

# NASTAVNO-NAUČNOM VEĆU FIZIČKOG FAKULTETA UNIVERZITETA U BEOGRADU

Pošto smo na IV sednici Izbornog veća Fizičkog fakulteta Univerziteta u Beogradu održanoj 29. januara 2020. godine određeni za članove Komisije za pripremu izveštaja po raspisanom konkursu za izbor jednog REDOVNOG PROFESORA za naučnu oblast FIZIKA ČESTICA I POLJA na Fizičkom fakultetu Univerziteta u Beogradu, podnosimo sledeći

## R E F E R A T

Na konkurs za izbor jednog redovnog profesora za naučnu oblast Fizika čestica i polja koji je objavljen u oglasniku "Poslovi", 12. februara 2020. godine, prijavila se jedna kandidatkinja, dr Marija Dimitrijević Ćirić, vanredni profesor Fizičkog fakulteta Univerziteta u Beogradu.

## BIOGRAFIJA, NASTAVNA I NAUČNA AKTIVNOST

dr Marije Dimitrijević Ćirić

### 1 Osnovni biografski podaci

Dr Marija Dimitrijević Ćirić je rođena 1975. godine u Jagodini, gde je završila osnovnu školu i gimnaziju. Na Fizičkom fakultetu Univerziteta u Beogradu diplomirala je 1998. godine na smeru Teorijska i eksperimentalna fizika sa prosečnom ocenom 9.81, a diplomski rad "*Hokingovo zračenje u CGHS modelu*" uradila je pod rukovodstvom prof. Maje Burić. Poslediplomske studije na Fizičkom fakultetu završila je 2002. godine sa prosečnom ocenom 9.63 na smeru Teorijska fizika elementarnih čestica i gravitacije, odbranom magistarskog rada "*Klasične i kvantne osobine BTZ crne rupe*". Mentor ovog rada je bio prof. Voja Radovanović. Doktorat " *$\kappa$ -deformed gauge theory and  $\theta$ -deformed gravity*", dr Marija Dimitrijević Ćirić je uradila u Minhenu, Nemačka, pod mentorstvom prof. Juliusa Wessa i odbranila na Ludwig-Maximilians Univerzitetu 2005. godine. Doktorat je nostrifikovan na Univerzitetu u Beogradu 2006. godine. Od 2007. do 2009. godine dr Marija Dimitrijević Ćirić bila je na postdoktorskom usavršavanju na Univerzitetu istočnog Pijemonta u Alesandriji, Italija.

Dr Marija Dimitrijević Ćirić je od 1999. godine zaposlena na Fizičkom fakultetu Univerziteta u Beogradu, a 2009. je dobila nagradu za najboljeg mladog istraživača Fizičkog fakulteta.

### 2 Nastavna aktivnost

Dr Marija Dimitrijević Ćirić radila je na Fizičkom fakultetu Univerziteta u Beogradu od 1999. godine do 2007. u asistentskom zvanju. U tom periodu držala je računske vežbe iz Elektrodinamike i Teorije elementarnih čestica i eksperimentalne vežbe iz Mehanike i termodinamike. Od 2007. do 2013. godine dr Marija Dimitrijević Ćirić radila je u zvanju docenta i držala nastavu na predmetima: Seminar savremene fizike, Fizika elementarnih čestica, Elektrodinamika 1 i Fizika jezgra i čestica na redovnim studijama, kao i Opštu teoriju relativnosti na master studijama. 2013. godine dr Marija Dimitrijević Ćirić je izabrana za vanrednog profesora na Fizičkom fakultetu Univerziteta u Beogradu i drži nastavu

iz Seminara savremene fizike, Specijalne teorije relativnosti, Teorije elementarnih čestica, Opšte teorije relativnosti i Fizike jezgra i čestica.

Dr Marija Dimitrijević Ćirić drži nastavu na drugoj i četvrtoj godini osnovnih studija i to na B,C i A smeru, kao i na master i doktorskim studijama. Ocene koje je u nekoliko poslednjih semestara dobila u studentskim anketama su od 4,07 do 4,97, u proseku oko 4,44: veoma dobre. U radu sa studentima je pažljiva i korektna, i izuzetno se trudi da svojim predavanjima prenese fizičku suštinu predmeta čak i kada su kompleksniji ili matematički zahtevniji. Treba posebno istaći da na master studijama B smeru dr Marija Dimitrijević Ćirić već više godina u kontinuitetu drži predavanja iz Opšte teorije relativnosti. Predmet je organizovan kroz predavanja, izradu domaćih zadataka i seminarski rad. Dr Marija Dimitrijević Ćirić se potrudila da ovaj predmet bude na visokom stručnom nivou, kao što je potrebno na master studijama, ali da istovremeno bude i atraktivan, te ga studenti rado i često biraju.

Osim fakultetske nastave, dr Marija Dimitrijević Ćirić je veoma aktivna u popularizaciji fizike. Održala je šest predavanja na festivalima nauke i u Kolarčevoj zadužbini.

