice of improved Schwarzschild BH as compared to Schwarzschild BH. Thin-shell stability increases for higher values of mass. Similarly, we obtain the same results for the choice of dark energy type matter contents (Fig. 7). The dark energy type matter contents show a more stable configuration than the quintessence type matter distribution. For phantom energy type EoS, thin-shell shows unstable behavior for every choice of physical parameters (Fig. 8). Hence, thin-shell expressed stable configuration for the choice of quintessence and dark energy type EoS shows unstable behavior for phantom energy type EoS.

Part II

Gravastars, theoretical alternatives to black holes, have captured the interest of scientists in astrophysics due to their unique properties. The second part of the presentation is devoted to further investigate the exact solution of a novel gravastar model based on the MazurMottola method within the framework of general relativity, specifically by incorporating the cloud of strings and quintessence. By analyzing the gravitational field and energy density of gravastars, valuable insights into the nature of compact objects in the universe can be gained. Understanding the stability of gravastars is also crucial for our comprehension of black holes and alternative compact objects. For this purpose, we present the Einstein field equations with the modified matter source and calculate the exact solutions for the inner and intermediate regions of gravastars. The exterior region is considered as a black hole surrounded by the cloud of strings and quintessence, and the spacetimes are matched using the Darmoise-Israel formalism. An investigation is conducted on the stability of gravastars using linearized radial perturbation. Additionally, the proper length, energy content, and entropy of the shell are computed. The stability of gravastars is positively correlated with the enhancement of the cloud of strings parameter, while it is negatively correlated with the growth in the quintessence field parameter. We conclude with a summary of the findings and their implications in the field of astrophysics and cosmology.

We start with the focusing on the 4-dimensional spacetime that is both spherically symmetric and static, and it is bounded by a spherical surface. Using the Schwarzschild coordinates, the respective metric is presented as follows

$$ds^2 = e^{\epsilon(r)}dt^2 - e^{\varepsilon(r)}dr^2 - r^2\sin^2\theta d\phi^2 - r^2 d\theta^2 \qquad (26)$$

here the gravitational functions of temporal and radial coordinates are denoted by $\epsilon(r)$ and $\varepsilon(r)$, respectively. By using the modified form of matter, the respective Einstein field equations for the metric (26) become

$$G_{ij} = R_{ij} - \frac{1}{2}g_{ij}R = T^{\text{eff}}_{ij},\ i,j = 0,1,2,3 \qquad (27)$$

where

$$T^{\text{eff}}_{ij} = \Theta_{ij} + \hat{T}_{ij} + \hat{\Theta}_{ij} \qquad (28)$$

here Θ_{ij} represents the matter due to cloud of string and $\hat{\Theta}_{ij}$ depicts the matter influenced by quintessence fields. Consequently, in the background of strings of clouds, the respective
Lagrangian density can be written as

$$L_s = -\frac{k}{2}\Sigma^{ij}\Sigma_{ij}, \qquad (29)$$

where the tension of the string and bi-vector is denoted by a constant k. In this regards, we obtain the following relation

$$\Sigma^{ij} = \epsilon^{a\beta}\frac{\partial x^i}{\partial\lambda^a}\frac{\partial x^j}{\partial\lambda^\beta}, \qquad (30)$$

here relation for the parameterization of the world sheet is referred as λ^a $(\lambda^a = \lambda^0, \lambda^1)$ and Levi-Civita tensor is represented by $\epsilon^{a\beta}$. By using induced metric, it can be described for the string as follows

$$h_{a\beta} = g_{ij}\frac{\partial x^i}{\partial\lambda^a}\frac{\partial x^j}{\partial\lambda^\beta} \qquad (31)$$

Consequently, the some important identities is obtained from Σ^{ij} given as

$$\Sigma^{i[a}\Sigma^{\beta\sigma]} = 0,\ \Sigma^{ia}\Sigma_{a\sigma}\Sigma^{\sigma j} = \mathbf{h}\Sigma^{ji},\ \nabla_i\Sigma^{i[a}\Sigma^{\beta\sigma]} = 0 \qquad (32)$$

where the determinant of $h_{\alpha\beta}$ is denoted with $\mathbf{h}$.

