様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科研費
KAKENHI

科学研究費助成事業　　研究成果報告書

令和　６年　５月２０日現在

機関番号：１２６０１
研究種目：研究活動スタート支援
研究期間：2022～2023
課題番号：２２Ｋ２０３６７

研究課題名（和文）Testing Theories of Gravity in Various Regimes in Cosmology with Gravitational Wave

研究課題名（英文）Testing Theories of Gravity in Various Regimes in Cosmology with Gravitational Wave

研究代表者
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交付決定額（研究期間全体）：（直接経費）　　2,200,000円

研究成果の概要（和文）：１．時間的スカラー分布を持つブラックホール摂動の単一の有効な記述を構築しました。これにより、ブラックホール付近の重力修正による興味深い現象を導き出すことができました。複数の論文を投稿し掲載されました。
２．インフレーション中の原始場の分布関数を計算しました。これは原始ブラックホールの形成に重要です。
３．初期宇宙における磁場の共鳴生成を説明するモデルを構築しました。これにより、銀河間スケールで観測される磁場の値を説明できます。

研究成果の学術的意義や社会的意義
1. The study of effective field theory provides a universal way to test theories of gravity in various scales of our Universe.
2. The study of the wavefunction of the Universe leads us to understand the non-perturbative feature that lies beyond our standard computation.

研究成果の概要（英文）：1. I successfully constructed a single effective description of black hole perturbations with timelike scalar profile. This allows us to extract an interesting phenomena due to modifications of gravity in the vicinity of black hole. This led to several publications.
2. I successfully computed the distribution function of a promordial field during inflation. This is important for studying the formation of primordial blakc holes.
3. I successfully constructed a model, describing the resonant production of magnetic field in the early universe. This explains the observed value of magnetic field on the intergalactic scales.

研究分野：Cosmology and Gravity

キーワード：Inflation　Black hole　Modified gravity　Dark energy　Magnetogenesis

１．研究開始当初の背景

The background and motivation of my research proposal can be explained as follows. General relativity or GR is, of course, one of the most well-tested theories, which describes how gravity behaves with respect to matter sources on large scales. Yet, there are several mysteries in our Universe, that cannot be fully answered within GR, e.g., dark energy, inflation, dark matter and so on. All these questions led many cosmologists including myself to study physics beyond the standard understanding. With that reasoning, therefore we aimed to explore any processes in our Universe that can be used to probe a new physics. To pursue this research, the background knowledge is the basic idea of various modified gravity theories as well as the background solutions available in those theories. Moreover, it is necessary to study how to unify those theories in a single framework, called the effective field theory (EFT). Thus, my aim of this research is to unify all those models in the context of scalar-tensor theories (one of the simplest modified gravity theories) on an arbitrary background geometry and describe physics, e.g., gravity and other interactions, within a single EFT. This EFT ultimately allows us to describe any phenomena happening in many modified gravity theories with a finite number of parameters. Then, employing the experimental data coming from detectors/observations such as LIGO/Virgo/KAGRA collaboration we will be able to provide a constraint to those parameters. Putting a bound to the modified-gravity parameters essentially tells us that on that scale of the experiment how much the theories are deviated from that of GR. In other words, the constraints tell us how the gravity behaves on the scales of the observations.

Apart from the black hole regime, I aimed to study physics during inflation. I computed the so-called wavefunction of the Universe. This allows to extract the information on the distribution function of the field on the sky. Moreover, I planned to study a model to generate a magnetic field during inflation. This model can be used to explain the observed value of magnetic field on the intergalactic scales.

２．研究の目的

The purposes of this research are:

1. Construct an effective field theory to describe physics at both cosmological and black hole regimes. Then, extract the observables such as the quasinormal-mode frequencies or the Love number from such a system.
2. Compute the wavefunction of the Universe with features during inflation.
3. Construct a model to generate the magnetic field during inflation, that can be used to explain the observed value of magnetic on intergalactic scales.

３．研究の方法

The methods of my research can be divided as follows.

1. Effective field theory of Black hole

    1.1 Study the effective field theory (EFT) constructed in the literature, as well as study the modified gravity theories and their background solutions.

    1.2 Construct the EFT in a consistent way on an arbitrary background.

    1.3 Compute the observables such as the quasinormal-mode spectrum.

2. Wavefunction of the Universe

    2.1 Study the formalism of the wavefunction of the Universe and its properties.

    2.2 Consider a model with resonant features during inflation and compute the wavefunction explicitly.

    2.3 Discuss the non-perturbative features of such a wavefunction.

3. Magnetogenesis

    3.1 Study models of magnetogenesis in literature.

    3.2 Construct our model, that can avoid all the problems such as the backreaction problem.

    3.3 Find a parameter space, in which our model can explain the observed value of magnetic field on the intergalactic scale without encountering the backreaction problem.