### 3 Naučna aktivnost

#### 3.1 Publikacije

Dr Marija Dimitrijević Ćirić objavila je 32 rada u vodećim međunarodnim časopisima, 31 u časopisima sa impakt faktorom preko 1: zbirni impakt faktor tih radova je 109, a ukupna citiranost, bez auto- i heterocitata je 1012. Posebno treba istaći, kao najcitiranije, radove [6] i [7] koji su direktno vezani za rezultate doktorata dr Dimitrijević Ćirić (317 odnosno 222 citata), dok su radovi [2], [3] i [8] citirani po više od 50 puta. Sem toga, održala je 23 predavanja na međunarodnim konferencijama i workshop-ovima koja su većinom predavanja po pozivu. Dr Marija Dimitrijević Ćirić jedan je od koautora monografske studije *“Symmetries in noncommutative geometry and field theory”* u izdanju Springer Verlag-a, kao i udžbenika *“Teorijska fizika elementarnih čestica”*.

#### 3.2 Učešće na naučnim projektima i međunarodna saradnja

Dr Marija Dimitrijević Ćirić bila je član projekta 171031 *“Fizičke implikacije modifikovanog prostor-vremena”* Ministarstva prosvete, nauke i tehnološkog razvoja Srbije i prethodnih naučnih projekata Grupe za čestice, polja i gravitaciju (Fizički fakultet i Institut za fiziku Univerziteta u Beogradu). U periodu 2002-2003 godine bila stipendista Nemačke organizacije za akademsku razmenu DAAD, a u periodu 2004-2005 godine imala je stipendiju Nemačkog naučnog društva DFG u okviru programa *“Stringtheorie im Kontext von Teilchenphysik, Quantenfeldtheorie, Quantengravitation, Kosmologie und Mathematik”*. Posle doktorskih studija na Univerzitetu u Minhenu i postdokorskog usavršavanja na Univerzitetu u Alesandriji (2007-2009), nastavila je intenzivnu međunarodnu saradnju sa nekoliko istraživačkih grupa, pre svega sa kolegama iz Torina, Napulja, Zagreba i Edinburga. Bila je član odnosno rukovodilac sledećih bilateralnih projekata:

- bilateralni hrvatsko-srpski projekat *“Teorije modifikovane gravitacije i ubrzano širenje svemira”* (2010-2012), i
- bilateralni italijansko-srpski projekat *“Gravitacija u kvantnom prostor-vremenu”*, rukovodilac projekta (2013-2015).

Osim toga, član je upravnog odbora (Management Committee) COST akcija *“MP 1405: Quantum Structure of Spacetime”* (2015-2019) i *“CA18108: Quantum Gravity Phenomenology in the Multi-Messenger Approach”* (2019-2023).

Dr Dimitrijević Ćirić je recenzent u više međunarodnih časopisa iz fizike, i to u *Classical and Quantum Gravity*, *European Physical Journal C*, *Journal of Physics A*, *International Journal of Modern Physics A*, *General Relativity and Gravitation*, *International Journal of Geometric Methods in Modern*

Dr Marija Dimitrijević Ćirić učestvovala je u organizaciji nekoliko međunarodnih konferencija i škola od kojih su dve, veoma uspešno, organizovane u Beogradu:

- Bayrischzell Workshop 2014: “*Quantized geometry and physics*”, Bayrischzell, May 23-26, 2014, <http://hep.itp.tuwien.ac.at/miw/bzell2014/>
- The CERN-SEENET-MTP PhD Training program, “*Supergravity*”, 21-27 June 21 2015, Belgrade, Serbia, <http://phd.seenet-mtp.info/belgrade-2015/>
- 1st COST QSPACE training school “*Quantum Structure of Spacetime and Gravity*”, August 21-28, Belgrade, Serbia, <http://www.qssg16.ipb.ac.rs/index.html>

## 4 Pregled naučnih rezultata

Osnovne oblasti istraživanja dr Marije Dimitrijević Ćirić su klasična i kvantna teorija polja i gravitacija na nekomutativnom (NK) prostor-vremenu. Motivacija za proučavanje NK prostor-vremena je dvojaka. Kvantna teorija polja (KTP), iako vrlo uspešno opisuje jake, slabe i elektromagnetne interakcije, ne opisuje dobro fiziku na veoma visokim energijama (veoma malim rastojanjima). Sa druge strane, opšta teorija relativnosti (OTR), koja je klasična teorija gravitacije, ne može konzistentno da se kvantuje. Kombinacija ova dva problema dovodi do ideje da prostor-vreme na skalama veličine Plankove skale  $l_P \sim 10^{-35}m$  nije glatka mnogostrukost. Jedna od mogućnosti je i NK prostor-vreme, prostor-vreme u kome koordinate ne komutiraju.