Further, by varying the Lagrangian density concerning the metric tensor g_{ij}, we get

$$\Theta_{ij} = \rho_s \frac{\Sigma^{ia}\Sigma_a^j}{\sqrt{-\mathbf{h}}} \tag{33}$$

where ρ_s denotes the density of the string cloud. We obtain the following expression $\partial_i(\sqrt{-g}\Sigma^{ia}) = 0$ by considering the identities mentioned in Eq.(32). In the background of string clouds, the respective components of the stress-energy tensor become

$$\Theta_{tt} = \Theta_{rr} = -\frac{a}{r^2}\ \Theta_{\theta\theta} = \Theta_{\phi\phi} = 0 \tag{34}$$

where the parameter a denotes the cloud of strings. Also, we obtain the following relation for quintessence matter distribution as follows

$$L_q = -\frac{1}{2}g^{ij}\partial_i\Psi\partial_j\Psi - V(\Psi). \tag{35}$$

The stress-energy-momentum tensor components that are physically viable under the influence of the quintessence field (Ψ) is specified by $V(\Psi)$, which denotes the potential term of the quintessence field.

$$\hat{\Theta}_{tt} = \hat{\Theta}_{rr} = \rho_q\ \hat{\Theta}_{\theta\theta} = \hat{\Theta}_{\phi\phi} = -\frac{\rho_q}{2}(3\omega_q + 1) \tag{36}$$

where ω_q and ρ_q denote the quintessence field parameter and quintessence density, respectively, and are used to characterize the system's internal makeup in the presence of the matter source $\hat{T}_{ij}$. To analyze the physical composition of spacetime, we examine the energy density of an isotropic matter distribution that covers the area. Here, the radial pressure is represented by p and the energy density is depicted with ρ. Further, the respective components of stress-energy tensor $\hat{T}_{ij}$ become

$$\hat{T}_{tt} = \rho,\ \hat{T}_{rr} = -p_r,\ \hat{T}_{\theta\theta} = \hat{T}_{\phi\phi} = -p_t \tag{37}$$

Further, we are interested in developing gravastar structure in the background of the cloud of strings and quintessence by using the exact field equations with a modified matter source. Overall, the gravastar configuration with the cloud of strings and quintessence is a fascinating model that may shed light on the nature of dark energy and the origins of the universe. Gravastar is a hypothetical model that is formed from the collapse of matter in the presence of a negative pressure source which can be better explained by quintessence field. Quintessence is a form of dark energy that is believed to be responsible for the acceleration of the universe's expansion. In this model, the gravastar consists of a thin-shell of negative pressure, surrounded by a thick shell of ultra-relativistic cosmic string. The cosmic string is a hypothetical one-dimensional object that is formed from the stretching of space-time due to the presence of a concentrated mass. In the gravastar structure, the quintessence shell is supported by the cosmic string, which generates the required self-gravity. The system's self-gravity is enhanced by the quintessence's negative pressure, which results in a stable equilibrium. The ability for stable orbits to occur inside the object is an intriguing feature of the gravastar structure. This is because the cosmic string shell generates a repulsive force, while the quintessence shell pulls on neighboring masses gravitationally.The combination of these forces can lead to the creation of a stable region within the gravastar where orbits can be maintained.

We have developed the gravastar structure by using the field equation in the framework of a modified matter source. For this purpose, we develop the gravastar by understanding its geometrical structure which can be partitioned into three different regions. The behavior of matter contents of these regions can be characterized through a specific type of EoS. Such geometrical structure is partitioned into interior $(0 \leq r < r_1)$, intermediate or thin-shell $(r_1 < r < r_2)$ and exterior region $(r_2 < r)$. Here, r_1 and r_2 denote the radius of inner and outer regions. Also, the thickness of the intermediate region is referred to as $r_2 - r_1$. The specific EoS for these regions is expressed as

$p =- \sigma$ for inner region;
$p = \sigma$ for intermediate region;
$p = 0 = \sigma$ for the outer region.

