令和5年度

京都大学大学院理学研究科

Ｄ３発表会アブストラクト

（2023年7月20日）

物　理　学　第　二　分　野

D3 発 表 会

日時　　　令和5年7月20日（木）　9時00分～
場所　　　理学研究科5号館　525号室+オンライン
発表時間　15分＋5分（質問）

《目　次》

Challenging mysteries of the Universe with gravity beyond general relativity

Center for Gravitational Physics and Quantum Information (CGPQI), Yukawa Institute for Theoretical Physics (YITP), Kyoto University – Paul Martens

Abstract Through four case studies, I illustrate how modifying gravity allows to answer cosmology mysteries and explore beyond general relativity. In order, I use Hořava-Lifshitz to tackle the Wheeler-DeWitt equation [1], Horndeski to investigate the cosmological constant problem [2] and VCDM to both observe a spherical collapse [3] and implement a bouncing Universe [4].

In this presentation, I explore, through four case studies, how the use of modified gravity theories could help us answer profound mysteries in modern cosmology and go beyond general relativity (GR). The latter has certainly proven a formidable framework via which we understand the past history and current dynamics of our Universe. However, some longstanding mysteries of cosmology, namely GR's non-renormalizability, dark matter and dark energy, could all be interpreted as an incompleteness of GR.

First, I present the theory of Hořava-Lifshitz (HL) gravity in d+1 dimensions. HL gravity is a recent quantum gravity candidate that could address the non-renormalizability of GR by treating time and space separately at higher energies. Incidentally, this theory also includes dark matter as an integration constant. In this formalism, I exhibit the Wheeler-DeWitt equation and demonstrate that the corresponding DeWitt wave function for tensor perturbation is indeed well-defined around the classical Big Bang singularity [1], unlike in GR.

Subsequently, I consider a previously proposed dynamical relaxation mechanism for the cosmological constant (CC) [5]. This would address the CC problem, and thus dark energy as well, but alone, process also empties the Universe of its content. Using a Horndeski class model, I then exhibit the working mechanism of a proof-of-concept model that incorporates a reheating phase to resolve this last issue [2].

The last two case studies use a type-II minimally modified gravity denominated as VCDM. Similarly to HL gravity, this class of theory treats time and space as physically different, and, like GR, only propagates two degrees of freedom. Through numerical simulations, I first show that the collapse of a scalar field in VCDM yields a sane apparent horizon, thusly bringing an extra validation of the theory [3].

Finally, I construct a bouncing Universe scenario in VCDM. Such a scenario has the advantage of avoiding any initial singularity. The setup built here satisfies the near scale invariant scalar perturbation power spectrum and the small tensor-to-scalar ratio. The model exhibits a possibly observable signature: a blue-tilted tensor perturbation power spectrum [4]. A short conclusion then draws possible outlooks for each study so far.

References

[1] DeWitt wave function in Hořava-Lifshitz cosmology with tensor perturbation; Paul Martens, Hiroki Matsui , Shinji Mukohyama; e-Print: 2205.11746 [gr-qc]; DOI: 10.1088/1475-7516/2022/11/031 ; Published in: JCAP 11 (2022), 031

[2] Reheating after relaxation of large cosmological constant; Paul Martens, Shinji Mukohyama, Ryo Namba; e-Print: 2205.11754 [hep-th]; DOI: 10.1088/1475-7516/2022/11/047; Published in: JCAP 11 (2022), 047

[3] Spherical scalar collapse in a type-II minimally modified gravity; Atabak Fathe Jalali, Paul Martens, Shinji Mukohyama; e-Print: 2306.10672 [gr-qc]; Submitted to Phys. Rev. D

[4] Bouncing cosmology in VCDM; Alexander Ganz, Paul Martens, Shinji Mukohyama, Ryo Namba; e-Print: 2212.13561 [gr-qc]; DOI: 10.1088/1475-7516/2023/04/060; Published in: JCAP 04 (2023), 060

[5] A Dynamical approach to the cosmological constant; Shinji Mukohyama, Lisa Randall; e-Print: hep-th/0306108 [hep-th]; DOI: 10.1103/PhysRevLett.92.211302; Published in: Phys.Rev.Lett. 92 (2004), 211302