Iz pregleda naučnih rezultata koji sledi, vidi se da rad dr Marije Dimitrijević Ćirić predstavlja kontinuiran i sistematski napor da se istraže matematičke i fizičke osobine nekomutativnih prostora. Prostori su definisani uglavnom polazeći od fizičkih modela, pre svega iz teorije struna, ili deformacijom klasičnih u tzv. kvantne simetrije i supersimetrije. Analizirani su važni fizički sistemi: gradijentna polja, spinori i gravitaciono polje, i u radovima su dobijeni različiti rezultati koji se grubo mogu odrediti kao i) konstrukcija modela polja i njihovih simetrija, ii) ispitivanje matematičke konzistentnosti uvedenih novih modela kao što je zatvorenost strukture ili renormalizabilnost teorije, i iii) analiza fenomenoloških posledica nekomutativnih modela i mogućnosti njihove eksperimentalne provere. Zbog toga je istraživanje dr Marije Dimitrijević Ćirić veoma značajno i našlo je, kao što se iz njene ukupne naučne aktivnosti vidi, svoje mesto u naporima naučne zajednice teorijskih fizičara da se istraži fizika izvan Standardnog modela odnosno na rastojanjima bliskim Plankovoj skali.

U radovima [2,3,4,5,14,19,28] proučavano je  $\kappa$ -deformisano prostor-vreme, NK prostor u kome koordinate zadovoljavaju Lijevu algebru. Ovaj prostor je zanimljiv iz više razloga: to je prvi NK prostor sa kvantnom grupom kao simetrijom, može se koristiti u formulaciji DSR teorija (teorije koje su deformacije specijalne teorije relativnosti), i ima neke primene u pokušaju formulisanja kvantne teorije gravitacije. Korišćena su dva pristupa:  $\star$ -proizvod pristup [2,3,4,5] i twist-pristup [14,19,28]. U  $\star$ -proizvod pristupu NK prostor se reprezentuje na prostoru komutirajućih koordinata, a informacija o nekomutativnosti je sadržana u novom proizvodu kojim se množe funkcije/polja,  $\star$ -proizvodu. Ovaj proizvod je asocijativan, nekomutativan i u komutativnom limesu prelazi u obično komutativno množenje. U radu [2] je analizirana klasična teorija skalnog i Dirakovog polja i definisan je integral za  $\kappa$ -deformisani prostor. U radovima [4,5] analizirana je teorija gradijentnih polja. Definirano je dejstvo i posebno je analiziran slučaj interagujućih  $U(1)$ -gradijentnog i Dirakovog polja. Koristeći Sajberg-Vitenovo (SW) preslikavanje, pokazano je da se u teoriji ne pojavljuju novi stepeni slobode, već se samo pojavljuju nove interakcije. Jedna od specifičnosti  $\kappa$ -deformisanog prostora je da su gradijentno polje i odgovarajući tenzor jačine polja reprezentovani diferencijalnim operatorima. U radu [14] je ovaj problem rešen korišćenjem twist formalizma, koji omogućava da se klasična simetrija matematički konzistentno deformiše pri čemu se klasična grupa simetrije zamenjuje sa Hopfovom algebrom ili kvantnom grupom deformisane simetrije. Ovo za posledicu ima i to da odgovarajuće prostor-vreme postane nekomutativno. Koristeći pogodno izabran twist operator, Poenkareova simetrija u  $4D$  je deformisana u twistovanu  $gl(1,3)$  simetriju, a  $4D$  prostor Minkovskog je deformisan u  $4D$   $\kappa$ -Minkovski prostor. Dejstvo za gradijentna polja i polja materije se prirodno zapisuju preko diferencijalnih formi,

čime je problem integracije i problem gradijentnih polja kao diferencijalnih operatora rešen. U [19] je, pored Abelovog tvista, razmotren i Džordanov (Jordanian) tvist kao način da se definiše  $\kappa$ -Minkovski prostor. Korišćenjem Džordanovog tvista, deformisana simetrija je sužena na tvistovanu Vajlovu simetriju. Diferencijalni račun se i u tom slučaju može konzistentno formulisati, ali cikličnost integrala nije zadovoljena. Ipak, uvođenjem odgovarajuće mere, formulisano je dejstvo za NK  $U(1)$  gradijentno polje. Razvojem po parametru deformacije je pokazano da se rezultat za razvijeno dejstvo u prvom redu poklapa sa rezultatom iz [14]. Polazeći od  $\kappa$ -deformisane Dirakove jednačine u EM polju dobijene u [14], u [28] je analizirano kretanje elektrona u konstantnom magnetnom polju. Dobijene su korekcije na Landauove nivoe koje zavise od parametra nekomutativnosti. Naredni koraci u ovoj oblasti istraživanja bi bili: analiza neabelovih gradijentnih teorija, kao i bolje razumevanje  $\kappa$ -deformisanih Landauovih nivoa i primena na kvantni Holov efekat u  $\kappa$ -Minkovski prostoru.