Now we are aimed to examine the impact of the cloud of strings and quintessence field on different physical features of gravastar. In this context, we shall calculate the stability through linearized perturbation. Then, we observe the proper length, shell energy and entropy of the gravastars.

In Figs. 9 and 10, we are interested in exploring the stable configuration of the gravastars in the framework of quintessence and cloud of strings. It is very interesting to mention that the stable regions of the gravastars are greatly affected by the presence of cloud of strings and quintessence field parameters. Figs. 9 is used to explore the effects of the cloud of strings parameter on the stability of the gravastars. It is found that stable regions increase as the cloud of strings parameter increases. This shows that the developed structure is more stable due to the effects of the cloud of strings (Figs. 9). In Figs. 10, we are interested in discussing the stability of the developed structure by considering different values of the quintessence field parameter. It is found that the stability regions decrease as the quintessence field parameter increases as shown in (Figs. 10). Hence, both quintessence and cloud of strings play remarkable role to maintain the stability of gravatars.

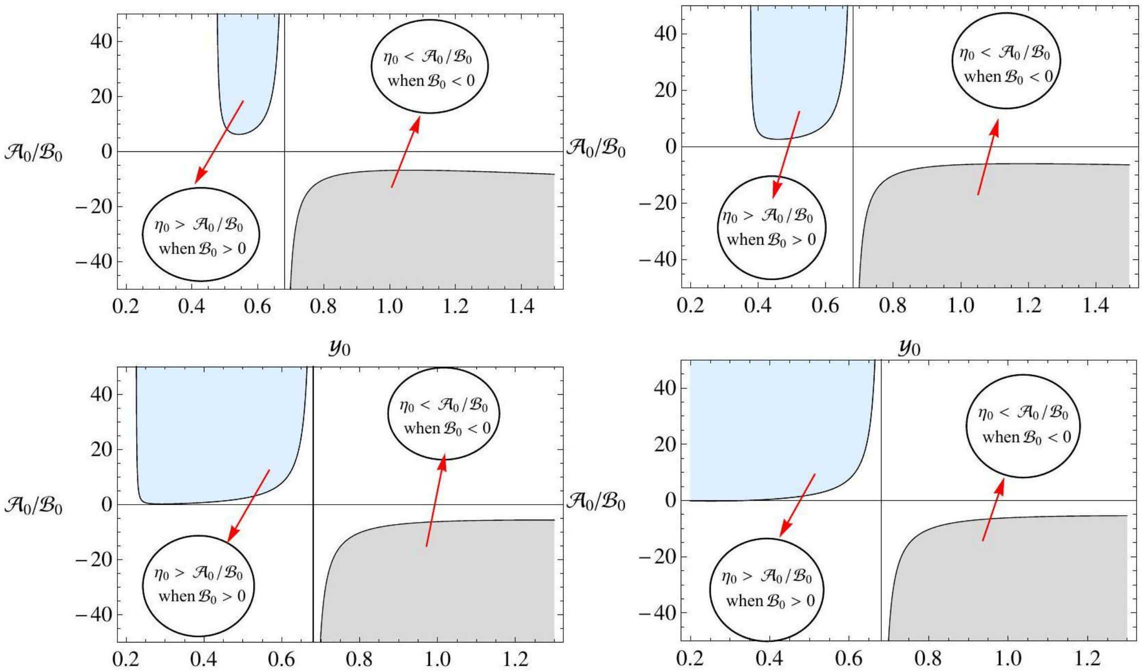

Figure 9. Plots of $\mathcal{A}_0/\mathcal{B}_0$ versus y_0 for different values of cloud parameter $a = 0.3$ (first plot), $a = 0.6$ (second plot), $a = 0.9$ (third plot), $a = 1.2$ (fourth plot) with $\omega_q = -2/3, \rho_c = 0.5, C_2 = 1, \gamma = 0.2, m = 0.5$. Here, the shaded regions depict the stability of gravastars through the behavior of η_0 if $\mathcal{B}_0 > 0$ (light blue region) and $\mathcal{B}_0 < 0$ (light gray region).