４．研究成果

The outcome of this research can be explained as follows.

1. Effective field theory of black hole

    1.1 I successfully constructed a single framework for describing dynamics of perturbations on an arbitrary background. This framework unifies all the known scalar-tensor theories and describe those modified-gravity effects using a finite set of parameters.

    1.2 I extracted the quasinormal-mode spectrum of the odd-parity perturbations. This calculation shows a deviation from that of general relativity and can be used to put a constraint on those parameters using the data from current observatioins.

I am planning to study further on the dynamics of even-parity perturbations as well as extracting the so-called tidal Love number. This would provide a better understanding of dynamics of perturbations around black holes.

2. Wavefunction of the Universe. I successfully computed the wavefunction of the Universe in inflation with resonant features. The result shows that when the field value is very large compared to the typical value the wavefunction exhibits the non-perturbative behavior, which cannot be captured by any order in perturbation theory.
I am plaining to apply the same machinery to other models of inflation, especially considering the slow-roll limit. This would shed light on how the wavefunction behaves with respect to the slow-roll parameters.

3. Magnetogenesis. I successfully constructed the model to generate a magnetic field during inflation without encountering the backreaction problem. The model in fact relies on the resonant production of magnetic field on the superhorizon scales. On that scale, the energy density of rh magnetic field can complete with the expansion of the Universe. Therefore, at the end, it can explain the late-time value of magnetic field. I am planning to apply such a resonant mechanism to other periods in the early Universe, for example, preheating or reheating. This would lead to an interesting phenomena of the magnetic field in the early Universe.

５．主な発表論文等

〔雑誌論文〕　計3件（うち査読付論文　3件／うち国際共著　0件／うちオープンアクセス　0件）

１．著者名 Mukohyama Shinji、Yingcharoenrat Vicharit	４．巻 2022
２．論文標題 Effective field theory of black hole perturbations with timelike scalar profile: formulation	５．発行年 2022年
３．雑誌名 Journal of Cosmology and Astroparticle Physics	６．最初と最後の頁 010～010
掲載論文のDOI（デジタルオブジェクト識別子） 10.1088/1475-7516/2022/09/010	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

１．著者名 Mukohyama Shinji、Takahashi Kazufumi、Yingcharoenrat Vicharit	４．巻 2022
２．論文標題 Generalized Regge-Wheeler equation from Effective Field Theory of black hole perturbations with a timelike scalar profile	５．発行年 2022年
３．雑誌名 Journal of Cosmology and Astroparticle Physics	６．最初と最後の頁 050～050
掲載論文のDOI（デジタルオブジェクト識別子） 10.1088/1475-7516/2022/10/050	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

１．著者名 Sasaki Misao、Vardanyan Valeri、Yingcharoenrat Vicharit	４．巻 107
２．論文標題 Super-horizon resonant magnetogenesis during inflation	５．発行年 2023年
３．雑誌名 Physical Review D	６．最初と最後の頁 83517
掲載論文のDOI（デジタルオブジェクト識別子） 10.1103/PhysRevD.107.083517	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

〔学会発表〕　計5件（うち招待講演　0件／うち国際学会　5件）

１．発表者名 Vicharit Yingcharoenrat
２．発表標題 Super-horizon resonant magnetogenesis during inflation
３．学会等名 Seminar at YITP, Kyoto（国際学会）
４．発表年 2023年

1．発表者名 Vicharit Yingcharoenrat
2．発表標題 Effective Field Theory of Black Hole Perturbations with Timelike Scalar Profile
3．学会等名 Online seminar at Waseda university.（国際学会）
4．発表年 2023年

1．発表者名 Vicharit Yingcharoenrat
2．発表標題 Effective Field Theory of Black Hole Perturbations with Timelike Scalar Profile
3．学会等名 Seminar at ICTP, Trieste.（国際学会）
4．発表年 2022年

1．発表者名 Vicharit Yingcharoenrat
2．発表標題 Effective Field Theory of Black Hole Perturbations with Timelike Scalar Profile
3．学会等名 COSMO’22, Rio de Janeiro, Brazil（国際学会）
4．発表年 2022年

1．発表者名 Vicharit Yingcharoenrat
2．発表標題 Effective Field Theory of Black Hole Perturbations with Timelike Scalar Profile
3．学会等名 Workshop on Gravity: Current challenges in black hole physics and cosmology, YITP, Kyoto（国際学会）
4．発表年 2022年

〔図書〕　計0件

〔産業財産権〕

〔その他〕

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6．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

7．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

8．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関