U radovima [9,11,12,13,15] je analizirana renormalizabilnost različitih modela na NK prostoru. U radu [15] je razmotren dvodimenzioni model interagujućeg  $U(1)$ -gradijentnog i skalarnog polja. Dobijene su naznake da je model renormalizabilan do na jednu petlju (nema UV divergencija, a IR se mogu renormalizovati). Računanje korekcija za propagatore i vertekse trebalo bi da da konačan odgovor na pitanje renormalizabilnosti. U radovima [9,11,12,13] razmatrana su dva ne(anti)komutativna Ves-Zumino modela. Ne(anti)komutativan superprostor je superprostor u kome bozonske koordinate ne komutiraju, a fermionske ne antikomutiraju. Ne(anti)komutativnost je dobijena koristeći gore pomenuti tvist formalizam. Prvi model,  $D$ -deformisani Ves-Zumino model, invarijantan je na tvistovanu supersimetriju (SUSY), ali i na klasičnu, nedeformisanu SUSY. Koristeći metod pozadinskog polja i supergrafova, pokazali smo da je model na jednu petlju renormalizabilan. Drugi model je invarijantan samo na tvistovanu SUSY i pokazuje se da nije renormalizabilan. Zaključak koji se nameće je da tvistovana SUSY nije dovoljna da obezbedi renormalizaciju. Ipak, da bi ovo moglo sa sigurnošću da se tvrdi, treba analizirati i slučaj vektorskog polja.

Radovi [1,6,7,16,17,20,24,25,26] se odnose na deo istraživanja vezan za gravitaciju, klasičnu i nekomutativnu. U radu [1] su analizirane neke kvantne osobine trodimenzione BTZ crne rupe. Dobijene su korekcije na položaj horizonta i entropiju BTZ crne rupe usled kvantnih efekata. Formulacija gravitacije na NK prostorima proučavana je u radovima [6,7,16,17,20,24,25,26]. Za razliku od gradijentnih teorija koje se relativno jednostavno generalizuju na nekomutativne, teoriju gravitacije odnosno opštu teoriju relativnosti (OTR) na NK prostoru je mnogo teže formulisati. Jedan od razloga je i taj što je OTR invarijantna na difeomorfizme, a njih je (kao prostorno-vremensku simetriju) teško generalizovati na NK difeomorfizme. U radovima [6,7] razvijen je i primenjen tvist formalizam. Klasični difeomorfizmi su generalizovani na tvistovane difeomorfizme, pa su zatim konstruisani dejstvo i jednačine kretanja invarijantni na ovu simetriju. U limesu komutativnog prostora, dejstvo se svodi na Ajštajn-Hilbertovo dejstvo za OTR, a jednačine na Ajnštajnovu jednačinu. Ova dva rada imaju dvostruki značaj. Sa jedne strane, razvijen je formalizam u kome se konzistentno mogu opisati simetrije NK prostora, tvist formalizam, a sa druge strane je prvi put formulisana NK teorija gravitacije sa deformisanom (tvistovanom) difeomorfizam-simetrijom. Međutim, kako tvistovana simetrija jos uvek nije shvaćena u potpunosti, sa dobijenom teorijom je teško raditi. Zbog toga je u radovima [16,17,20,24,25,26] pažnja usmerena na formulaciju gravitacije kao teorije sa lokalnom Lorencovom ili anti-de Sitter simetrijom. U radu [17] je razvijen metod kompozitnih polja, koji omogućava relativno jednostavno računanje korekcija višeg reda po parametru nekomutativnosti. U radu [16] je ovaj metod delimično primenjen i nadjene su korekcije drugog reda za Ajnštajn-Hilbertovo dejstvo, kosmološki član i topološki Gaus-Bone član. U radovima [20,24,25,26] je formulisana model NK gravitacije kao NK gradijentne teorije  $SO(2,3)$  grupe. Prednost ovog modela je u tome što se u okviru njega spinska koneksija i tetraade tretiraju na isti način jer predstavljaju delove gradijentnog  $SO(2,3)$  polja. Koristeći Sajberg-Vitenovo preslikavanje, izračunate su NK korekcije na klasično dejstvo (Ajnštajn-Hilbertovo dejstvo sa ili bez kosmološke konstante). Prva nenulta NK korekcija je drugog reda po parametru nekomutativnosti. Iz NK dejstva razvijenog po parametru nekomutativnosti dobijaju se NK Ajnštajnovu jednačine. Te jednačine se mogu rešavati perturbativno, polazeći od rešenja klasičnih Ajnštajnovih jednačina i računajući korekcije koje su drugog reda. Na ovaj način je nadjena i NK korekcija na prostor Minkovskog. Dobijeni prostor je zakrivljen, a krivina je proporcionalna kvadratu parametra nekomutativnosti. Vidimo da nekomutativnost, kao i obična materija, predstavlja izvor zakrivljenja prostora. Osim toga, u radovima

[25,26] je pokazano da su koordinate u kojima je parametar nekomutativnosti konstantan, zapravo Fermijeve normalne koordinate (inercijalne koordinate slobodno-padajućeg posmatrača). Ovaj rezultat omogućava bolje razumevanje narušenja difeomorfizam-simetrije u NK gravitaciji. Naime, izbor konstantnog parametra nekomutativnosti zapravo predstavlja izbor preferiranog koordinatnog sistema, a to za posledicu ima fiksiranje "gauge"-a u difeomorfizam-simetriji.  $SO(2,3)$  model NK gravitacije se dalje može proširiti uključivanjem polja materije i njihovom interakcijom sa gravitacionim poljem. Takođe, mogu se analizirati i NK korekcije na druga rešenja klasičnih Ajnštajnovih jednačina, kao što su Švarčšildovo ili kosmološko rešenje.