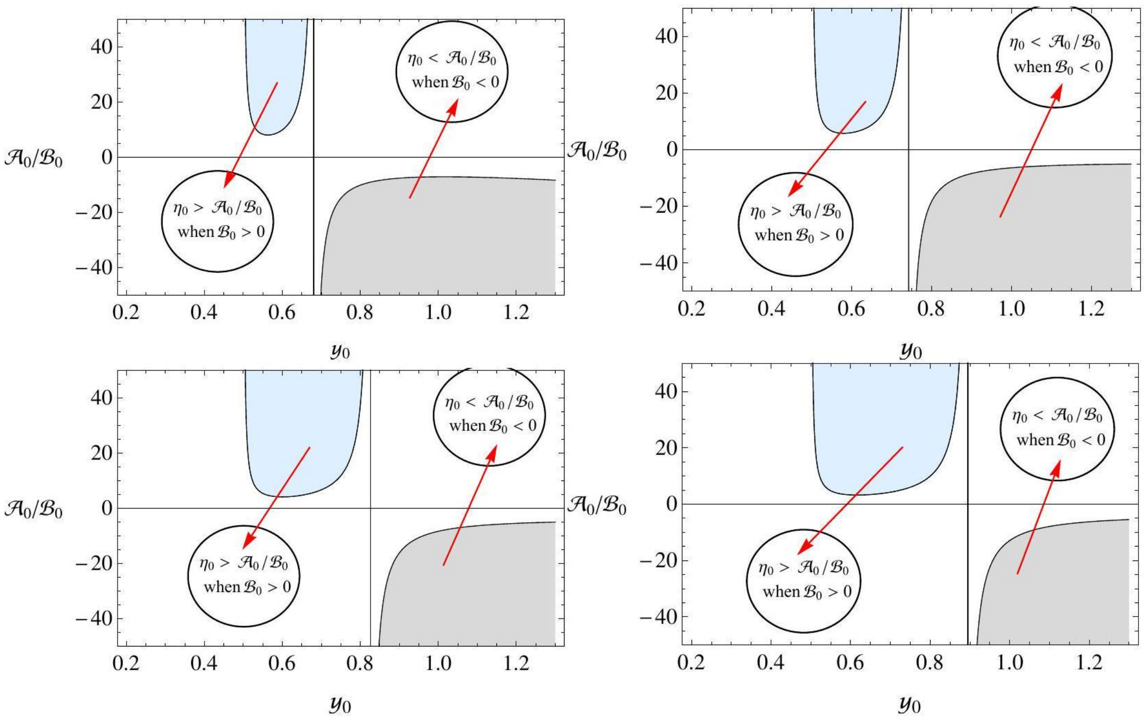

Figure 10. Plots of $\mathcal{A}_0/\mathcal{B}_0$ versus y_0 for different values of quintessence parameter $\gamma = 0.2$ (first plot), $\gamma = 0.8$ (second plot), $\gamma = 1.5$ (third plot), $\gamma = 2$ (fourth plot) with $\omega_q = -2/3, \rho_c = 0.5, C_2 = 1, a = 0.2, m = 0.5$.