Twist formalizam je primenjen na gradijentne teorije u radu [8]. Teorija u kojoj je parametar nekomutativnosti dinamička promenljiva, formulisan je koristeći twist formalizam u [10]. U radu [27] je preko twist formalizma uvedena neasocijativna (NA) deformacija faznog prostora. NA deformacije su u poslednjih nekoliko godina postale vrlo aktuelan problem. Pojavile su se prvi put u teoriji zatvorenih struna i negeometrijskih pozadinskih polja. Naime, teorija polja zatvorene strune koja se kreće u pozadinskom polju negeometrijskog  $R$ -fluksa, efektivno se mogu opisati neasocijativnom geometrijom. Twist formalizam omogućava (kao i u NK slučaju) konzistentno definisanje diferencijalnog računa, kao i uvođenje koneksije i krivine na NA faznom prostoru. Koraci su slični onima u [7], ali su zbog prisustva neasocijativnosti komplikovaniji. Krajnji rezultat rada [27], NA Ajnštajnovе vakuumске jednačine u koordinatnom prostoru, dobijen je perturbativno, razvojem po parametru neasocijativnosti  $R$ -fluksu. Prve nenulte korekcije su prvog reda po  $R$ . U nastavku bi trebalo razmotriti značaj NA difeomorfizam simetrije, kuplovanje gravitacije sa poljima materije, integraciju na NA faznom prostoru i formulaciju dejstva i varijacionog principa.

Radovi [21,22,23] pripadaju oblasti teorije kondenzovanog stanja, ali se u njima ipak koristi deo formalizma teorije polja i gravitacije. Tako je u [21] gravitacioni formalizam prvog reda (spinska koneksija i tetrade) iskorišćen da se izračunaju spinska koneksija i skalaran krivina 2D i 3D Černovih izolatora. Ovi izrazi su bitni za formulaciju efektivnog opisa Černovih izolatora. U [22] je diskutovana primena Blohove teoreme za opis sistema sa frakcionim anomalnim kvantnim Holovim efektom. Posebno je istaknuta neinvarijantnost Berijeve krivine i značaj izbora "gauge" uslova. Diskutovani su Blohov "gauge" i periodični "gauge" i pokazano je da je Beri krivina u periodičnom "gauge"-u zapravo usrednjena Beri krivina po svim hamiltonijanima u Blohovom "gauge"-u. U [23] je razmotreno BCS sparivanje kompozitnih fermiona koji su opisani kao Dirakovi spinori. Kompozitni fermioni su značajni za opis fizike elektrona u frakcionom kvantnom Holovom režimu. U slučaju jednog sloja, stanja sa energijskim procepom mogu da budu anizotropna, to jest anizotropni i izotropno stanje mogu da koegzistiraju, slično kao i A i B faze u superfluidnom  $^3He$ . U slučaju dvosloja, pokazano je da smanjenjem rastojanja izmedju slojeva broj kompozitnih fermiona opada, to jest kompozitni fermioni upareni na "p-wave" način se transformišu u obične HLR (Halperin-Lee-Read) kompozitne fermione. renormalizabilan (nema UV divergencija, a IR se mogu renormalizovati). Računanje korekcija za propagatore i vertekse trebalo bi da da konačan odgovor na pitanje renormalizabilnosti. U radovima [9,11,12,13] razmatrana su dva ne(anti)komutativna Ves-Zumino modela. Ne(anti)komutativan superprostor je superprostor u kome bozonske koordinate ne komutiraju, a fermionske ne antikomutiraju. Ne(anti)komutativnost je dobijena koristeći gore pomenuti twist formalizam. Prvi model,  $D$ -deformisani Ves-Zumino model, je invarijantan na twistovanu supersimetriju (SUSY), ali i na klasičnu, nedeformisanu SUSY. Koristeći metod pozadinskog polja i supergrafova, pokazali smo da je model na jednu petlju renormalizabilan. Drugi model je invarijantan samo na twistovanu SUSY i pokazuje se da nije renormalizabilan. Zaključak koji se nameće je da twistovana SUSY nije dovoljna da obezbedi renormalizaciju. Ipak, da bi ovo mogli sa sigurnošću da tvrdimo, treba analizirati i slučaj vektorskog polja, a takođe i pokušati da bolje razumemo značenje twistovane simetrije.

Radovi [1,6,7,16,17,20,24,25,26,30,32] se odnose na deo istraživanja vezan za gravitaciju, klasičnu i nekomutativnu. U radu [1] su analizirane neke kvantne osobine trodimenzione BTZ crne rupe. Dobiјene su korekcije na položaj horizonta i entropiju BTZ crne rupe usled kvantnih efekata. Formulacija gravitacije na NK prostorima proučavana je u radovima [6,7,16,17,20,24,25,26]. Za razliku od gradijentnih teorija, koje se relativno jednostavno generalizuju na NK gradijentne teorije, teoriju gravitacije, tj. opštu teoriju relativnosti (OTR) na NK prostoru je mnogo teže formulisati. Jedan od razloga

je i taj što je OTR invarijantna na difeomorfizme, a njih je (kao prostorno-vremensku simetriju) teško generalizovati na NK difeomorfizme. U radovima [6,7] razvijen je i primenjen tvist formalizam. Klasični difeomorfizmi su generalizovani na tvistovane difeomorfizme, pa su zatim konstruisani dejstvo i jednačine kretanja invarijantni na ovu simetriju. U limesu komutativnog prostora, dejstvo se svede na Ajnštajn-Hilbertovo dejstvo za OTR, a jednačine na Ajnštajnovе jednačine. Ova dva rada imaju dvostruki značaj. Sa jedne strane, razvijen je formalizam u kome se konzistentno mogu opisati simetrije NK prostora, tvist formalizam, a sa druge strane je prvi put formulisana NK teorija gravitacije sa deformisanom (tvistovanom) difeomorfizam simetrijom. Medjutim, kako tvistovana simetrija jos uvek nije shvaćena u potpunosti, sa dobijemom teorijom je teško raditi. Zbog toga je u radovima [16,17,20,24,25,26] pažnja usmerena na formulaciju gravitacije kao teorije sa lokalnom Lorencovom ili anti de Sitter simetrijom. U radu [17] je razvijen metod kompozitnih polja, koji omogućava relativno jednostavno računanje korekcija višeg reda po parametru nekomutativnosti. U radu [16] je ovaj metod delimično primenjen i nadjene su korekcije drugog reda za Ajnštajn-Hilbertovo dejstvo, kosmološki član i topološki Gaus-Bone član. U radovima [20,24,25,26] je formulisana model NK gravitacije kao NK gradijentne teorije  $SO(2,3)$  grupe. Prednost ovog modela je u tome što se u okviru njega, spinska koneksija i tetrade tretiraju na isti način. One predstavljaju delove gradijentnog  $SO(2,3)$  polja. Koristeći Sajberg-Vitenovo preslikavanje, izračunate su NK korekcije na klasično dejstvo (Ajnštajn-Hilbertovo dejstvo sa ili bez kosmološke konstante). Prva nenulta NK korekcija je drugog reda po parametru nekomutativnosti. Iz razvijenog (po parametru nekomutativnosti) NK dejstva se dobijaju NK Ajnštajnovе jednačine. One jednačine se mogu rešavati perturbativno, polazeći od rešenja klasičnih Ajnštajnovih jednačina i računajući korekcije koje su drugog reda po parametru nekomutativnosti. Na ovaj način je nadjena i NK korekcija na prostor Mikovskog. Dobijeni prostor je zakrivljen, a krivina je proporcionalna kvadratu parametra nekomutativnosti. Vidimo da nekomutativnost, kao i obična materija, predstavlja izvor zakrivljenja prostora. Osim toga, u radovima [25,26] je pokazano da su koordinate u kojima je parametar nekomutativnosti konstantan, zapravo Fermijeve normalne koordinate (inercijalne koordinate slobodnopadajućeg posmatrača). Ovaj rezultat omogućava bolje razumevanje narušenja difeomorfizam simetrije u NK gravitaciji. Naime, izbor konstantnog parametra nekomutativnosti, zapravo predstavlja izbor preferiranog koordinatnog sistema, a to za posledicu ima fiksiranje "gauge"-a u difeomorfizam simetriji.  $SO(2,3)$  model NK gravitacije se dalje može proširiti uključivanjem polja materije i njihovom interakcijom sa gravitacionim poljem i ovaj problem je delimično razmatran u radovima [30,32]. U radu [30] je razmotrena deformacija nekomutativne elektrodinamike, bazirana na  $SO(2,3)$  modelu NK gravitacije. Kao specijalan primer, razmotreno je kretanje elektrona u konstantnom magnetnom polju i deformacija Landauovih nivoa. U radu [32] je prethodna analiza uopštena na neabelove gradijentne teorije i kao poseban primer je razmotrena NK Kvantna hromodinamika, to jest  $SU(3)$  gradijentna teorija. U okviru modela  $SO(2,3)$  NK gravitacije se mogu analizirati i NK korekcije na druga rešenja klasičnih Ajnštajnovih jednačina, kao što su Švarečildovo ili kosmološko rešenje.