The behavior of proper length versus thickness of the shell for different values of the cloud of quintessence is shown in the left plot of Fig. 11. Proper length increases as thickness as well as the cloud of strings parameter increases. The graphical analysis of energy content versus thickness of the shell for different values of quintessence is shown in the middle plot of Fig. 11. It increases as the thickness as well as the cloud of strings parameter increases.
The degree of disorder or disturbance in a geometric structure is related to the entropy measure. To understand the randomness of gravastar geometry, we look at the entropy of thin-shell gravastars. Mazur and Mottola's idea is used to calculate an equation for the entropy of a thin-shell gravastar as

$$S = \int_{y}^{y+\delta} 4\pi r^2 h(r) \sqrt{e^{\varepsilon(r)}} dr \tag{38}$$

For local temperature, the entropy density is calculated as

$$h(r) = \frac{\eta K_B}{\hbar} \sqrt{\frac{p(r)}{2\pi}} \tag{39}$$

where η is represented as a dimensionless parameter. Here, we take Planck units $(K_B = 1 = \hbar)$ so that the shell's entropy becomes

$$S = 2\sqrt{2\pi}\delta\eta y^2 \sqrt{\frac{1}{-a+3^{2/3}e^{-C_4 y^{2/3}}+1}} \sqrt{C_6 e^{-\frac{3 3^{2/3} e^{-C_3 y^{2/3}}}{a-1}}} \tag{40}$$

It is noted that shell's entropy is also proportional to δ. Similarly, we investigate the entropy of the shell along the thickness of the shell for different values of the cloud of strings are shown in the right plot of Fig. 11. It is noted that the entropy increases by increasing δ as well as the cloud of strings parameter.

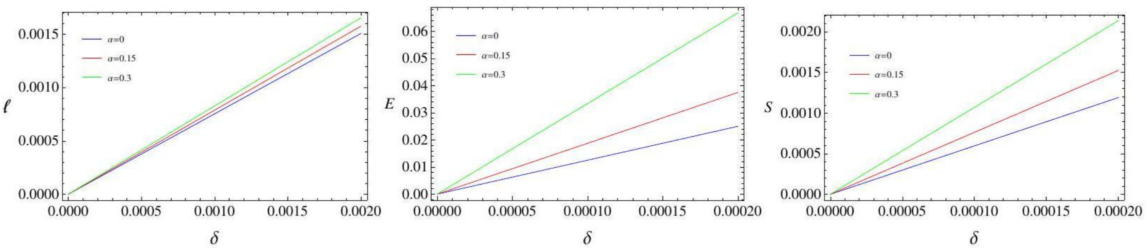

Figure 11. Behavior of proper length (left plot), energy contents (middle plot) and entropy of shell (right plot) for different values of the cloud of strings parameter $a = 0, 0.15, 0.3$.

CONCLUSIONS

The following conclusions have been presented on the basis of research carried out on the topic of “Impact on Thermodynamics and Stability via Thin-shell of Compact Objects”:

1. It has been noted that certain parameter selections resulting in a massive scalar shell structure exhibited an oscillatory configuration. This configuration featured a continual exchange of potential and kinetic energy, which was made possible by the fluctuating surface pressure of the shell and the pull of gravity. From the graphical behavior of the metric function it has been found that the position of the event horizon of RGI Schwarzschild is less than the Schwarzschild BH.
2. It has been shown that the graphical analysis of thin-shell follows the basic condition of thin-shell that the shell radius must be greater than the radius of event horizon. It is noted that thin-shell expressed stable behavior for both quintessence and dark energy type matter contents. It is found that the dark energy type matter contents show a more stable configuration than the quintessence type matter distribution. It is concluded that the stability of thin-shell is decreased for the choice of RGI Schwarzschild BH as compared to Schwarzschild BH.
3. For the first time the Einstein field equation has been developed in the framework of a modified matter source. Further, it has been obtained the solution for the gravastar structure and it has been established that the solution does not have a singularity. Additionally, the energy density and pressure of the system remain constant, which is consistent with the characteristics associated with dark energy.
4. For the first time the gravastar structure has been developed by considering Darmois-Israel formalism. It is noted that the cloud of strings parameter enhances the stable regions of gravastars and stability decreases as string parameter decreases. It has been shown that the stable region decreases as the quintessence field parameter increases.
5. The analysis of the connection between the thickness of the shell and its proper length has shown that as both the thickness and the cloud of strings parameter increase, the proper length also increases. The analysis reveals that the entropy of the shell's region is directly proportional to the thickness of the shell.
6. For the first time a singularity-free solution has been obtained that is physically acceptable. It has been shown that the this solutions are reduced to the exact Mazur and Mottola model in the absence of the cloud of strings and quintessence fields.

НАУЧНЫЙ СОВЕТ DSc.03/31.03.2022.T/FM.10.04 ПО ПРИСУЖДЕНИЮ УЧЕНЫХ СТЕПЕНЕЙ ПРИ ИНСТИТУТЕ ФУНДАМЕНТАЛЬНЫХ И ПРИКЛАДНЫХ ИССЛЕДОВАНИЙ, «ТИИИМСХ» НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ УНИВЕРСИТЕТ

ТАШКЕНТСКИЙ УНИВЕРСИТЕТ ПРИКЛАДНЫХ НАУК

ДЖАВЕД ФЕЙСАЛ

ВЛИЯНИЕ НА ТЕРМОДИНАМИКУ И СТАБИЛЬНОСТЬ ЧЕРЕЗ ТОНКУЮ ОБОЛОЧКУ КОМПАКТНЫХ ОБЪЕКТОВ

01.03.01 – Астрономия
01.04.02 – Теоретическая физика
(физико-математические науки)

ПРЕДСТАВЛЕНИЕ

по присуждению ученой степени доктора наук (DSc) на основе научных публикаций без диссертации

Ташкент – 2024

Тема диссертации доктора наук (DSc) по физико-математическим наукам зарегистрирована в Высшей аттестационной комиссии при Министерстве высшего образования, науки и инноваций Республики Узбекистан под номером B2024.1.DSc/FM257.

Работа выполнена в Ташкентский Университет Прикладных Наук.

Представление на трех языках (узбекский, английский, русский (резюме)) размещен на веб-странице Научного совета (www.ifar.uz) и Информационно-образовательном портале «Ziyonet» (www.ziyonet.uz).

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Представление научного исследования состоится «__» **__________ 2024 года в ____ часов** на заседании Научного Совета **DSc.03/31.03.2022.T/FM.10.04** по защите диссертаций на соискание ученых степеней при Институте фундаментальных и прикладных исследований, “ТИИИМСХ” Национальный Исследовательский университет по адресу: 100000, г. Ташкент, Qori Niyaziy Street 39, Институт фундаментальных и прикладных исследований, Зал 108; Тел.: 71 237-09-61; email: info@ifar.uz.

С представлением научного исследованияможно ознакомиться в Информационно-ресурсном центре при Институте фундаментальных и прикладных исследований, “ТИИИМСХ” Национальный Исследовательский университет (регистрационный номер ____) (Адрес: 100000, г. Ташкент, Qori Niyaziy Street 39, Институт фундаментальных и прикладных исследований, Зал 205; Тел.: 71 237-09-61).

Представление научного исследования разослано «____» _______ 2024 г.
(протокол рассылки № от __ ________ 2024 г.).

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ВВЕДЕНИЕ (Аннотация к представлению)

Целью исследования является разработка и совершенствование теоретических моделей ренормгрупповой улучшенной теории гравитации и соответствующих решений для компактных объектов.

Задачи исследования:

изучить геометрическую конструкцию тонкой оболочки с внутренним плоским пространством-временем и внешним RGI Шварцшильда БХ с помощью подхода «вырезать и вставить»;

рассчитать тензор энергии-импульса из приведенной формы уравнений поля Эйнштейна на гиперповерхности, которые развивают динамические уравнения этих построенных геометрий;

проанализировать графическое поведение метрической функции и исследовать динамическую конфигурацию тонкой оболочки, состоящей из безмассового и массивного скалярного поля, с помощью КГ и уравнений сохранения;

исследовать стабильную конфигурацию тонкой оболочки, заполненной материей, распределение которой соответствует типу квинтэссенции, темной энергии и фантомной энергии EoS с линеаризованным радиальным возмущением относительно равновесного радиуса оболочки;

анализировать динамику тонкой оболочки в контексте скалярного поля, используя эффективный потенциал и радиус тонкой оболочки без учета положения равновесия радиуса оболочки;