Tvist formalizam je primenjen na gradijentne teorije u radu [8]. Teorija u kojoj je parametar nekomutativnosti dinamička promenljiva, formulisana je koristeći tvist formalizam u [10]. U radu [27] je preko tvist formalizma uvedena neasocijativna (NA) deformacija faznog prostora. NA deformacije su u poslednjih 7-8 godina postale vrlo aktuelan problem. Pojavile su se prvi put u teoriji zatvorenih struna i negeometrijskih pozadinskih polja. Naime, teorija polja zatvorene strune, koja se kreće u pozadinskom polju negeometrijskog  $R$ -fluksa se efektivno mogu opisati neasocijativnom geometrijom. Tvist formalizam omogućava (kao i u NK slučaju) konzistentno definisanje diferencijalnog računa, kao i uvođenje koneksije i krivine na NA faznom prostoru. Koraci su slični onima u [7], ali su zbog prisustva neasocijativnosti komplikovaniji. Krajnji rezultat rada [27], NA Ajnštajnovе vakuumске jednačine u koordinatnom prostoru, dobijen je perturbativno, razvojem po parametru neasocijativnosti  $R$ -fluksu. Prve nenulte korekcije su prvog reda po  $R$ . U nastavku bi trebalo razmotriti značaj NA difeomorfizam simetrije, kuplovanje gravitacije sa poljima materije, integraciju na NA faznom prostoru i formulaciju dejstva i varijacionog principa.

Radovi [29,31] se takodje baziraju na primeni tvist formalizma. Specijalni oblik tvista, angularni tvist, uveden je u radu [29]. Ovaj tvist uvodi nekomutativnost koordinata koja je tipa lijeve algebre, to jest linearna je po koordinatama. Kada se predje na sferene ili cilindrične koordinate, ovaj tvist za-

pravo pokazuje da vreme i ugaona koordinata ne komutiraju. U radu [29] je najpre razmotrena NK deformacija diferencijalne geometrije i  $\star$ -proizvod, koje ovaj tvist definiše. Zatim je, koristeći oblik tvista u sfernim koordinatama, definisana NK teorija kompleksnog skalarnog polja kuplovanog sa EM poljem. Iz dobijenog modela izračunara je jednačina kretanja koja definiše kretanje skalarnog polja u fiksiranom gravitacionom i EM polju. Primenjen je semi-klasičan pristup, u kome su skalarno i EM polje tretirani kao nekomutativna polja, dok je gravitaciono polje tretirano kao komutativno, klasično polje. Jednačina kretanja NK skalarnog polja je rešena u geometriji naelektrisanje crne rupe (Reissner-Nordström crna rupa) sa graničnim uslovima koji odgovaraju kvazinormalnim modama (KNM) oscilovanja crne rupe. Dobijeno je da frekvance KNM, koje su u komutativnom slučaju degenerisane po magnetnom kvantnom broju  $m$ , u prisustvu nekomutativnosti zavise od  $m$ , te nekomutativnost ukida degeneraciju spektra. Cepanje KNM je proporcionalno parametru nekomutativnosti i magnetnom kvantnom broju  $m$ . U radu [29] su ovi rezultati dobijeni analitičkim računom i u aproksimaciji skoro-ekstremalne crne rupe. Korišćenjem numeričkih metoda, to jest metoda verižnih razlomaka, analiza je dodatno proširena na neekstremalne crne rupe u radu

M. Dimitrijević Ćirić, N. Konjik, A. Samsarov, *Noncommutative scalar field in the non-extremal Reissner-Nordström background: QNM spectrum*, arXiv:1904.04053.

U daljem radu se planira analiza spinorskih i gravitacionih kvazinormalnih moda. U radu [31] je angularni tvist primenjen na analizu renormalizabilnosti kvantne teorije skalarnog polja koja ne poseduje translacionu simetriju. Primećeno je da fenomen mešanja ultravioletnih i infracrvenih divergencija, koji je karakterističan za kvantne teorije na NK prostorima, i u ovom modelu postoji. Osim toga, razmotrena je i kinematika raspada masene čestice u ovom modelu NK prostor-vremena. Kako je uobičajna Lorencova simetrija zamenjena Hopf algebrom NK Lorencove simetrije, to se zakon održanja impulsa modifikuje i dovodi do zanimljivih posledica. Interesantno je ovaj model nekomutativnosti primeniti na analizu raspada realnih čestica iz Standardnog modela i uporediti izračunate rezultate sa postojećim eksperimentalnim rezultatima. Na taj način bi se mogla oceniti granica za vrednost NK parametra.