рассмотреть уравнение сохранения и уравнение КГ для изучения поведения эффективного потенциала, радиуса оболочки и скалярного поля на фоне собственного времени; исследовать устойчивую конфигурацию развитой структуры с помощью линеаризованного радиального возмущения относительно равновесного радиуса оболочки на фоне фантомного EoS;

разработать уравнение поля Эйнштейна в рамках модифицированного источника материи и рассчитать структуру гравазвезд и их физические свойства;

определить компоненты тензора энергии-импульса, которые играют заметную роль в исследовании устойчивости гравастар посредством линеаризованного радиального возмущения.

Объектом исследования являются астрофизические компактные объекты, гравастары, альтернативные теории гравитации, драконовая материя.

Предметом исследования являются теоретические модели для изучения точных аналитических решений компактных гравитационных объектов, гравастаров.

Методами исследования являются методы вычислительной математики, методы теоретической астрофизики, современные методы математической физики, аналитические и численные методы расчета дифференциальных уравнений для поля и движения частиц.

Научная новизна исследования заключается в следующем:

Впервые компоненты тензора энергии-импульса рассчитываются на основе приведенной формы уравнений поля Эйнштейна на гиперповерхности, которые развивают динамические уравнения этих построенных геометрий. Было замечено, что положение горизонта событий RGI Шварцшильда меньше, чем ЧД Шварцшильда. Была исследована стабильная конфигурация тонкой оболочки, заполненной материей, распределение которой соответствует типу квинтэссенции, темной энергии и фантомной энергии EoS с линеаризованным радиальным возмущением относительно равновесного радиуса оболочки.

Динамика тонкой оболочки в контексте скалярного поля обсуждается с использованием эффективного потенциала и радиуса тонкой оболочки без учета положения равновесия радиуса оболочки. Было рассмотрено уравнение сохранения и уравнение КГ для изучения поведения эффективного потенциала, радиуса оболочки и скалярного поля на фоне собственного времени.

Впервые стабильная конфигурация развитой структуры исследована с использованием линеаризованного радиального возмущения относительно равновесного радиуса оболочки на фоне фантомоподобного EoS. Было получено, что графический анализ тонкой оболочки следует основному условию тонкой оболочки, согласно которому радиус оболочки должен быть больше радиуса горизонта событий.

Отмечается, что тонкая оболочка демонстрирует стабильное поведение как для содержания материи типа квинтэссенции, так и для темной энергии. Тонкая оболочка представляла собой нестабильную конфигурацию при любом выборе физических параметров для фантомной энергии типа EoS. Обнаружено, что содержание материи типа темной энергии демонстрирует более стабильную конфигурацию, чем распределение материи типа квинтэссенции. Сделан вывод, что стабильность тонкой оболочки снижается при выборе RGI Schwarzschild BH по сравнению с Schwarzschild BH.

Впервые разработано уравнение поля Эйнштейна в рамках модифицированного источника материи. Далее была рассчитана структура гравастаров и их физические свойства. Применяя УО к внутренней области и анализируя уравнения движения и уравнения сохранения, установлено, что решение не имеет особенности. Кроме того, плотность энергии и давление системы остаются постоянными, что соответствует характеристикам, связанным с темной энергией.

Практические результаты исследования следующие

Рассмотрено уравнение состояния, соответствующее состоянию промежуточной оболочки, а также определен соответствующий метрический потенциал. В качестве внешнего многообразия было использовано точное решение черной дыры, окруженное облаком струн и квинтэссенцией. Структура гравастара была разработана с учетом формализма Дармуа-Исраэля. Были получены компоненты тензора энергии-импульса, которые играют заметную роль в исследовании устойчивости гравазвезд посредством линеаризованного радиального возмущения. Показано, что стабильная область уменьшается с увеличением параметра поля квинтэссенции.

Анализ показывает, что энтропия области оболочки прямо пропорциональна толщине оболочки. Аналогичным образом мы исследуем энтропию оболочки, изменяя ее толщину для разных значений облака струн. Стоит отметить, что энтропия увеличивается с увеличением толщины и параметра облака струн.

Впервые получено решение без сингулярностей, которое является физически приемлемым. Интересно отметить, что разработанные точные новые решения сводятся к точной модели Мазура и Моттолы при отсутствии облака струн и полей квинтэссенции.

Достоверность результатов исследований обеспечивается применением современных апробированных методов математической физики, вычислительной математики и релятивистской астрофизики. Результаты были получены строго в рамках математического аппарата общей теории относительности и теоретической физики. Также используются современные численные и аналитические методы расчета, результаты сравниваются с имеющимися данными наблюдений и результатами других авторов. Структурированные выводы диссертации соответствуют основным правилам астрофизики компактных объектов.

Научная значимость результатов исследования заключается в том, что анализ решения гравастар может быть полезен для разработки новых теорий гравитации.

Практическая значимость результатов исследований состоит в том, что они могут сыграть роль в получении верхних пределов и ограничений на модельные параметры теорий гравитации.

Внедрение результатов исследования. На основе разработанных теоретических моделей для компактных объектов:

научные результаты, полученные в отношении движения частиц, были использованы учеными из Фуданьского университета (FU) в Шанхае (справочник FU, Китай, 30 апреля 2024 г.);

Публикация результатов исследований. Результаты исследования доктора наук представлены в 31 рецензируемых статьях, опубликованных в престижных научных журналах, рекомендованных Высшей аттестационной комиссией при Министерстве высшего образования, науки и инноваций Республики Узбекистан.

ВЫВОДЫ

На основе исследований, проведенных по теме «Влияние на термодинамику и стабильность через тонкую оболочку компактных объектов», сделаны следующие выводы:

1. Показано, что при выборе некоторых параметров, приводящих к образованию массивной скалярной оболочечной структуры, наблюдается колебательная конфигурация. Эта конфигурация характеризовалась постоянным обменом потенциальной и кинетической энергией, что стало возможным благодаря изменяющемуся поверхностному давлению оболочки и силе тяжести. Из графического поведения метрической функции было обнаружено, что положение горизонта событий RGI Шварцшильда меньше, чем ЧД Шварцшильда.
2. Показано, что графический анализ тонкой оболочки следует основному условию тонкой оболочки, согласно которому радиус оболочки должен быть больше радиуса горизонта событий. Отмечается, что тонкая оболочка демонстрирует стабильное поведение как для содержания материи типа квинтэссенции, так и для темной энергии. Обнаружено, что содержание материи типа темной энергии демонстрирует более стабильную конфигурацию, чем распределение материи типа квинтэссенции. Сделан вывод, что стабильность тонкой оболочки снижается при выборе RGI ЧД Шварцшильда по сравнению с ЧД Шварцшильда.
3. Впервые получены модифицированные уравнения гравитационного поля в рамках модифицированной тории гравитации при наличии фантомной материи. Получено решение для структуры гравастара и установлено, что решение не имеет сингулярностей. Также показано, что плотность энергии и давление системы остаются постоянными, что соответствует характеристикам, связанным с темной энергией.
4. Впервые получено решение для структуры гравастара с учетом формализма Дармуа-Израиля. Отмечено, что параметр «облако струн» увеличивает стабильные области гравастаров, а стабильность снижается по мере уменьшения параметра струны. Показано, что стабильная область уменьшается с увеличением параметра поля квинтэссенции.
5. Анализ связи толщины оболочки с ее собственной длиной показал, что с увеличением толщины и параметра облака струн увеличивается и собственная длина. Анализ показывает, что энтропия области оболочки прямо пропорциональна толщине оболочки.
6. Впервые получено решение бех сингулярностей, которое является физически приемлемым. Показано, что эти решения сводятся к

точной модели Мазура и Моттолы при отсутствии облака струн и полей квинтэссенции.

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

I bo'lim (part I; I часть)

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