Radovi [21,22,23] pripadaju oblasti teorije kondenzovanog stanja, ali se u njima ipak koristi deo formalizma teorije polja i gravitacije. Tako je u [21] gravitacioni formalizam 1. reda (spinska koneksija i tetrad) iskorišćen da se izračunaju spinska koneksija i skalarna krivina 2D i 3D Černovih izolatora. Ovi izrazi su bili bitni za formulaciju efektivnog opisa Černovih izolatora. U [22] je diskutovana primena Blohove teoreme za opis sistema sa frakcionim anomalnim kvantnim Holovim efektom. Posebno je istaknuta neinvarijantnost Berijeve krivine i značaj izbora "gauge" uslova. Diskutovani su Blohov "gauge" i periodični "gauge" i pokazano je da je Beri krivina u periodičnom "gauge"-u zapravo usrednjena Beri krivina po svim hamiltonijanima u Blohovom "gauge"-u. U [23] je razmotreno BCS sparivanje kompozitnih fermiona koji su opisani kao Dirakovi spinori. Kompozitni fermioni su značajni za opis fizike elektrona u frakcionom kvantnom Holovom režimu. U slučaju jednog sloja, stanja sa energijskim procepom mogu da budu anizotropna, to jest anizotropni i izotropno stanje mogu da koegzistiraju, slično kao i A i B faze u superfluidnom  $^3\text{He}$ . U slučaju dvosloja, pokazano je da smanjenjem rastojanja između slojeva broj kompozitnih fermiona opada, to jest kompozitni fermioni upareni na "p-wave" način se transformišu u obične HLR (Halperin-Lee-Read) kompozitne fermione.

Dr Marija Dimitrijević Ćirić je prezentovala naučne rezultate u seminaru pod naslovom: "????". Seminar je održala ?? 2020. godine na Fizičkom fakultetu.

## 5 Rukovodjenje master i doktorskim radovima

Dr Marija Dimitrijević Ćirić je rukovodila izradom dva master rada:

1. V. Veljić, "Dinamički modeli tamne energije", Fizički fakutet, Beograd, 2012.
2. N. Konjik, "Linearizovana masena gravitacija", Fizički fakultet, Beograd, 2014.

Pored toga, dr Marija Dimitrijević Ćirić je bila mentor doktorske teze

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**Napomena:** Broj citata je sa isključenim autocitatima (autora i kooautora).

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## Z A K L J U Č A K

Na osnovu biografije i prikazanih rezultata nastavnog i naučnog rada, vidi se da je kandidat, dr Marija Dimitrijević Ćirić, izuzetno dinamičan, angažovan i uspešan fizičar. U držanju nastave dr Dimitrijević Ćirić ispoljava zavidan smisao za pedagoški rad, kako nivoom kurseva koje drži tako i pedagoškim pristupom i odnosom prema studentima. Njena prosečna ocena u studentskim anketama u poslednje dve školske godine je 4.44. Treba istaći njenu odličnu komunikaciju sa studentima i iskrenu podršku i pomoć koju im pruža i po završetku osnovnih i master studija. Dr Dimitrijević Ćirić je bila mentor 1 doktorske disertacije i 2 master rada koji su odbranjeni na Fizičkom fakultetu.

Osim toga, dr Marija Dimitrijević Ćirić je ostvarila izuzetne rezultate u svom dosadašnjem naučnom radu. Objavila je 31 naučni rad u vodećim međunarodnim časopisima (sa impakt faktorom većim od 1), koji su citirani 1012 puta (bez auto- i heterocitata) i imaju zbirni impakt faktor 109. U ovim radovima dr Marija Dimitrijević Ćirić je značajno doprinela razvoju klasične i kvantne teorije polja i gravitacije na nekomutativnim prostorima, a u poslednjih nekoliko godina, i razvoju matematičkih koncepata (neasocijativne algebre, kvantne grupe) koji se koriste u teorijskoj fizici visokih energija. Njeni radovi su međunarodno prepoznati i visoko citirani. Ima veoma intenzivnu međunarodnu saradnju koja se ogleda u zajedničkim radovima i aktivnoj saradnji sa kolegama iz inostranstva, kao i u učešću u međunarodnim projektima i mrežama (bilateralni projekti, COST akcije, SEENET) i organizovanju konferencija i škola. Treba istaći da je dr Dimitrijević Ćirić jedan od članova jezgra evropske grupe fizičara i matematičara koji pokušavaju da obezbede finansiranje, i koordiniraju istraživanja, u nekomutativnoj teoriji polja. Osim toga, kao što studenti znaju, dr Marija Dimitrijević Ćirić se izuzetno trudi da uključi što više mladih istraživača u postojeću međunarodnu saradnju.

Dr Marija Dimitrijević Ćirić je koautor dve knjige. Jednu, monografskog karaktera, je izdao Springer i koristi se kao udžbenik na doktorskim studijama fizike za predmet Nekomutativna geometrija. Druga knjiga je recenzirani udžbenik za predmet Teorija elementarnih čestica koji se sluša na četvrtoj godini istraživačkog smera studija fizike na Fizičkom fakultetu.

Na osnovu iznetih činjenica, smatramo da dr Marija Dimitrijević u potpunosti ispunjava uslove da bude izabrana u zvanje redovnog profesora. Zato predlažemo Nastavno-naučnom veću Fizičkog fakulteta Univerziteta u Beogradu da dr Mariju Dimitrijević izabere u zvanje redovnog profesora za naučnu oblast Fizika čestica i polja.

Beograd, 31. mart 2020.

dr Voja Radovanović, redovni profesor Fizičkog fakulteta

dr Maja Burić, redovni profesor Fizičkog fakulteta

dr Djordje Šijački, naučni savetnik Instituta za fiziku

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